CASE 2924: Application of SOCONY MOBIL OIL CO. for a dual completion and for a tubing exception.

CASE NO. 2924

Application,
Transcripts,
Small Exhibits
ETC.

Docket No. 30-63
Docket No. 31-63

DOCKET: EXAMINER HEARINGS OCTOBER 18, 1963, AND OCTOBER 30, 1963

BOTH HEARINGS 9:00 A.M. OIL CONSERVATION COMMISSION CONFERENCE ROOM, STATE LAND OFFICE BUILDING, SANTA FE, NEW MEXICO

Examiner: Daniel S. Nutter; Alternate Examiner: Elvis A. Utz

DOCKET NO. 30-63 - OCTOBER 18, 1963:

CASE 2910: (Continued from the October 9, 1963, examiner hearing)

Application of Big (6) Drilling Company for extension of an existing oil pool and special pool rules, Lea County, New Mexico. Applicant, in the above-styled cause, seeks the extension of the Scharb Bone Spring Oil Pool to comprise the W/2 of Section 5, all of Section 6, and the N/2 of Section 7, Township 19 South, Range 35 East, Lea County, New Mexico, and for special rules therefor, including 80-acre spacing and proration units to comprise any two contiguous 40-acre tracts, and for fixed well locations.

DOCKET NO. 31-63 - OCTOBER 30, 1963:

CASE 2678: (Reopened and continued from the October 9, 1963, examiner hearing)

In the matter of Case No. 2678 being reopened pursuant to provisions of Order No. R-2359, which order established temporary 160-acre proration units for the East Saunders Permo-Pennsylvanian Pool, Lea County, New Mexico, for a period of one year. All interested parties may appear and show cause why said pool should not be developed on 40-acre proration units.

CASE 2903: (Continued from the October 9, 1963, examiner hearing)

Application of Coastal States Gas Producing Company for a dual completion, Lea County, New Mexico. Applicant, in the above-styled cause, seeks approval of the dual completion (conventional) of its Gulf State Well No. 1, located in Unit F of Section 20, Township 17 South, Range 36 East, Lea County, New Mexico, to produce oil from the Double-A Abo Pool and an undesignated Lower Leonard pool through parallel strings of tubing.

CASE 2921:

Application of Robert G. Hanagan for a non-standard gas proration unit, Lea County, New Mexico. Applicant, in the above-styled cause, seeks approval of a non-standard gas proration unit comprising the S/2 SW/4 of Section 1 and the N/2 NW/4 of Section 12, Township 12 South, Range 34 East, Four Lakes-Devonian Gas Pool, Lea County, New Mexico, to be dedicated to a well to be drilled 660 feet from the South and West lines of said Section 1.

Docket No. 30-63
Docket No. 31-63

CASE 2922:

Application of Consolidated Oil & Gas, Inc. for an unorthodox location and a dual completion, Rio Arriba County, New Mexico. Applicant, in the above-styled cause, seeks approval of the dual completion (conventional) of its Jicarilla No. C-1-11 to produce gas from the Blanco Mesaverde and Basin Dakota Gas Pools. Said well is at an unorthodox Blanco Mesaverde Pool location 890 feet from the South line and 990 feet from the East line of Section 11, Township 26 North, Range 4 West, Rio Arriba County, New Mexico.

CASE 2923:

Application of Cities Service Oil Company for a special gas-lift gas allocation, Lea County, New Mexico. Applicant, in the above-styled cause, seeks authority to produce Blinebry gas from its State "S" Well No. 1 located in Unit E of Section 15, Township 21 South, Range 37 East, Lea County, New Mexico, and to utilize said gas for Hare Pool gas-lift operations on its State "S" Well No. 4 located in said Unit E. Gas produced from said State "S" Well No. 1 would be metered and charged to the Blinebry Oil Pool casinghead gas production from applicant's State "S" Well No. 6 also located in the said Unit E.

CASE 2924:

Application of Socony Mobil Oil Company for a dual completion and for a tubing exception, Lea County, New Mexico. Applicant, in the above-styled cause, seeks approval of the dual completion (conventional) of its State Bridges No. 58-DD in Unit M of Section 24, Township 17 South, Range 34 East, Lea County, New Mexico, to produce oil from the Vacuum Glorieta and Vacuum Blinebry Oil Pools through parallel strings of tubing. Applicant further seeks an exception to Commission Rule 107(d)4 to produce the Glorieta formation through the casing-tubing annulus from perforations at approximately 6000 feet up to 2 3/8-inch tubing landed in a dual packer at approximately 4020 feet.

CASE 2925:

Application of Sunray DX Oil Company for the creation of a Strawn Gas Pool and for Special Temporary Pool Rules, Eddy County, New Mexico. Applicant, in the above-styled cause, seeks the creation of a new Strawn Gas Pool for its New Mexico State "AH" Well No. 1, located in Unit K of Section 30, Township 18 South, Range 23 East, Eddy County, New Mexico, and the establishment of temporary pool rules therefor, including a provision for 640-acre proration units and for fixed well locations.

Docket No. 30-63
Docket No. 31-63

CASE 2926:

Application of Sinclair Oil & Gas Company for an exception to Order No. R-1670, Lea County, New Mexico. Applicant, in the above-styled cause, seeks an order permitting its Barber Gas Unit Well No. 1, located in Unit E of Section 8, Township 20 South, Range 37 East, Eumont Gas Pool, Lea County, New Mexico, to produce 600 MCF of gas per month in exception to the shut-in provisions of Rule 15(A) of Order No. R-1670, Southeast New Mexico Gas Pool Rules, said gas to be utilized in the oil well gas-lift system on applicant's B. J. Barber Lease.

CASE 2927:

Application of Skelly Oil Company for gas commingling, Rio Arriba County, New Mexico. Applicant, in the above-styled cause, seeks an exception to Rule 21(A) of Order No. R-1670, Northwest New Mexico Gas Pool Rules, to permit the commingling of gas produced from its Jicarilla "C" Wells Nos. 3, 7, 4, 8 and 6, located in Units M and P of Section 21, Unit A of Section 28 and Units E and J of Section 27 respectively, Township 25 North, Range 5 West, South Blanco-Pictured Cliffs Pool, Rio Arriba County, New Mexico, allocating said gas to the individual wells on the basis of periodic testing. Applicant further proposes to meter said commingled gas and to commingle it with commingled casinghead gas produced from seven Otero-Gallup oil wells on its Jicarilla "C" lease.

CASE 2928:

Application of Texaco Inc. for a triple completion, Lea County, New Mexico. Applicant, in the above-styled cause, seeks approval of the triple completion (combination) of its State of New Mexico "O" NCT-1 Well No. 14, located in Unit J of Section 36, Township 17 South, Range 34 East, Lea County, New Mexico, to produce oil from the Vacuum-Wolfcamp and North Vacuum-Abo Pools through parallel strings of 2-7/8 inch casing and to produce oil from the Vacuum-Blinebry Pool through 1-1/2 inch tubing run inside 3-1/2 inch casing, all casing strings to be cemented in a common well bore.

CASE 2929:

Application of Texaco Inc. for salt water disposal, Lea County, New Mexico. Applicant, in the above-styled cause, seeks authority to dispose of produced salt water in the Basal San Andres formation through its State of New Mexico "O" NCT-1 Well No. 12 located in Unit J of Section 36, Township 17 South, Range 34 East, Vacuum Field, Lea County, New Mexico.

Docket No. 30-63
Docket No. 31-63

CASE 2930:

Application of William G. Ross for a unit agreement, Lea County, New Mexico. Applicant, in the above-styled cause, seeks approval of the South Wilson Deep Unit Area comprising 3,920 acres, more or less, of State and Fee lands in Township 21 South, Range 34 East, Lea County, New Mexico.

State of New Mexico
Oil Conservation Commission

ir/

GOVERNOR
JACK M. CAMPBELL
CHAIRMAN

State of New Mexico

Oil Conservation Commission

LAND COMMISSIONER
E. S. JOHNNY WALKER
MEMBER

STATE GEOLOGIST
A. L. PORTER, JR.
SECRETARY - DIRECTOR

P. O. BOX 871
SANTA FE

November 18, 1963

Mr. James E. Sperling
Modrall, Seymour, Sperling, Roehl and Harris
Attorneys at Law
Post Office Box 466
Albuquerque, New Mexico

Re: Case No. 2924
Order No. R-2604
Applicant:
SOCONY MOBIL OIL CO.

Dear Sir:

Enclosed herewith are two copies of the above-referenced Commission order recently entered in the subject case.

Very truly yours,

A. L. Porter, Jr.

A. L. PORTER, Jr.
Secretary-Director

ir/

Carbon copy of order also sent to:

Hobbs OCC X

Artesia OCC

Aztec OCC

OTHER Mr. Joe Gordon

BEFORE THE OIL CONSERVATION COMMISSION
OF THE STATE OF NEW MEXICO

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

CASE No. 2924
Order No. R-2604

APPLICATION OF SOCONY MOBIL OIL
COMPANY FOR A DUAL COMPLETION AND
FOR A TUBING EXCEPTION, LEA COUNTY,
NEW MEXICO.

ORDER OF THE COMMISSION

BY THE COMMISSION:

This cause came on for hearing at 9 o'clock a.m. on October 30, 1963, at Santa Fe, New Mexico, before Daniel S. Nutter, Examiner duly appointed by the Oil Conservation Commission of New Mexico, hereinafter referred to as the "Commission," in accordance with Rule 1214 of the Commission Rules and Regulations.

NOW, on this 18th day of November, 1963, the Commission, a quorum being present, having considered the application, the evidence adduced, and the recommendations of the Examiner, Daniel S. Nutter, and being fully advised in the premises,

FINDS:

(1) That due public notice having been given as required by law, the Commission has jurisdiction of this cause and the subject matter thereof.

(2) That the applicant, Socony Mobil Oil Company, seeks authority to complete its State Bridges Well No. 58-DD, located in Unit M of Section 24, Township 17 South, Range 34 East, NMPM, Lea County, New Mexico, as a dual completion (conventional) to produce oil from the Vacuum-Glorieta and Vacuum-Blinebry Oil Pools through parallel strings of 2 3/8-inch tubing.

(3) That the applicant also seeks an exception to Rule 107 (d)4 of the Commission Rules and Regulations to produce the Glorieta formation through the casing-tubing annulus from perforations at approximately 6000 feet up to 2 3/8-inch tubing landed in a dual packer at approximately 4020 feet.

(4) That the applicant has not established that the proposed method of completion will result in efficient recovery of oil.

(5) That inefficient multiple completions ultimately cause waste.

~~(6) That the subject application should be denied.~~

IT IS THEREFORE ORDERED:

(1) That the subject application is hereby denied.

(2) That jurisdiction of this cause is retained for the entry of such further orders as the Commission may deem necessary.

DONE at Santa Fe, New Mexico, on the day and year hereinabove designated.

STATE OF NEW MEXICO
OIL CONSERVATION COMMISSION

JACK M. CAMPBELL, Chairman

E. S. WALKER, Member

A. L. PORTER, Jr., Member & Secretary

esr/

Case 2924

Mobil

MAIN OFFICE OCC

Mobil Oil Company

A Division of Socony Mobil Oil Company, Inc. 1963 OCT 9 PM 1:37

P. O. BOX [redacted] HOBBS, NEW MEXICO
1800 88240

October 8, 1963

Mr. A. L. Porter, Jr., Secretary-Director
New Mexico Oil Conservation Commission
P. O. Box 871
Santa Fe, New Mexico

Dear Mr. Porter:

Socony Mobil wishes to secure administrative approval under Rule 107 (d) (4) for a special tubing installation in the dual completion of the State Bridges No. 58-DD in the Vacuum Glorieta and Blinebry pools.

The subject well is located in Unit M Section 24, T17S, R34E. Permission to drill the subject well was given on August 14 for the well to be completed as a dual producer.

As shown on the attached drawing, "Proposed Tubing Installation," the deeper zone, Blinebry, is to be produced in a 2-3/8" tubing string. The upper Glorieta zone is to be produced through the annulus area between the 2-3/8" long string and the 5" liner up to the top of the liner at 4024 feet. This annulus area is to be approximately 1900 feet in length, whereas Rule 107 (d) (2) and (3) requires flowing oil wells to be tubed with tubing set no more than 250 feet above the top of the pay. At this point the Glorieta produces into a short string of 2-3/8" tubing through a dual packer which is to be set in the 7" above the liner top.

As shown on the second drawing, which includes calculation of the area equivalents, the annulus area for Glorieta production is only a small amount less than the flow area in 2-7/8" tubing. Our calculations of the pressure drop in an annulus area has not been completed but we believe that the annular flow will not offer excessive pressure drop as compared to a conventional tubing installation.

The subject tubing installation offers the sizing needed for conventional pumping equipment which has become a necessity in our Blinebry zone because of apparent scaling tendencies.

Please advise if this cannot be handled by administrative approval and, if required, set this matter for examiner hearing at the earliest possible date.

DOCKET MAILED

Date 10-15-63

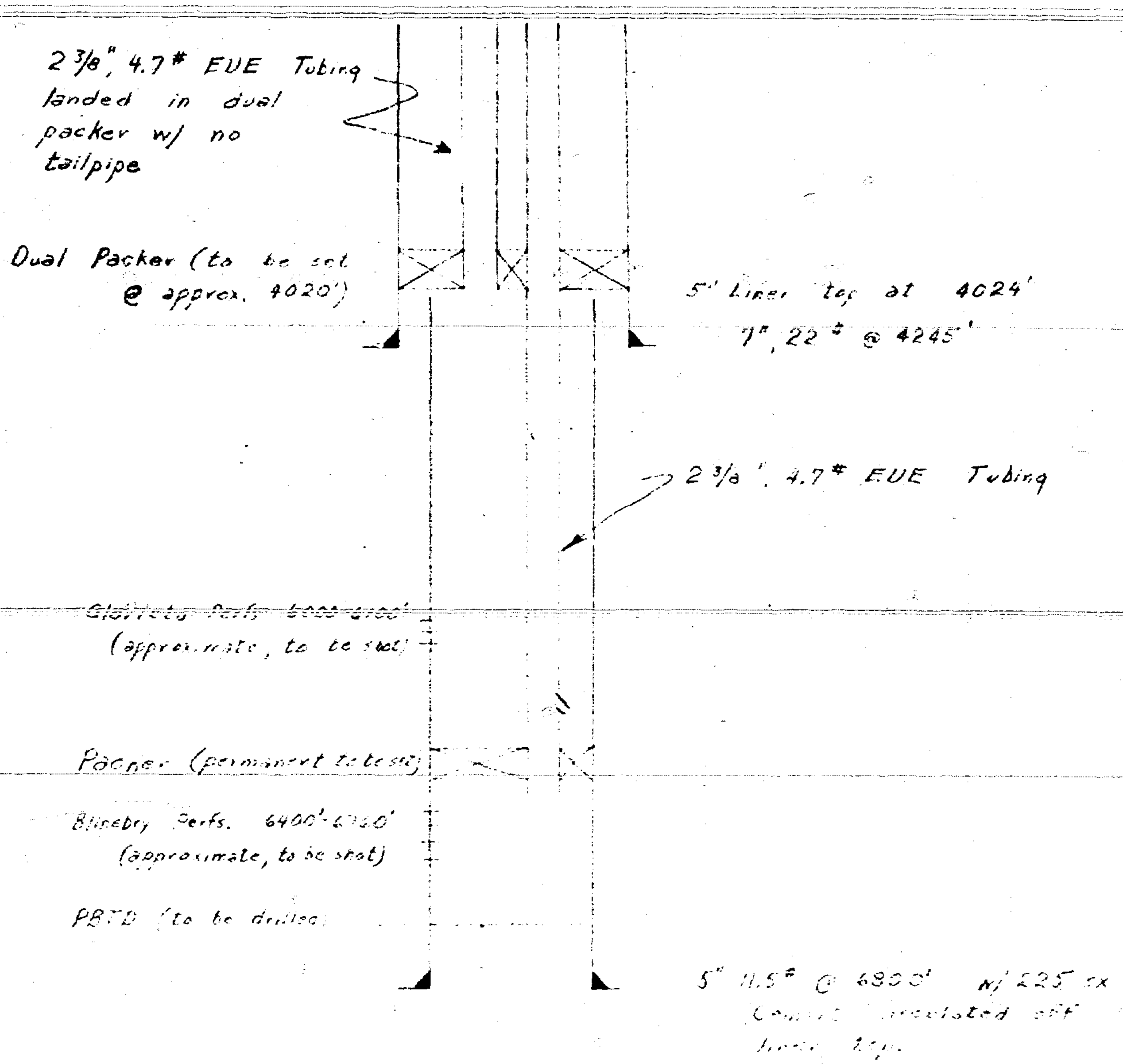
Yours very truly,

Lee E. Robinson, Jr.

Lee E. Robinson, Jr.
Acting Producing Superintendent

JCGordon/nrh
Attachments

cc: Mr. Joe Ramey, Hobbs



NO.	DATE	BY	ALTERATION

PROPOSED TUBING INST.
St. Bridges No. 58 DD
Vacuum Glorieta & Blinebry Pools

SOCONY MOBIL OIL COMPANY, INC.
HOBBS PRODUCING DISTRICT

DRAWN JCG
CHECKED
SCALE None
DATE 10-4-63
DWG. NO. A-170-D&P

Case 2974

CALCULATION OF VOLUMES (AREA EQUIVALENT COMPARISON)

Capacity of 5", 11.5# casing — 14.7 Bbls per 1000 ft.

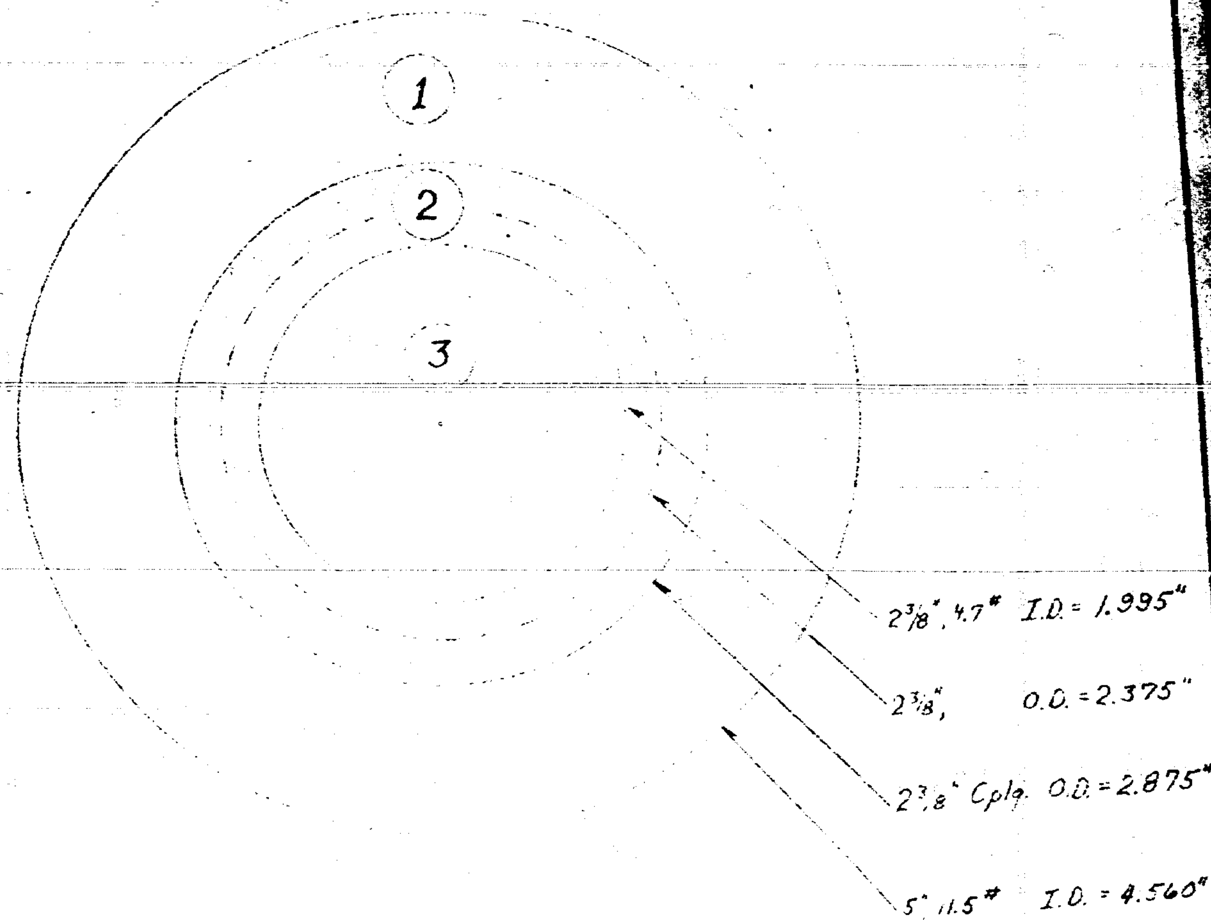
(3) Capacity of 2 3/8", 4.7# tubing 3.9 Bbls per 1000 ft.

(2) Displacement of 2 3/8", 4.7# EUE tubing 5.5

Subtotal - 2 3/8" 9.4

(1) Annular volume of tubing - casing 5.3 Bbls per 1000 ft.

Comparison volume of 2 7/8" tubing 5.8 Bbls per 1000 ft.



NO.	DATE	BY	ALTERATION

PROPOSED TUBING INST.

St. Bridges No. 58 DC
Vacuum Glorieta & Blinebry Pools

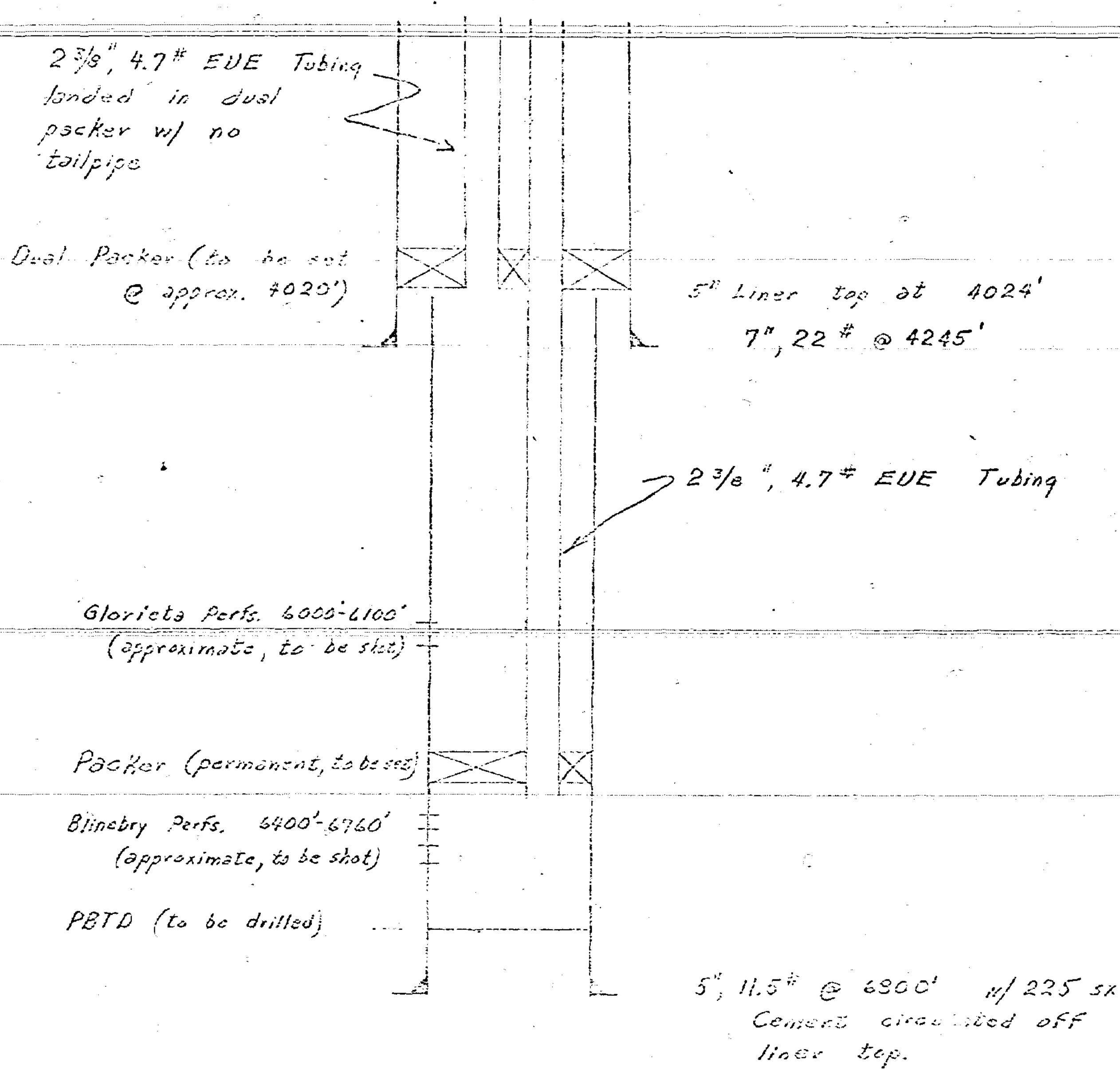
SOCONY MOBIL OIL COMPANY, INC.

HOBBS PRODUCING DISTRICT

DRAWN JCG
CHECKED
SCALE Full
DATE 10-4-63
DWG. NO. A-180-D6P

Case 2924

CO7227(11-61)



BEFORE EXAMINER NUTTER
OIL CONSERVATION [illegible]
[illegible] EXHIBIT NO. 1
CASE NO. 2729

NO.	DATE	BY	ALTERATION

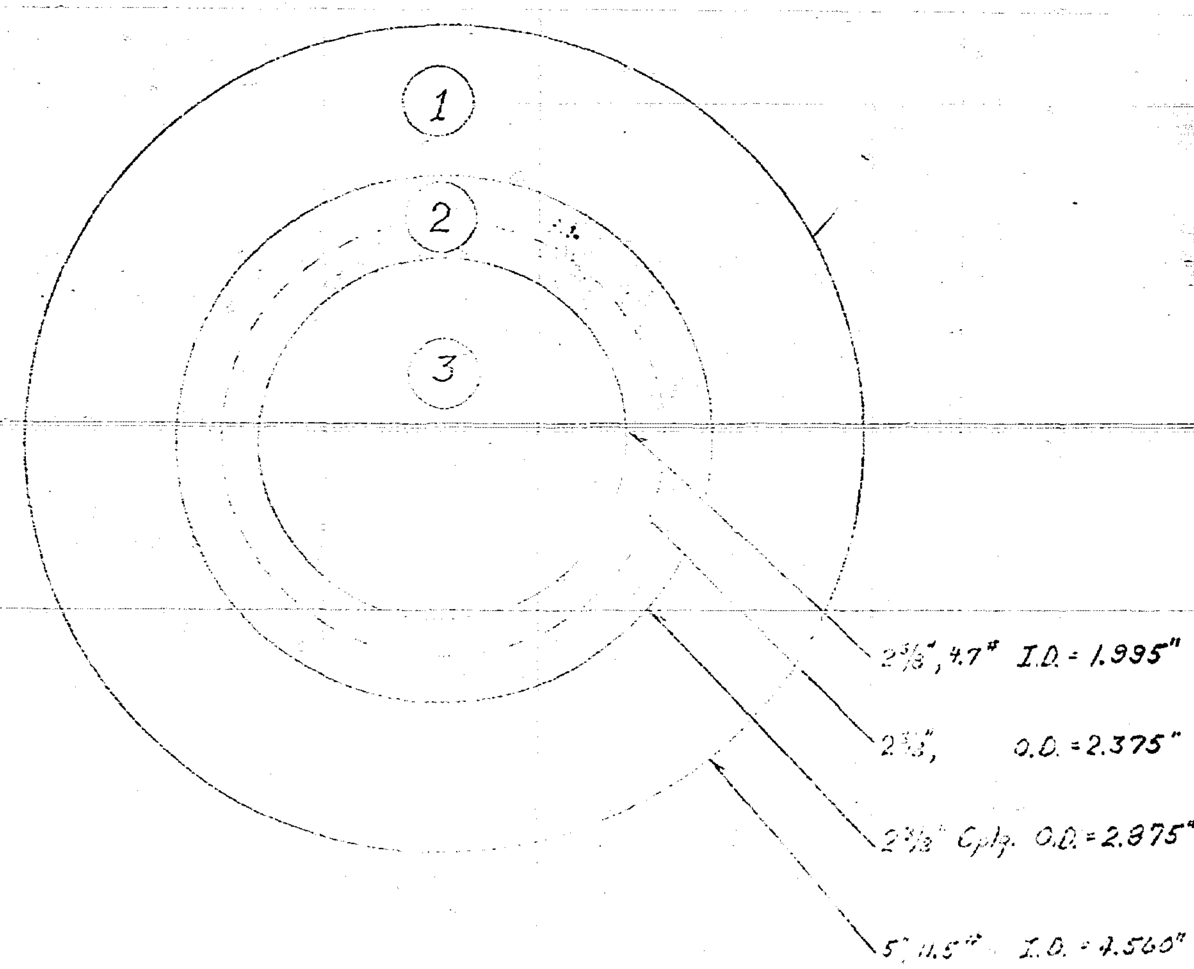
PROPOSED TUBING INST.
[illegible]
[illegible] Glorieta [illegible]

SOCONY MOBIL OIL COMPANY, INC.
Hobbs Producing District

DRAWN JCS
CHECKED
SCALE [illegible]
DATE [illegible]
DWG. NO. A-170-DEP

CALCULATION OF VOLUMES (AREA EQUIVALENT COMPARISON)

Capacity of 5", 11.5# casing –		14.7	Bbls per 1000 Ft.
(3) Capacity of 2 3/8", 4.7# tubing	3.9.		Bbls per 1000 Ft.
(2) Displacement of 2 3/8", 4.7# EUE tubing	5.5		
Subtotal – 2 3/8"		9.4	
(1) Annular volume of tubing-casing		5.3	Bbls. per 1000 Ft.
Comparison volume of 2 7/8" tubing		5.8	Bbls. per 1000 Ft.



BEFORE EXAMINER NUTTER
OIL CONSERVATION COMMISSION
EXHIBIT NO. 2
CASE NO. 2914

NO.	DATE	BY	ALTERATION

Proposed [illegible]

SOCONY MOBIL OIL COMPANY, INC.

DRAWN [illegible] | CHECKED | SCALE [illegible] | DATE [illegible] | DWG. NO. [illegible]

MAIN OFFICE OCC

1963 NOV 15 AM 8 : 11

Generalized Newtonian (Pseudoplastic) Flow in Stationary Pipes and Annuli

by

J. G. SAVINS

Magnolia Petroleum Company

Dallas, Texas

BEFORE EXAMINER NUTTER
OIL CONSERVATION COMMISSION
Appl EXHIBIT NO. 3
CASE NO. 2924

T. P. 8044

Generalized Newtonian (Pseudoplastic) Flow in Stationary Pipes and Annuli

J. G. SAVINS | MAGNOLIA PETROLEUM CO.
DALLAS, TEX.

INTRODUCTION

The first paper in this series[1] outlined practical methods for applying the theory of steady-state flow of an ideal Bingham plastic liquid through a circular pipe and axially through a stationary concentric annulus to the engineering analysis of friction loss problems.

In the present paper the properties of another useful rheological model, the pseudoplastic generalized Newtonian liquid, are considered. The terminology applied to the rheological models is derived from the following classification of rheological models. The term "generalized Newtonian" is a class designation applied to models which do not have yield points but which exhibit a dependence on shear rate. The term "pseudoplastic" applies to a sub-group of models within this class which exhibit a decrease in "viscosity" with increasing shear rate. The term "power model" refers to a mathematical model proposed for describing the behavior of the pseudoplastic liquid. This model is of interest since certain of the salt saturated, oil emulsion, and "low solids" drilling fluids, inverted emulsion- and oil-base drilling fluids, aqueous gels, gelled crudes and blocking agents employed in hydraulic fracturing operations are of this type.

The present treatment considers the equations describing steady-state Poiseuille flow through a circular pipe and a stationary concentric annulus, and Couette flow between concentric rotating cylinders for a particular pseudoplastic model. As in the previous paper[1] it is demonstrated how these equations can be applied to engineering calculations of friction losses. Graphical procedures for recovering the various flow curves and example calculations are included. A method for simplifying turbulent-flow correlations is also proposed.

PROPERTIES OF PSEUDOPLASTIC GENERALIZED NEWTONIAN LIQUID

In contrast to the Bingham plastic the generalized Newtonian liquid is yield point-free. However, in the flow region the relation between stress and rate of shear is not linear as it is with ordinary Newtonian fluids. If the stress increases with shear rate at a less than linear rate the system is called pseudoplastic. While there is no yield point in this system, the Bingham advocates[2] coined the term pseudoplastic to distinguish this kind of behavior from Bingham plastic behavior. For the pseudoplastic a plot of flow rate vs friction loss or rpm vs torque, from pipe flow or rotational viscometer measurements, respectively, generally has three qualities: (1) it can be clearly extrapolated toward the origin; (2) there is very little slope at the origin. This accounts for the high apparent viscosities at low mixing and pumping rates; and (3) the flow curve possesses a continuous curvature which gradually diminishes as the shear increases.

Rheological measurements on a pseudoplastic liquid can be easily misinterpreted as indicating Bingham plastic behavior. A typical case in point is illustrated in Fig. 1. These data were obtained from measurements on an oil-emulsion mud using a commercially available rotational-type viscometer (Model 35 Fann V-G meter). Applying the "two-point"* method[3] gives a plastic viscosity of 17 cp and a yield point of 24 lb/100 ft²; at the same time weighting material settles very easily in this system. This illustrates that it is not possible to distinguish between the pseudoplastic and the Bingham plastic from only two data points.

It is possible to determine qualitatively which model is more appropriate by a combination of dynamic and static measurements. Experience indicates that the simplest criterion for the Bingham plastic liquid is that the calculated dynamic yield point should be of the same magnitude as the measured gel strengths. For the oil-emulsion drilling fluid illustrated in Fig. 1, a value of 4 lb/100 ft² was obtained for gel strengths measured

*In the two-point method the plastic viscosity is proportional to the reciprocal of the differential slope, while the yield point is read directly from the intercept on the dial reading axis corresponding to zero rpm.

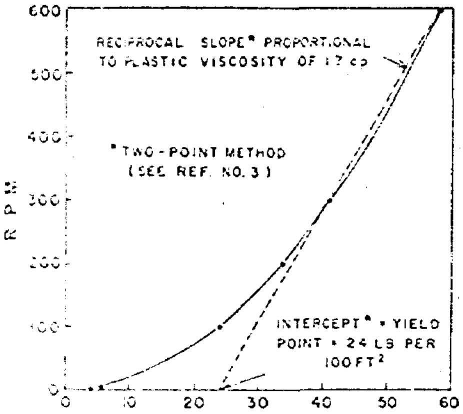


Fig. 1 — Typical Flow Curve, Oil Emulsion Drilling Fluid.

Original manuscript received in Society of Petroleum Engineers office May 27, 1958. Revised manuscript received Nov. 3, 1958.
[1]References given at end of paper.

after 0 and 10-minute rest times. Thus, if the calculated yield point is significantly larger than the static gel strengths, the system may be pseudoplastic. If the gels measured at the longer rest times are quite low and there is little evidence of thixotropy, as is often the case in well established drilling fluids, the system is definitely pseudoplastic. Another useful criterion which can be applied where more than two data points are available, e.g., from use of the Model 35 V-G meter, is that on a logarithmic plot most pseudoplastic flow curves are straight lines while the Bingham plastic flow curve is continuously curved concave to the dial reading axis.

Fortunately, there will be many cases where a friction loss calculated using the Bingham model and one calculated using the pseudoplastic model will differ only by an amount well within the limits of accuracy with which the independent variables can be measured. However, the practice of predicting the "suspending power" of a mud for weighting material or of a fracturing fluid for sand from a calculated yield point can give rise to serious error if the material is actually pseudoplastic.

POWER MODEL LIQUID

There have been various mathematical models proposed for the pseudoplastic fluids. One that has found widespread use is called the "power model", defined as a body for which the rate of shear is proportional to some power of the shearing stress.

$$e = k\tau^N , \qquad (1)$$

where e is shear rate in two dimensional flow, τ is shearing stress, and k,N are rheological parameters ($N>1$). Its flow curve is a straight line on a logarithmic plot. Reiner[2] discusses the shortcomings of this model in considerable detail. It is clear that it does not correctly portray the behavior of real fluids as $\tau \rightarrow 0$ and again as $\tau \rightarrow \infty$. However, these limitations appear to be unimportant for many practical problems and the model has been applied with surprising accuracy to the design of piping systems involving the manufacture, handling and application of a significant number of pseudoplastic materials.

BASIC FLOW EQUATIONS

The Pipe Case

The equation[4] for slip-free flow of a power model liquid in a cylindrical pipe is as follows.

$$(2N + 6)\frac{V}{D} = k\left(\frac{D\Delta p}{4L}\right)^N, \qquad (2)$$

where V is bulk average velocity, D is pipe ID, and $\frac{\Delta P}{L}$ is pressure gradient.

It is convenient to write Eq. 2 in the form

$$D_p = \gamma_p k \tau_p^N , \qquad (3a)$$

where

$$\gamma_p = \frac{8}{2N+6} \qquad (3b)$$

$$\tau_p = \frac{D\Delta p}{4L} \qquad (3c)$$

$$D_p = \frac{8V}{D} \qquad (3d)$$

When plotted on logarithmic paper as D_p vs τ_p a straight line is produced. It is seen that N is the slope whereas the intercept of the line on the τ_p or $\frac{D\Delta p}{4L}$ axis where D_p is unity, is related to $\gamma_p k$,

$$\left(\frac{D\Delta p}{4L}\right) = K'_p \qquad (4a)$$

where

$$K'_p = (\gamma_p k)^{-n'} \qquad (4b)$$

$$n' = N^{-1} \qquad (4c)$$

It is of interest to note that Farrow, *et al*[5], Fischer[6], Krieger and Maron[7] and Weltmann[8], among others, and more recently Metzner and Reed[9], have pointed out the feasibility of characterizing the degree of non-Newtonian behavior of various materials through the parameter N or its reciprocal.

With this method of plotting flow data for a pseudoplastic liquid the following precautions need to be observed. From the hydrodynamics of flow in a cylindrical tube the term $\frac{D\Delta p}{4L}$ is always the wall shearing stress, but the term D_p is the wall shear rate only for the simple Newtonian liquid. In the case of the model presented here the wall shear rate is D_p/γ_p. Neglect of the term has led several investigators into serious errors in correlating flow data on a given liquid from measurements in different geometries. It should also be noted that the intercept from this logarithmic plot is a dual function of both the rheological properties and conduit geometry. This means that in the K'_p form the intercept is applicable only to problems involving flow in cylindrical tubing.

The Concentric Annulus Case

An analytical expression for the flow of a power model liquid in a concentric annulus of circular section has been derived by Fredrickson and Bird[10],

$$Q = \frac{\pi D_2^3 k}{8}\left(\frac{D_2\Delta p}{4L}\right)^N \Omega_p , \qquad (5a)$$

where

$$\Omega_p = \left[\sum_{\substack{i=0 \\ i \neq \frac{N+3}{2}}}^{N+1} \Xi_{N_i}\lambda^{2i} + \Xi_N \lambda^{N+3}\right], \qquad (5b)$$

in which

$$\Xi_{Ni} = \binom{N+1}{i}\frac{(-1)^i}{N-2i+3}\left[1 - (-1)^{N+1}\alpha^{N-2i+3}\right] \qquad (5c)$$

$$\Xi_N = \binom{N+1}{\frac{N-1}{2}}(-1)^{\frac{N-1}{2}} \ln(1/\alpha) \quad (N \text{ odd}) \qquad (5d)$$

$$\Xi_N = 2\sum_{i=0}^{N+1}\frac{\binom{N+1}{i}(-1)^i}{2i - N + 1} \quad (N \text{ even}), \qquad (5e)$$

$$\binom{N+1}{\frac{N-1}{2}} = \frac{(N+1)!}{\left(\frac{N-1}{2}\right)!\left(\frac{N+1}{2}\right)!},$$

$$\binom{N+1}{i} = \frac{(N+1)!}{i!(N+1-i)!},$$

λ = values of r/R for which $\tau = 0$,
D_2 = inside diameter of outer tube, and
αD_2 = outside diameter of inner tube.

Eq. 5b may also be expressed as

$$\Omega_p = \frac{(1-\alpha)^{N+2}}{(N+2)} \Upsilon \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5f)$$

Fredrickson and Bird[10] hav tabulated values of Υ for selected values of N and α. However, it is difficult to apply their method to the practical engineering problems of relating flow rate to friction losses since it is first necessary to find Υ by interpolation, solve Eq. 5f for Ω_p, and finally express Eq. 5a in terms of these parameters.

From the very satisfactory manner in which the flow of a Bingham plastic liquid in a concentric annulus can be considered as plane rectilinear flow between fixed parallel plates[1], it seems desirable to examine the analogous equation for the slip-free flow of a power model liquid in a narrow annulus. Now the expression describing the flow of a power model liquid between fixed parallel plates[11] is

$$Q = \frac{W D_s^2 k}{(2N+4)} \left(\frac{D_s \Delta p}{2L}\right)^N, \quad . \quad . \quad . \quad . \quad . \quad (6a)$$

where D_s is width of the rectangular section and W is length of the section ($W >> D_s$). Making the substitutions,

$$W = \frac{\pi D_2}{2}(1+\alpha) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6b)$$

$$D_s = \frac{D_2}{2}(1-\alpha), \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6c)$$

we obtain the following equation describing slip-free flow of a power model liquid in a narrow concentric annulus.

$$Q = \frac{\pi D_2 k}{8}\left(\frac{D_2 \Delta p}{4L}\right)^N \Theta, \quad . \quad . \quad . \quad . \quad . \quad (6d)$$

where

$$\Theta = \frac{(1-\alpha)^{N+2}}{(N+2)}\left(\frac{1+\alpha}{2}\right). \quad . \quad . \quad . \quad . \quad . \quad (6e)$$

It is seen that the complicated term Υ appearing in Eqs. 5a and 5f is replaced in Eq. 6d by the group, $\left(\frac{1+\alpha}{2}\right)$.

In Table 1 are presented ratios of $\Upsilon \Big/ \frac{1+\alpha}{2}$ for selected values of N and α. For a fixed value of N the maximum error occurs at the lowest value of α; for example, at $N = 2$ the error is 13.99 per cent at $\alpha = 0.1$, but only 0.04 per cent at $\alpha = 0.9$. For a fixed value of α the error increases with increasing deviation from simple Newtonian behavior; for example at $\alpha = .3$ the error is 2.28 per cent at $N = 1$, 5.87 per cent at $N = 3$ and 11.1 per cent at $N = 10$. However, a majority of the pseudoplastic drilling and fracturing fluids, gels, etc., will probably have $N < 3$, α usually occuring between 0.3 and 0.9.

On the basis of the cited ranges in N and α and a probable maximum error of about 5 per cent, it appears that the simpler narrow annulus expression, Eq. 6d, will relate flow rate and friction loss with an accuracy well within the acceptable limits of practical engineering applications.

Rewriting Eq. 6d in the form of Eq. 2 gives

$$\frac{(4N+8)V}{D_2(1-\alpha)} = k\left[\frac{D_2(1-\alpha)\Delta p}{4L}\right]^N \quad . \quad . \quad . \quad (7)$$

Eq. 7 reduces to the equation for plane rectilinear flow of a Newtonian liquid between fixed parallel plates when $N = 1$. It is convenient to rewrite Eq. 7 in the form

$$D_A = \gamma_A k \tau_A^N, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8a)$$

$$\gamma_A = \left(\frac{12}{4N+8}\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8b)$$

$$\tau_A = \frac{D_2(1-\alpha)\Delta p}{4L}. \quad . \quad . \quad . \quad . \quad . \quad . \quad (8c)$$

$$D_A = \frac{12V}{D_2(1-\alpha)}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8d)$$

When plotted on logarithmic paper as D_A vs τ_A a straight line is produced. Again, N is the slope while the intercept on the τ_A or $D_2\frac{(1-\alpha)\Delta p}{4L}$ axis where D_A is unity, is related to $\gamma_A k$,

$$\left[\frac{D_2(1-\alpha)\Delta p}{4L}\right]_{\text{Int.}} = K'_A, \quad . \quad . \quad . \quad . \quad . \quad (9a)$$

where

$$K'_A = (\gamma_A k)^{-N'} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9b)$$

Here the shear rate is D_A/γ_A.

The Rotational Viscometer Case

The equation which describes the behavior of a power model liquid in the rotational viscometer, in the absence of slip, is[5]

$$D_v = \frac{2\beta^2\omega}{\beta^2 - 1} = k\gamma_v\tau_v^N, \qquad (01) \quad . \quad . \quad . \quad .$$

where

$\beta = R_2/R_1$

$\tau_v = T/2\pi R_1^2 L$

R_2 = outer cylinder radius

R_1 = inner cylinder radius

ω = angular velocity

T = torque

L = inner cylinder effective length

$$\gamma_v = \left(\frac{\beta^2}{N\beta^{2N}}\right)\left(\frac{\beta^{2N}-1}{\beta^2-1}\right)$$

When plotted on logarithmic paper as $\frac{2\beta^2\omega}{\beta^2-1}$ vs $\frac{T}{2\pi R_1^2 L}$ a straight line is produced. By way of contrast, when a Bingham plastic liquid is plotted in this manner the plot will be continuously curved in a direction concave to the τ_v or $T/2\pi R_1^2 L$ axis throughout most of the range, followed toward the lower end of the range

TABLE 1—COMPARISON BETWEEN EXACT AND NARROW ANNULUS SOLUTIONS FOR POWER MODEL LIQUID IN CONCENTRIC ANNULUS

Ratio = $\Upsilon \Big/ \frac{1+\alpha}{2}$

α/N	1	2	3	4	5	6	7	8	9	10
0.1	1.0741	1.1399	1.1903	1.2261	1.2536	1.2810	1.2999	1.3153	1.3283	1.3393
0.2	1.0394	1.0741	1.1019	1.1226	1.1396	1.1531	1.1644	1.1735	1.1814	1.1892
0.3	1.0228	1.0431	1.0587	1.0716	1.0814	1.0893	1.0965	1.1021	1.1088	1.1110
0.4	1.0133	1.0259	1.0350	1.0423	1.0488	1.0530	1.0572	1.0596	1.0636	1.0659
0.5	1.0079	1.0147	1.0201	1.0246	1.0281	1.0309	1.0334	1.0346	1.0359	1.0370
0.6	1.0042	1.0080	1.0101	1.0133	1.0160	1.0180	1.0200	1.0210	1.0220	1.0230
0.7	1.00199	1.0038	1.0054	1.00599	1.00799	1.00905	1.00999	1.01105	1.01199	1.0130
0.8	1.00087	1.00165	1.00243	1.00298	1.00354	1.00395	1.00454	1.00498	1.00554	1.00593
0.9	1.000209	1.000419	1.00063	1.00034	1.00105	1.001156	1.001366	1.00157	1.00178	1.00199

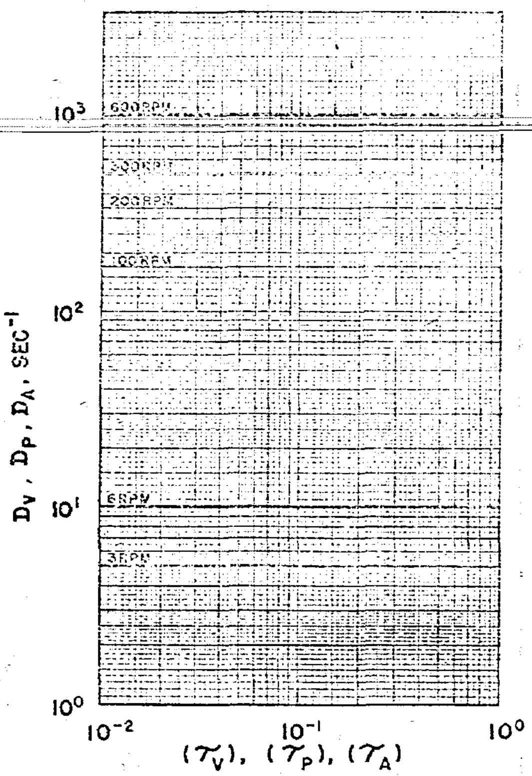


Fig. 2—Plotting Sheet.

by a region which will appear to be linear. These differences provide a ready means of distinguishing between the power model and the Bingham plastic. Returning to the logarithmic plot of the power model, N is the slope of the line; however, the intercept of the line on the τ_v or $T/2\pi R_1^2L$ axis where $\frac{2\beta^2\omega}{\beta^2 - 1}$ is unity, is related to $\gamma_v k$,

$$\left(\frac{T}{2\pi R_1^2 L}\right)_{int.} = K'_v \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11a)$$

where

$$K'_v = (\gamma_v k)^{n'} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11b)$$

The term $T/2\pi R_1^2L$ is always the shearing stress at the surface of the inner cylinder, but the term $\frac{2\beta^2\omega}{\beta^2 - 1}$ is the shear rate at the surface of the inner cylinder only for the simple Newtonian liquid. For the power model liquid the shear rate is $\frac{2\beta^2\omega}{\gamma_v(\beta^2 - 1)}$. In the case of the intercept from the logarithmic plot it should be noted from the stated definition of K'_p, K'_A and K'_v that flow data on a given power model liquid obtained in tubing or annular sections of varying sizes will form a composite plot, i.e., a single straight line, for either pipe or annular section data, whereas the flow data on the same liquid obtained in the rotational viscometer with inner and outer cylinders of varying sizes will form a family of parallel straight lines.

CORRELATIONS BETWEEN ROTATIONAL VISCOMETER, PIPE AND ANNULAR SECTION

It is evident from Eqs. 3, 8 and 10 that in logarithmic plots these expressions give rise to curves with identical slope but with different intercept values. The relationship expressed by Eqs. 4, 9 and 11 also indicates that the latter values can be readily expressed in terms of one another. This feature is the basis for correlating rotational viscometer, pipe and annular section flow curves.

Rotational Viscometer — Pipe Correlation

It follows from Eqs. 4b and 11b that

$$K'_p = K'_v \bigg/ \left(\frac{\gamma_v}{\gamma_p}\right)^{n'} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

This expression conveniently relates the rotational viscometer and pipe flow curves in terms of β, the rotor bob radii ratio, and N or n', the slope of a logarithmic plot of Eq. 10. Since γ_v/γ_p is a function solely of β and N or n', a table or graph of K'_v/K'_p may be readily prepared for a given value of β and any range in N or n'. Table 2 gives values of $\frac{K'_v}{K'_p}$ for a 1 to 10 range in N and also includes corresponding values of γ_p and γ_v. For purposes of illustration the latter term is based on $\beta = 1.0678$, the radii ratio used in the commercially available viscometer referred to earlier. A graphical solution of Eq. 12 is described in Appendix A and illustrated in Fig. 3.

Rotational Viscometer — Annulus Section Correlation

Following the same plan as was used for the pipe case we can write from Eqs. 9b and 11b,

$$K'_A = K'_v \bigg/ \left(\frac{\gamma_v}{\gamma_A}\right)^{n'} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (13)$$

Again, $\frac{\gamma_v}{\gamma_A}$ is a function solely of β and N. Table 3

TABLE 2—ROTATIONAL VISCOMETER* — PIPE CORRELATION FUNCTIONS

N	n'	γ_p	γ_v	K'_v/K'_p
1.0000	1.00	1.00000	1.00000	1.0000
1.1111	0.90	0.97297	0.99318	0.9817
1.2500	0.80	0.94117	0.98437	0.9647
1.4285	0.70	0.90324	0.97229	0.9493
1.6666	0.60	0.85715	0.95844	0.9352
2.0000	0.50	0.80000	0.93853	0.9232
2.5000	0.40	0.72727	0.90959	0.9144
3.3333	0.30	0.63153	0.86421	0.9102
5.0000	0.20	0.50000	0.73239	0.9143
10.0000	0.10	0.30769	0.59411	0.9363

*Using β = 1.0678

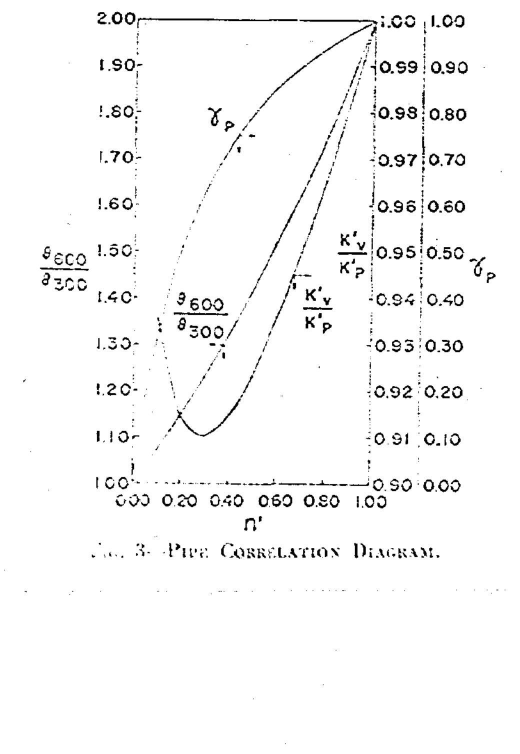


Fig. 3—Pipe Correlation Diagram.

summarizes values of $\frac{K'_v}{K'_A}$ for a 1 to 10 range in N and also includes corresponding values of γ_A and γ_v. A graphical solution of Eq. 13 is described in Appendix A and illustrated in Fig. 4.

PRACTICAL APPLICATION

Predicting Pipe and Annulus Flow Curves from Rotational Viscometer Data

It was convenient, in view of extensive correlations already tabulated, to base the procedures described in Appendix B for constructing the pipe and annulus flow curves from rotational viscometer data on the design features of a specific design of rotational viscometer, the Model 35 Fann V-G meter. However, the procedures can be regarded as guides, useful with any rotational viscometer design from which the stress at the inner cylinder, τ_r, and the radii ratio, β, can be determined.

With regard to the mentioned instrument, there are six fixed values of $\frac{2\beta^2\omega}{\beta^2-1}$ corresponding to the six speed settings as shown in Table 4. The relationship between n' and the ratio of the 600-rpm dial reading θ_{600} to the 300-rpm dial reading θ_{300} is

$$n' = 3.32 \log \frac{\theta_{600}}{\theta_{300}} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad (14)$$

Table 5 summarizes some values of $\frac{\theta_{600}}{\theta_{300}}$ for the range from 1.00 to 0.10 in n'. The relationship between τ_r in lb/ft² and any dial reading θ when the instrument is equipped with the standard torsion spring unit is

$$\tau_r = (0.01066)\theta \quad . \; . \; . \; . \; . \; . \; . \; . \quad (15a)$$

and when range extension springs are available,

$$\tau_r = (RF)(0.01066)\theta \quad . \; . \; . \; . \; . \; . \; . \quad (15b)$$

where RF is range extension factor for the spring, i.e., 1/5, 1, 3, 5, etc.

The Criterion for Turbulence

It is desirable from an engineering viewpoint to preserve the concept of the friction factor-Reynolds number diagram when developing a method which defines a criterion for turbulence for any given rheological model. Metzner and Reed[7] correlated laminar and turbulent pipe flow data from the literature on the conventional friction factor plot. However, their development contains a cumbersome Reynolds number expression, the calculation of which can be simplified for the power model liquid. Furthermore, for this model, laminar friction loss calculations can become less involved compared to the method they employ. Weltmann[5] also retains the basic form of the friction factor plot, modeling her method for the generalized Newtonian after Hedstrom's[11] treatment for Bingham plastic flow in pipes. A disadvantage of Weltmann's method is the necessity for interpolating between curves of constant N which are superimposed on the friction factor plot.

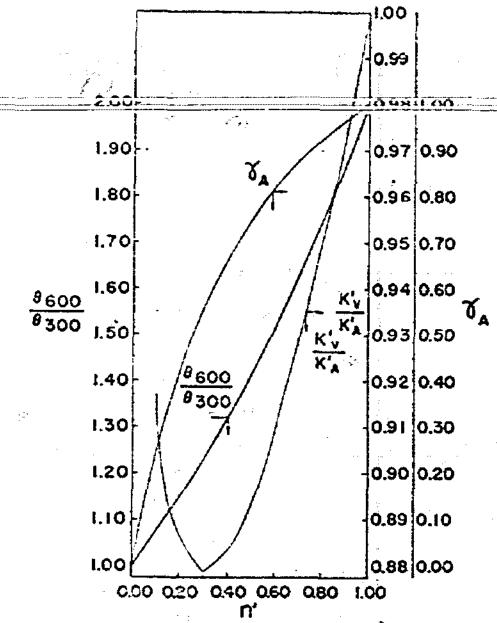


Fig. 4—Annular Section Correlation Diagram.

The method developed here likewise preserves the concept of the friction factor-Reynolds number relationship but does so in a simpler manner for the power model liquid. It is assumed that the transition between laminar and turbulent flow in both pipe and annular section occurs when a modified Reynolds number exceeds 2,000 and that in turbulent flow, friction factors for both pipe and annular section correlate on the Stanton-Pannell-type curve. The limitations involved are discussed in a following section.

The modified Reynolds number is developed as follows from the relationship,

$$f = \tau\left(\frac{2}{V^2\rho}\right), \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad (16a)$$

where

$$\tau = \left(\frac{\text{cross section}}{\text{wetted perimeter}}\right)\frac{\Delta p}{L} \quad . \; . \; . \; . \quad (16b)$$

Now the usual friction factor-Reynolds number rela-

TABLE 3—ROTATIONAL VISCOMETER* ANNULUS SECTION CORRELATION FUNCTIONS

N	n'	γ_A	γ_v	K'_v/K'_A
1.0000	1.00	1.00000	1.00000	1.0000
1.1111	0.90	0.96423	0.99318	0.9737
1.2500	0.80	0.92307	0.98437	0.9498
1.4285	0.70	0.97501	0.97279	0.9284
[illegible]	0.60	0.81819	0.95844	0.9094
[illegible]	0.50	0.75000	0.93553	0.8939
[illegible]	0.40	0.66666	0.90959	0.8831
3.3333	0.30	0.56250	0.86421	0.8791
5.0000	0.20	0.42857	0.78239	0.8866
10.000	0.10	[illegible]	0.59411	0.9170

*Using β = 1.0678

TABLE 4—THE NEWTONIAN SHEAR RATE AT THE INNER CYLINDER AS A FUNCTION OF RPM SETTING*

rpm	$\frac{2\beta^2\omega}{\beta^2-1}$ (sec⁻¹)
600	1,022
300	511
200	340
100	170
6	10.2
3	5.1

*Standard rotor-bob combination and speed settings (Model 35 Fann V-G meter)

TABLE 5—VALUES OF N AND n' AS A FUNCTION OF $\frac{\theta_{600}}{\theta_{300}}$

N	n'	$\frac{\theta_{600}}{\theta_{300}}$
1.000	1.00	2.000
1.111	0.90	1.867
1.250	0.80	1.741
1.428	0.70	1.625
1.666	0.60	1.516
2.000	0.50	1.414
2.500	0.40	1.320
3.333	0.30	1.231
5.000	0.20	1.149
10.00	0.10	1.072

tionships in viscous flow for the pipe and narrow annulus are as follows.

Pipe $f = 16/R_e$ . . . . (17a)

Annular section ($\alpha \rightarrow 1$) $f = 24/R_e$ . . . . (17b)

Combining Eqs. 16 and 17, we can write the following Reynolds number groups for the simple Newtonian liquid.

Pipe $R_e = 8V^2\rho/\tau_p$ . . . . . (18a)

Annular section ($\alpha \rightarrow 1$) $R_e = 12V^2\rho/\tau_A$ . . . . . (18b)

By analogy for the power model liquid we can write,

Pipe $\gamma_p R_e = 8V^2\rho/\tau_p$ . . . . (19a)

Annular section ($\alpha \rightarrow 1$) $\gamma_A R_e = 12V^2\rho/\tau_A$, . . . (19b)

where the products $\gamma_p R_e$ and $\gamma_A R_e$ are the modified Reynolds number, reducing to Eqs. 18a and 18b when $N = 1$. The group $\gamma_p R_e$ is identical with the modified Reynolds number $\left(\frac{D^{1/N} V^{2-1/N} \rho}{K'_p \, 8^{1/N-1}}\right)$ described by Metzner and Reed[9].

Limitations

The procedures just described for handling the turbulent flow region for the power model liquid are based on assumptions similar in principal to those suggested elsewhere for non-Newtonian liquids[1,5,6,12]. These assumptions are: (1) the onset of turbulence can be expressed in terms of an arbitrarily chosen value of the modified Reynolds number and (2) in turbulent flow, friction factor data for both pipe and annular section can be correlated on a Stanton-Pannell-type curve.

These are tentative proposals still lacking experimental verification over a wide range of non-Newtonian behavior for the power model liquid. It is unlikely that they will yield much more than a qualitative idea about turbulent region friction losses for highly pseudoplastic power model liquids. For example, it certainly appears logical to expect that for flow in tubes the more pronounced viscosity gradient between wall and axis accompanying increased non-Newtonian behavior might effectively retard the onset of turbulence through a damping-like action on eddy sites and other points of disturbance. The net result would then be expected to be the appearance of a spectrum of critical modified Reynolds numbers and turbulent friction loss correlations for varying degrees of non-Newtonian behavior unless the modified Reynolds number can be redefined to include a damping term.

Calculation of Friction Losses

Appendix B describes procedures for predicting pipe and annulus flow curves from rotational viscometer data. Once these flow curves are constructed it is an easy matter to determine if a point of interest lies in laminar or turbulent flow using the procedures outlined in Appendix B. Briefly, the group D_p or D_A is calculated according to Eqs. 3d or 8d and located on the appropriate flow curve. Then τ_p or τ_A (Eqs. 3e or 8e) is found by inspection and the modified Reynolds number calculated from Eqs. 19a or 19b.

If the flow is laminar, i.e., $\gamma_p R_e$ or $\gamma_A R_e < 2{,}000$, the friction loss $\Delta p/L$ is simply

Pipe $\Delta p/L = 4\tau_p/D$ . . . . . (20a)

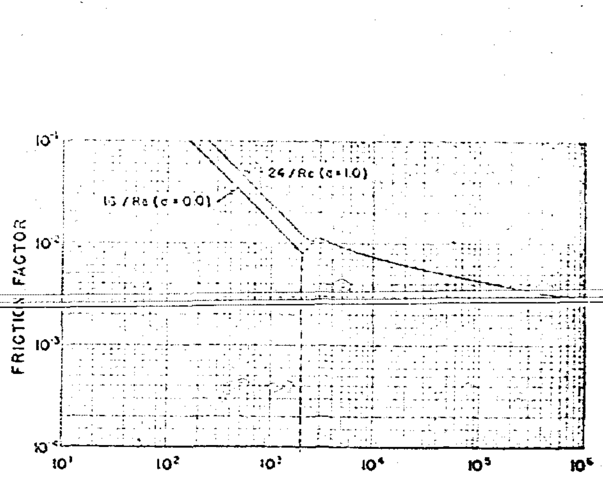


Fig. 5—Friction Factor Diagram.

Annular section ($\alpha \rightarrow 1$) $\Delta p/L = 4\tau_A/D_2(1 - \alpha)$. (20b)

If the flow is turbulent the friction factor (f) corresponding to $\gamma_p R_e$ or $\gamma_A R_e$ is found from a Stanton-Pannell-type correlation, Fig. 5. The friction loss $\Delta p/L$ is then simply

Pipe $\Delta p/L = \dfrac{2fV^2\rho}{D}$ . . . . . (21a)

Annular section ($\alpha \rightarrow 1$) $\Delta p/L = \dfrac{2fV^2\rho}{D_2(1 - \alpha)}$ . . (21b)

Sample Calculations

The following examples illustrate the methods outlined in Appendices A and B for predicting friction losses in tubing and annuli for power-model-type systems. Note that the system of units described in Table 6 is used exclusively in these examples.

The following data were recorded for a fracturing fluid using the standard Model 35 V-G meter (range factor = 1.0).

rpm	θ	τ_R*
600	58.0	0.618
300	41.0	0.437
200	33.5	0.357
100	23.7	0.253
6	5.8	0.0618
3	4.1	0.0437

*τ_R = (1) [0.01066]θ

These τ_R values are plotted in Fig. 6 as Curve V. By inspection, $K'_v = 0.0193$ and $\theta_{600}/\theta_{300} = 1.415$.

From Fig. 3, $n' = 0.50$, $K'_v/K'_p = 0.9233$, and $\therefore K'_p = 0.02090$. Using $K'_p = 0.02090$ as the base point, Curve P, the pipe flow curve, is plotted in Fig. 6.

Dimensions of tubing, circulation rate, and fluid density are as follows.

Example No. 1

ID of tubing (D) = 2 in.
Circulation rate (Q) = 1.63 bbl/min
Density (ρ) = 7.508 lb/gal

$$V = \frac{[17.16]\ (1.63)}{(2)^2} = 7 \text{ ft/sec}$$

$$D_p = \frac{[96](7)}{(2)} = 336 \text{ sec}^{-1}$$

$\tau_p = 0.385$ lb/ft^2 (from Curve P, the abscissa value corresponding to $D_p = 336$ sec^{-1})

$$\gamma_p R_e = \frac{[1.858]\ (7)^2\ (7.508)}{(0.385)} = 1{,}775$$

$\gamma_p R_e < 2{,}000$

TABLE 6—TERMS AND SYSTEM OF UNITS USED IN FRICTION LOSS CALCULATIONS

Quantity	Notation	Units
Bulk average velocity	V	ft/sec
Correlation variable (annulus)	D_A	sec^{-1}
Correlation variable (pipe)	D_p	sec^{-1}
Correlation variable (rot. visc.)	D_r	sec^{-1}
Density	ρ	lb/gal
Dial reading	θ	degrees
Diameter ratio (annular section)	α	dimensionless
Diameter ratio (rotational visc.)	μ	dimensionless
Flow curve intercept (annulus)	K'_A	lb (force)-$sec^{n'}/ft^2$
Flow curve intercept (pipe)	K'_p	lb (force)-$sec^{n'}/ft^2$
Flow curve intercept (rot. visc.)	K'_r	lb (force)-$sec^{n'}/ft^2$
Flow rate	Q	bbl/min
Friction factor	f	dimensionless
Friction loss	$\Delta p/L$	psi/ft
ID of outer pipe	D_2	in.
Modified Reynolds No. (annulus)	$\gamma_A R_e$	dimensionless
Modified Reynolds No. (pipe)	$\gamma_p R_e$	dimensionless
OD of inner pipe	D_1	in.
Reciprocal structure No.	n'	dimensionless
Shear rate factor (rot. visc.)	γ_r	dimensionless
Shear rate factor (annulus)	γ_A	dimensionless
Shear rate factor (pipe)	γ_p	dimensionless
Shear stress (annulus)	τ_A	lb/ft^2
Shear stress (pipe)	τ_p	lb/ft^2
Shear stress (rotational viscometer)	τ_r	lb/ft^2

$$\frac{\Delta p}{L} = \frac{(0.385)}{[3]\,(2)} = 0.06416 \text{ psi/ft}$$

EXAMPLE NO. 2

D, ρ = unchanged

$Q = 4.66$ bbl/min

$$V = \frac{[17.16]\ (4.66)}{(2)^2} = 20 \text{ ft/sec}$$

$$D_p = \frac{[96]\ (20)}{(2)} = 960^{-1}$$

$\tau_p = 0.652$ lb/ft² (from Curve P, the abscissa value corresponding to $D_p = 960$ sec⁻¹)

$$\gamma_p R_e = \frac{[1.858]\ (20)^2\ (7.508)}{(0.652)} = 8{,}558$$

$\gamma_p R_e > 2{,}000$

$f = 0.0079$ (from Fig. 5, Stanton-Pannell curve; where $\gamma_p R_e = 8{,}558$)

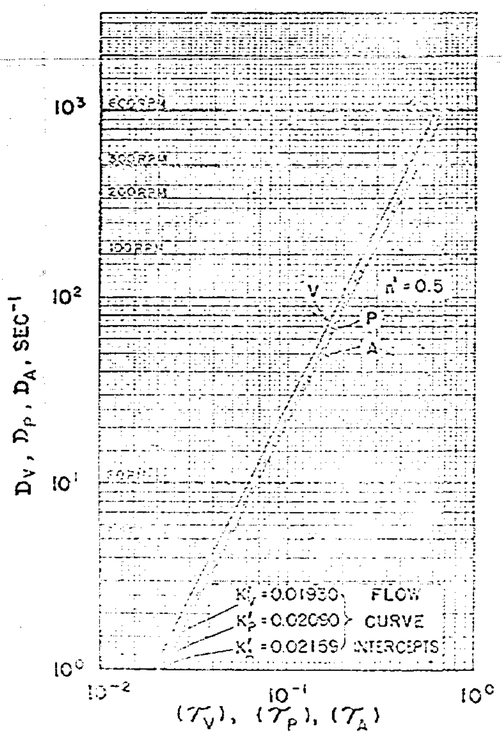


FIG. 6—EXAMPLE PLOT OF VG METER DATA AND RESULTING PIPE AND ANNULAR SECTION FLOW CURVES.

$$\Delta p/L = \frac{[0.03872]\ (0.0079)\ (20)^2\ (7.508)}{(2)}$$

$= 0.4592$ psi/ft

Similar procedures were followed in constructing the annular section flow curve ($\alpha = 0.50$) plotted as Curve A in Fig. 6.

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APPENDIX A

DESCRIPTION OF GRAPHICAL AIDS

PLOTTING SHEET

A sample plotting sheet is presented in Fig. 2. The ordinate scale is labeled D_r, D_p and D_A, sec⁻¹. The scale is indexed as 10°, 10, etc. Horizontal lines are drawn across the plotting sheet from the following ordinate points: 1,022, 511, 340, 170, 10.2 and 5.1, and labeled 600, 300, 200, 100, 6 and 3 rpm, respectively. (These are the values, see Table 4, of the Newtonian shear rate at the wall of the inner cylinder of the Model 35 V-G meter when the standard rotor-bob combination is used.)

The abscissa scale is labeled (τ_r), (τ_p) and (τ_A), lb/ft². It is indexed as 10^{-2}, 10^{-1}, 10°, etc.

PIPE CORRELATION DIAGRAM

A sample correlation diagram is presented in Fig. 3. The curves are graphical solutions of Eqs. 3b, 12 and 14, and have been provided to facilitate accurate interpolation.

The ordinate scale, left margin, is labeled $\theta_{..}/\theta_{..}$ and is indexed as 1:00; 1.10; 1.20; 1.30; 1.40; 1.50; 1.60; 1.70; 1.80; 1.90 and 2.00. The right margin consists of a double scale. The inner scale is labeled K'_r/K'_p and is indexed as 0.90; 0.91; 0.92; 0.93; 0.94; 0.95; 0.96; 0.97; 0.98; 0.99 and 1.00. The outer scale is labeled γ_p and is indexed as 0; 0.10; 0.20; 0.30; 0.40; 0.50; 0.60; 0.70; 0.80; 0.90 and 1.00.

The abscissa scale is labeled n' and is indexed as 0.00; 0.10; 0.20; 0.30; 0.40; 0.50; 0.60; 0.70; 0.80; 0.90 and 1.00.

Annular Section Correlation Diagram

A sample correlation diagram is presented in Fig. 4. The curves are graphical solutions of Eqs. 8b, 13 and 14.

The ordinate scale, left margin, is labeled $\theta_{600}/\theta_{300}$ and is indexed as 1.00; 1.10; 1.20; 1.30; 1.40; 1.50; 1.60; 1.70; 1.80; 1.90 and 2.00. The right margin consists of a double scale. The inner scale is labeled K'_e/K'_A and is indexed as 0.88; 0.89; 0.90; 0.91; 0.92; 0.93; 0.94; 0.95; 0.96; 0.97; 0.98; 0.99 and 1.00. The outer scale is labeled γ_A and is indexed as 0; 0.10; 0.20; 0.30; 0.40; 0.50; 0.60; 0.70; 0.80; 0.90 and 1.00.

The abscissa scale is labeled n' and is indexed as 0.00; 0.10; 0.20; 0.30; 0.40; 0.50; 0.60; 0.70; 0.80; 0.90 and 1.00.

APPENDIX B

PROCEDURES FOR CONSTRUCTING FLOW CURVES

The V-G Meter Curve

Multiply the dial reading θ at each speed setting by (RF) (0.01066), where RF is the range extension factor, to obtain τ_v values. (Note: $RF = 1.0$ for the standard version of the Model 35 V-G meter.) Record on the plotting sheet, Fig. 2, τ_{600} on the 600-rpm line, τ_{300} on the 300-rpm line, etc., and construct the best line through the points. If the line is significantly concave to the τ_v axis, the method outlined in the first paper[1] for computing pressure drop due to Bingham plastic flow should be used.

The Pipe Flow Curve

On the plotting sheet read the intercept K'_e from the V-G meter curve on the scale where D_p is unity. Next, determine $\theta_{600}/\theta_{300}$. On the pipe correlation diagram, Fig. 3, read n' corresponding to $\theta_{600}/\theta_{300}$. Next, read K'_e/K'_p corresponding to n'. From K'_e/K'_p and K'_e find K'_p. With K'_p as the base point draw a straight line parallel to the V-G meter curve; this displaced line is the pipe flow curve.

The Annular Section Flow Curve

On the plotting sheet read the intercept K'_e from the V-G meter curve on the scale where D_A is unity. Next, determine $\theta_{600}/\theta_{300}$. On the annular section correlation diagram, Fig. 4, read n' corresponding to $\theta_{600}/\theta_{300}$. Next, read K'_e/K'_A corresponding to n'. From K'_e/K'_A and K'_e find K'_A. With K'_A as the base point draw a straight line parallel to the V-G meter curve; this displaced line is the annular section flow curve.

Friction Loss in Pipe

Step (a)
Calculate

$$V = (17.16)\frac{Q}{D^2}$$

$$D_p = (96)\frac{V}{D}.$$

Step (b)
Find τ_p, lb/ft², corresponding to D_p by inspection from the pipe flow curve

Step (c)
Calculate

$$\gamma_p R_e = (1.858)\frac{V^2\rho}{\tau_p}.$$

Step (d) $\gamma_p R_e < 2{,}000$

$$\frac{\Delta p}{L} = \frac{\tau_p}{(3)\ D}.$$

Step (e) $\gamma_p R_e > 2{,}000$
Refer to Fig. 5; find f corresponding to $\gamma_p R_e$ on the Stanton-Pannell line.

Step (f)
Calculate

$$\frac{\Delta p}{L} = (0.03872)\frac{fV^2\rho}{D}$$

Friction Loss in Annular Section

Step (a)
Calculate

$$\alpha = D_1/D_2$$

$$V = (17.16)\frac{Q}{D_2^2(1-\alpha^2)}$$

$$D_A = (144)\frac{V}{D_2(1-\alpha)}.$$

Step (b)
Find τ_A, lb/ft², corresponding to D_A by inspection from the annular section flow curve.

Step (c)
Calculate

$$\gamma_A R_e = (2.787)\frac{V^2\rho}{\tau_A}.$$

Step (d)
$\gamma_A R_e < 2{,}000$

$$\frac{\Delta p}{L} = \frac{\tau_A}{(3)\ D_2(1-\alpha)}.$$

Step (e) $\gamma_A R_e > 2{,}000$
Refer to Fig. 5; find f corresponding to $\gamma_A R_e$ on the Stanton-Pannell line.

Step (f)
Calculate

$$\frac{\Delta p}{L} = (0.03872)\frac{fV^2\rho}{D_2(1-\alpha)}.$$

★★★

DUAL COMPLETION
SOCONY MOBIL NO. 58-DD STATE BRIDGES
CASE NO. 2924 OCTOBER 30, 1963

Calculation of friction loss in pipe and annular sections - steps taken from "Generalized Newtonian (Pseudoplastic) Flow in Stationary Pipes and Annuli," paper by J. C. Savins, Field Research Laboratory, Socony Mobil Oil Company, Inc.

BEFORE EXAMINER N...
OIL CONSERVATION CO...
Appl. EXHIBIT NO. ...
CASE NO. 292...

Where	V	=	bulk average velocity, ft/sec.
	Q	=	flow rate, bbl/min.
	D	=	ID of tubing, in.
	D_p	=	correlation variable (pipe), sec.$^{-1}$
	τ_p	=	shear stress (pipe), lb/ft.^{2}
	$\nu_p R_e$	=	modified Reynolds No. (pipe), dimensionless
	ρ	=	density, lb/gal.
	Δp	=	pressure drop, psi
	f	=	friction factor (dimensionless)
	α	=	diameter ratio (annular section, dimensionless
	D_1	=	OD of inner pipe, in.
	D_2	=	ID of outer pipe, in.
	D_A	=	correlation variable (annulus), sec.$^{-1}$
	τ_A	=	shear stress (annulus), lb/ft.^{2}
	$\nu_A R_e$	=	modified Reynolds No. (annulus), dimensionless
and	A)		100 BPD in 2" nom. tubing
	B)		100 BPD in 2" x 5" annulus
	C)		200 BPD in 2" nom. tubing
	D)		200 BPD in 2" x 5" annulus

using calculations contained in Appendix B (last page) of Savins paper

A - a) (friction loss in pipe)

$$V = (17.16)\frac{Q}{D^2}$$

$$= (17.16)\ \frac{100\ \text{BPD}/1440}{(1.995)^2} = 0.299\ \text{ft/sec.}$$

$$D_p = (96)\frac{V}{D} = (96)\frac{0.299}{1.995} = 14.4 \text{ sec}^{-1}$$

b) $\tau_p = 5.70\times10^{-5}$ lb/ft^2

from pipe flow curve

c) $\nu_p R_e = (1.858)\frac{V^2 \rho}{\tau_p}$

$$= (1.858)\frac{(0.299)^2\, 6.7}{5.70\times10^{-6}} = 1.96\times10^{4}$$

d) (if $\gamma_p R_e < 2{,}000$)

$$\frac{\Delta p}{L} = \frac{\tau p}{(3)\,D} = \frac{\cdot}{(3)\,1.995} = \underline{\qquad\qquad} \text{ psi/ft}$$

or

e) (if $\gamma_p R_e > 2{,}000$)

f (from Fig. 5) $= .0060$

f) $\frac{\Delta p}{L} = (0.03872)\frac{f\, V^2 \rho}{D}$

$$= (0.03872)\frac{0.0060(0.299)^2\, 6.7}{1.995}$$

$$= 6.9\times10^{-5} \text{ psi/ft.}$$

C - using a) thru f) as above in A

$$\frac{\Delta p}{L} = 20.4\times10^{-5} \text{ psi/ft.}$$

B - (friction loss in annular section)

a) $\alpha = D_1/D_2$

$= 2.340/4.560 = 0.512$

$$V = 17.16\frac{Q}{(D_2)^2(1-\alpha^2)}$$

$$= 17.16\frac{Q}{(4.560)^2(1-0.2628)}$$

$$= 17.16\frac{100/1440}{(4.560)^2(1-0.2628)}$$

$= 0.0777$ ft/sec.

$$D_A = (144) \frac{V}{D_2 (1-\alpha)}$$

$$= (144) \frac{0.0777}{(4.560)(1-0.512)}$$

$= 5.03 \text{ sec}^{-1}$

b) $\tau_A = 5.70 \times 10^{-5}$ lb/ft.^{2}

from annular section flow curve

c) $$\gamma_A R_e = (2.787) \frac{V^2 \rho}{\tau_A}$$

$$= (2.787) \frac{(0.0777)^2 \, 6.7}{5.70 \times 10^{-5}}$$

$= 1975$

d) if $\gamma_A R_e < 2{,}000$

$$\frac{\Delta p}{L} = \frac{\tau_A}{(3) \; D_2 \; (1-\alpha)}$$

$$= \frac{5.70 \times 10^{-5}}{(3) \; 4.560 \; (1-0.512)}$$

$= 8.54 \times 10^{-6}$ psi/ft.

pressure drop 2" x 5" annulus

e) if $\gamma_A R_e > 2{,}000$

f (from Fig. 5) =

f) $$\frac{\Delta p}{L} = (0.03872) \frac{f \, V^2 \rho}{D_2 \; (1-\alpha)}$$

$$= (0.03872) \frac{(0.0777)^2}{4.560 \; (1-0.512)}$$

= ________ psi/ft.

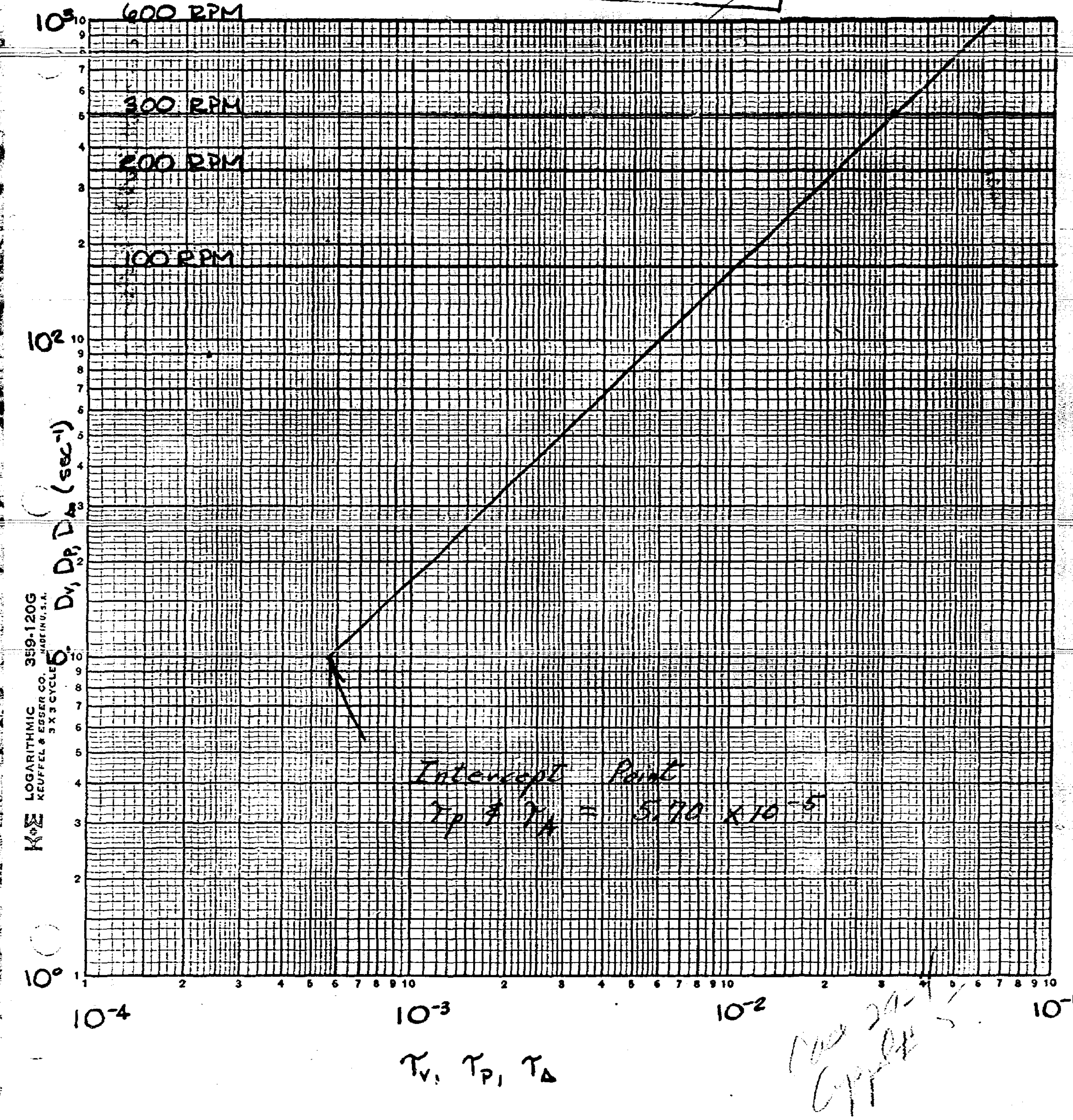
D - using a) thru f) as above in B

$\frac{\Delta p}{L} = 22.1 \times 10^{-6}$ psi/ft.

Joseph C. Gordon, Jr.
John L. Kennedy
10/30/63

BEFORE EXAMINER NUTTER

CASE NO.



10-29-63
JLK

BEFORE THE
NEW MEXICO OIL CONSERVATION COMMISSION
Santa Fe, New Mexico
October 30, 1963

EXAMINER HEARING

IN THE MATTER OF:

Application of Socony Mobil Oil Company for a dual completion and for a tubing exception, Lea County, New Mexico. Applicant, in the above-styled cause, seeks approval of the dual completion (conventional) of its State Bridges No. 58-DD in Unit M of Section 24, Township 17 South, Range 34 East, Lea County, New Mexico, to produce oil from the Vacuum Glorieta and Vacuum Blinebry Oil Pools through parallel strings of tubing. Applicant further seeks an exception to Commission Rule 107(d)4 to produce the Glorieta formation through the casing-tubing annulus from perforation at approximately 6000 feet up to 2 3/8 inch tubing landed in a dual packet at approximately 4020 feet.

Case No. 2924

BEFORE: Daniel S. Nutter, Examiner

TRANSCRIPT OF HEARING

MR. NUTTER: We will call Case 2924.

MR. DURRETT: Application of Socony Mobil Oil Company for a dual completion and for a tubing exception, Lea County, New Mexico.

MR. SPERLING: Jim Sperling, appearing for the applicant in this case. We have one witness, Mr. Gordon.

(Witness sworn.)

J O S E P H C. G O R D O N,

called as a witness, having been first duly sworn was examined and testified as follows:

DIRECT EXAMINATION

BY MR. SPERLING:

Q State your name, place of residence and occupation.

A Joseph C. Gordon, Senior Production Engineer for Socony Mobil Oil Company at Hobbs, New Mexico.

Q Mr. Gordon, have you testified on previous occasions before the Commission?

A Yes, sir, I have.

Q And your qualifications are a matter of record?

A Yes, sir.

MR. SPERLING: Are his qualifications acceptable?

MR. NUTTER: Yes, sir, Mr. Sperling.

MR. SPERLING: Thank you.

Q (By Mr. Sperling) What is your position with Socony Mobil Oil Company?

A I'm a section leader in charge of the Drilling and Production Section; on the Engineering Staff at Hobbs.

Q You are familiar with the application that has been filed in this matter?

A Yes, sir, I am.

Q What does the application propose?

A The application proposes the dual completion in a conventional manner of our State Bridges No. 58-DD. This well is a former completion in the Vacuum Grayburg-San Andres Field, producing through 7-inch casing set on top of an openhole completion. The well, this year, was drilled deeper and a liner was set to a new total depth of approximately 6,800 feet. The liner now has behind it the Glorieta formation at approximately 6,000 feet, and we are now in the process of testing the Blinebry formation at an approximate depth of 6,400 feet as shown on Exhibit 1.

This shows a schematic diagram of our completion made, our proposed completion, which involves the use of two strings of tubing. The longer string for Blinebry production to be run into the Blinebry formation, set in a packer above the Blinebry. The Glorieta production to be produced through a conventionally sized 2 3/8 inch string of tubing set in a packer at the top of the liner.

The Glorieta production would, therefore, require passage through the casing tubing annulus in the section from 6,000 feet up to approximately 4,000 feet, where it would enter the 2 3/8 inch tubing string, and from there on to the surface.

(Whereupon, Applicant's Exhibit No. 1 marked for identification.)

Q Now, the application contemplates an exception to Commission Rule 107. Would you tell us what that provides, in substance?

A Rule 107 Section d, Number 3 requires that tubing shall be set as near the bottom as practical, and tubing perforations shall not be more than 250 feet above the top of the pay.

Q What physical conditions are present in this well that require this application and the request for an exception?

A Our present experience with other Blinebry completions in this immediate area has shown us the desirability of having 2 3/8 inch tubing, if at all possible, in order to put in conventional size pumping equipment, and also to permit use of phosphate pack treatments to reduce a scale condition which has shown a growing tendency in the last few months to be present in the Blinebry.

We have successfully packed and apparently successfully treated phosphate for scale condition through 2 3/8 inch tubing in a present single Blinebry completion. We, therefore, think it advisable to try to produce the Blinebry through the 2 3/8 inch tubing, a conventional size installation.

Tubing inside of the 5-inch, 11½ pound casing prohibits the use of anything like normal sized tubing for the Glorieta in the tubing 5-inch casing annulus. There is not enough physical room here for anything except extremely small tubing for the Glorieta. So, therefore, we are requesting permission to eliminate a tubing string for the Glorieta in this, entering through the liner.

(Whereupon, Applicant's Exhibit No. 2 marked for identification.)

Q Would you refer to Exhibit 2?

A Exhibit 2- -

Q Tell us what it is designated to show.

A Exhibit 2 is a cross-section of our tubing-casing section here. The outer circle there is the I. D. of the 5-inch 11½ pound casing; the I. D. is 4.560 inches.

The next full circle is the O. D. of the 2 3/8 inch coupling, 2.785 inches. The dashed lines, or the dashed circle there indicates the O. D. of the tubing, which is 2.375 inches; and the solid inner circle there is the regular I. D. of 2 3/8 inch tubing, or 1.995 inches.

This is a schematic cross section. The circled numbers there represent the areas involved here in the respective annulus metal, and inside tubing volumes. At the top of the drawing here we have shown this to be the Calculation of Volumes to be used as an Area Equivalent for Comparison purposes.

We have done all our work on volumes here showing the capacity of 5-inch 11½ pound casing to be 14.7 barrels per 1000 feet. The inner capacity of 2 3/8-inch, 4.7 pound tubing is 3.9 barrels per 1000 feet. The area 2 is the displacement or the metal volume of 2 3/8-inch, 4.7 pounds EVE tubing, which is 5.5 barrels per 1000 feet, for a sub-total of, call it 2 3/8-inch volume of 9.4 barrels per 1000 feet. Subtracting this from the volume available inside the casing, gives us 5.3 barrels per 1000 feet of annular volume.

By comparison here we have also shown the volume of 2 7/8 inch tubing, as approximately 5.8 barrels per 1000 feet. The volume of the tubing-casing annulus in this particular case is very close to the interior volume of 2 7/8-inch tubing. Therefore we would say that the annular area is equivalent as an area to the interior area of 2 7/8 inch tubing.

Q In addition to these calculations, Mr. Gordon, you have made other calculations which I confess, with my non-scientific mind, I can't understand. Would you explain those to us?

(Whereupon, Applicant's Exhibit No. 3 marked for identification.)

A Yes, sir. Exhibit 3 is a copy of a paper entitled "Generalized Newtonian (Pseudoplastic) Flow in Stationary Pipes and Annuli". This paper was written by J. G. Savins of the Field Research Laboratory of Socony Mobil Oil Company. I would like to offer this paper because it does have an appendix at the back wherein they work out the problem of pressure drops in annulus.

By reference here to Appendix B, which is the last page of this paper, therein they show the formulized steps for this calculation of pressure drops using tubes and annular spaces. By background this work was occasioned through work in drilling muds and air-gas types of drilling.

Using the formulas presented by Mr. Savins there, we have worked out our problem for the data and our conditions that we have in our well State Bridges 58-DD. We have a copy of those calculations and we have arrived at a comparative type answer with those calculations.

MR. SPERLING: I would like to present that as the next exhibit.

(Whereupon, Applicant's Exhibit No. 4 marked for identification.)

Q (By Mr. Sperling) That's Exhibit 4, I believe, is it not?

A Yes, sir. On this exhibit and the following pages here we have assumed, as shown on the first page, down at the lower section there, four conditions entitled A), B), C) and D) where we would work the problem using Mr. Savins equations. A), 100 barrels per day in 2-inch nominal tubing; B), 100 barrels per day in a 2-inch by 5-inch annulus; C), 200 barrels per day in 2-inch nominal tubing and D), 200 barrels per day in 2-inch by 5-inch annulus. The answers to these problems, as worked out using the Savins equations are outlined in the body of the work as shown here.

On Page 2 we show the answer to condition A to be a pressure drop of 6.9 times 10 to the minus 5 psi per foot. By comparison we also have the solution to Problem B shown on the third page, as 8.54 times 10 to the minus 6 psi per foot. This is the equivalent pressure drop for 100 barrels a day in 2-inch tubing, and 100 barrels per day in this annulus. The annular section B offers less resistance by calculation here to the flow of fluid.

We also have shown the same calculation for 200 barrels per day in these situations, and here the answers are shown on Page 2 for condition C as 20.4 times 10 to the minus 5 psi per foot; and on Page 3 for condition D as 22.1 times 10 to the minus 6 psi per foot. Again, here the tubing pressure drop is greater than the annulus pressure drop for these conditions of flow.

Q Does that complete your explanation of the calculations and the conclusions that you reached based thereon?

A The only thing I might offer is an exhibit of our viscometer plot taken on a sample of Glorieta crude. I don't know if this would materially add to the presentation here or not.

(Whereupon, Applicant's Exhibit No. 5 marked for identification.)

Q Do you want to offer any further explanation concerning Exhibit 5?

A Yes, sir. This exhibit shows the curve derived from the plot as explained in Mr. Savins paper, of the indicated viscometer readings at the rotational speed of 600 and 300 RPM. The line drawn through these two points furnishes an intercept point which is the value used in the calculations in Mr. Savins paper.

Q As I understand, the producing formations from this proposed, or to which this dual well is to be completed, are the Glorieta and the Blinebry Vacuum in both cases, is that right?

A Yes, sir.

Q Are these zones economical to produce in this area as single completions?

A No, sir, they are not economical as single completions.

Q Well, in summary, Mr. Gordon, I assume that your calculations have shown that the method of completions which you have proposed here will not materially differ from that which is contemplated by the rule that we have referred to.

A Yes, sir. We believe we have shown the pressure drop to be less in this annular case. Therefore, this tubing-casing annulus offers a comparable means both pressure drop and area equivalent for the production of the Glorieta formation.

Q Which of these for this formation in this area are the most productive, that is presently and potentially?

A Presently the Blinebry, because of its growing scaling tendency is also exhibiting some water production and appears to be the weaker sister of these two zones.

The Glorieta at the present time is still exhibiting very satisfactory flowing performance, and therefore we have no hesitation in requesting this means of producing the Glorieta. We do not believe that we are going to damage the reservoir or damage the production characteristic.

Q Do you have anything else to add, Mr. Gordon?

A No, sir.

MR. SPERLING: At this time we would like to offer Exhibits 1 through 5.

MR. NUTTER: Applicant's Exhibits 1 through 5 are admitted in evidence.

(Whereupon, Applicant's Exhibits Nos. 1 through 5 were admitted in evidence.)

MR. SPERLING: That's all I have on direct, Mr. Examiner.

MR. NUTTER: Does anyone have any questions of Mr. Gordon?

CROSS EXAMINATION

BY MR. NUTTER:

Q Your Exhibit Number 5 is based primarily upon the -- or correction; the calculations of your pressure drops, that's Exhibit Number --

A That's 4.

Q That's 4?

A Yes.

Q It's based, primarily, upon Mr. Savins study of these pseudoplastic flows through annular spaces, is that correct?

A Yes, sir.

Q And he defines the pseudoplastic materials that he's making this study of as being the sub-group of models which exhibited a decrease in viscosity with increasing shear rate, which would seem to be directed principally at drilling muds and such as that?

A Yes, sir, but these are the non-gelling type of drilling muds in this case.

Q He further goes on to say that the model is of interest since certain of the salt saturated, oil emulsion, and "low solids" drilling fluids, inverted emulsion and oil base drilling fluids, aqueous gels, gelled crudes and blocking agents employed in hydraulic fracturing operations are of this type. Is he talking about crude oil flowing through an annular space?

A Yes, sir, in that crude oil or pore water exhibits this non-gelling or this decrease of shear rate with rotational speeds.

Q Well, now --

A We have a straight line on the plot; the type of fluid here in the case of crude oil permits us to draw a straight line through two points without further examining the other rotational speeds, which in the case of some muds would show a curving tendency, or a tendency to gel.

Q He's probably talking about a fluid coming up through an annular space which has probably been pushed upward by a solid force behind it, is he not?

A I believe his derivation here is strictly in vertical tubes. The pressure drops amount, in this case amounts to be irrespective of whether the movement is upward or downward.

Q As a matter of fact I haven't read the entire paper.

I haven't seen anything where he's talking about vertical flow. I presumed it would be horizontal, but you presumed it was vertical?

A Mr. Savins was contacted for exactly which formula to use and these are the ones that he suggested and pointed out to us.

Q He's not talking about a fluid coming up through the annular space being driven by an expanding gas in that fluid, is he?

A No. In this the development here is strictly on fluid.

Q That's being moved by a solid force being more fluid behind it?

A Yes, sir.

Q And in the flow of crude oil through the annular space in a well that flow is caused by the expansion of the gas in the oil and would be based on an entirely different principle than Mr. Savins source of energy in his problem here?

A Yes, sir. Strictly speaking, if we were looking at the absolute values as derived from Mr. Savins formulas we would be using different principles. Here we were trying to emphasize the comparative amounts of pressure drop in the two different situations, assuming comparable and exactly identical conditions, because there is nothing else at the present time in the literature, to our knowledge, that does concern the two-phase flow in annulus. There has been some work done on two-phase flow in vertical pipes or tubes, but nothing in the annulus, and therefore, this is the only thing that seemed to offer a mathematical means of comparison.

Now, from work which we have done on two-phase pipelines, horizontal pipelines we have observed that in the cases of gas and fluid flow, that up to a certain point the total pressure drop present is, more closely corresponds to the pressure drop due to the fluid, whereas at a certain point above, let's call it a ratio, the gaseous phase of the two phase, fluids will take over and become the controlling pressure drop and you will exhibit increased pressure drop due to the presence of the gas phase. This is in horizontal pipe, it also, I believe, indicates this increased pressure drop due to gas flow at much higher ratios than what we have present in this particular Glorieta formation.

Q Now, in Savins computation of friction or of pressure drop on these pseudoplastic materials, has he taken into consideration any friction loss due to the oil in the annulus bumping across, say for instance, the tubing collars as it comes up that annulus?

A No, sir, to my knowledge he has not. This is an extremely mathematical type of derivation based on some field rule.

Q He hasn't taken into consideration any slippage of the gas as it comes up the annulus?

A No, sir, Mr. Savins paper is purely a fluid paper.

Q What is this treatment that you have been using on the Blinebry to reduce the scale there?

A We have been packing the area of the liner in the perforated, perforations a solid pack with small grained phosphate particles introduced into this space through the tubing, by gravity. This has been a treatment now for approximately two weeks, so it's really too early to say if this is the cure-all. We believe it is though.

Q Have you tried, for instance, treating a well with this phosphate through 2 1/16 inch tubing rather than 2 3/8?

A No, sir, our people would prefer to use conventional sized pumping equipment where they have encountered this scale condition, and they would prefer to use 2 3/8 inch tubing in these cases.

Q Which would preclude a tapered tubing string and the use of the tubing in the 2,000 feet from 4,000 feet to 6,000?

A Yes, sir, except for an extremely small sized tubing string, which would not take any pumping equipment, and which I do not believe would offer any advantage as far as the Glorieta production is concerned.

Q Where would you put a seating nipple in this string of 2 3/8 inch tubing to the Blinebry formation?

A In the Blinebry formation we have not put any seating nipples into the tubing string. When these wells go on the pump we are planning to run mechanical seating nipples.

Q With the arrangement that you have here for the Glorieta your pump is going to have to be at least 2,000 feet above the perforations to the Glorieta, isn't it?

A At such time as the Glorieta declined to the point where it required pumping equipment we would have a different problem, and we might, we would have to install pumping equipment at approximately 4,000 feet unless we made some other arrangements in regard to the tubing string.

Q In this proposed completion that you have here, you couldn't pump the Glorieta if the tubing fluid level dropped below the 4,000 feet?

A Correct.

MR. NUTTER: Are there any other questions of Mr. Gordon? He may be excused.

(Witness excused.)

MR. NUTTER: Do you have anything further, Mr. Sperling?

MR. SPERLING: That's all I have, Mr. Examiner.

MR. NUTTER: Does anyone have anything they wish to offer in Case 2924? We will take the case under advisement.

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STATE OF NEW MEXICO)
) ss.
COUNTY OF BERNALILLO)

I, ADA DEARNLEY, Court Reporter, do hereby certify that the foregoing and attached transcript of proceedings before the New Mexico Oil Commission at Santa Fe, New Mexico, is a true and correct record to the best of my knowledge, skill and ability.

IN WITNESS WHEREOF I have affixed my hand and notarial seal this 9th day of November, 1963.

Ada Dearnley
Notary Public - Court Reporter

My Commission Expires:
June 19, 1967

I do hereby certify that the foregoing is a complete record of the proceedings in the Examiner hearing of Case No. 2924, heard by me on Oct 30, 1963

[signature], Examiner
New Mexico Oil Conservation Commission

DRAFT

JMD/esr
Nov. 15, 1963

BEFORE THE OIL CONSERVATION COMMISSION
OF THE STATE OF NEW MEXICO

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

CASE No. 2924

Order No. R- R-2604

APPLICATION OF SOCONY MOBIL OIL
COMPANY FOR A DUAL COMPLETION AND
FOR A TUBING EXCEPTION, LEA COUNTY,
NEW MEXICO.

ORDER OF THE COMMISSION

BY THE COMMISSION:

This cause came on for hearing at 9 o'clock a.m. on October 30, 1963, at Santa Fe, New Mexico, before Daniel S. Nutter, Examiner duly appointed by the Oil Conservation Commission of New Mexico, hereinafter referred to as the "Commission," in accordance with Rule 1214 of the Commission Rules and Regulations.

NOW, on this ______ day of November, 1963, the Commission, a quorum being present, having considered the application, the evidence adduced, and the recommendations of the Examiner, Daniel S. Nutter, and being fully advised in the premises,

FINDS:

(1) That due public notice having been given as required by law, the Commission has jurisdiction of this cause and the subject matter thereof.

(2) That the applicant, Socony Mobil Oil Company, seeks authority to complete its State Bridges Well No. 58-DD, located in Unit M of Section 24, Township 17 South, Range 34 East, NMPM, Lea County, New Mexico, as a dual completion (conventional) to produce oil from the Vacuum-Glorieta and Vacuum-Blinebry Oil Pools through parallel strings of 2 3/8-inch tubing.

(3) That the applicant also seeks an exception to Rule 107 (d) 4 of the Commission Rules and Regulations to produce the Glorieta formation through the casing-tubing annulus from perforations at approximately 6000 feet up to 2 3/8-inch tubing landed in a dual packer at approximately 4020 feet.

(4) That the applicant has not established that the proposed method of completion will result in efficient recovery of oil.

(5) That inefficient multiple completions ultimately cause waste.

(6) That the subject application should be denied.

IT IS THEREFORE ORDERED:

(1) That the subject application is hereby denied.

(2) That jurisdiction of this cause is retained for the entry of such further orders as the Commission may deem necessary.

DONE at Santa Fe, New Mexico, on the day and year hereinabove designated.