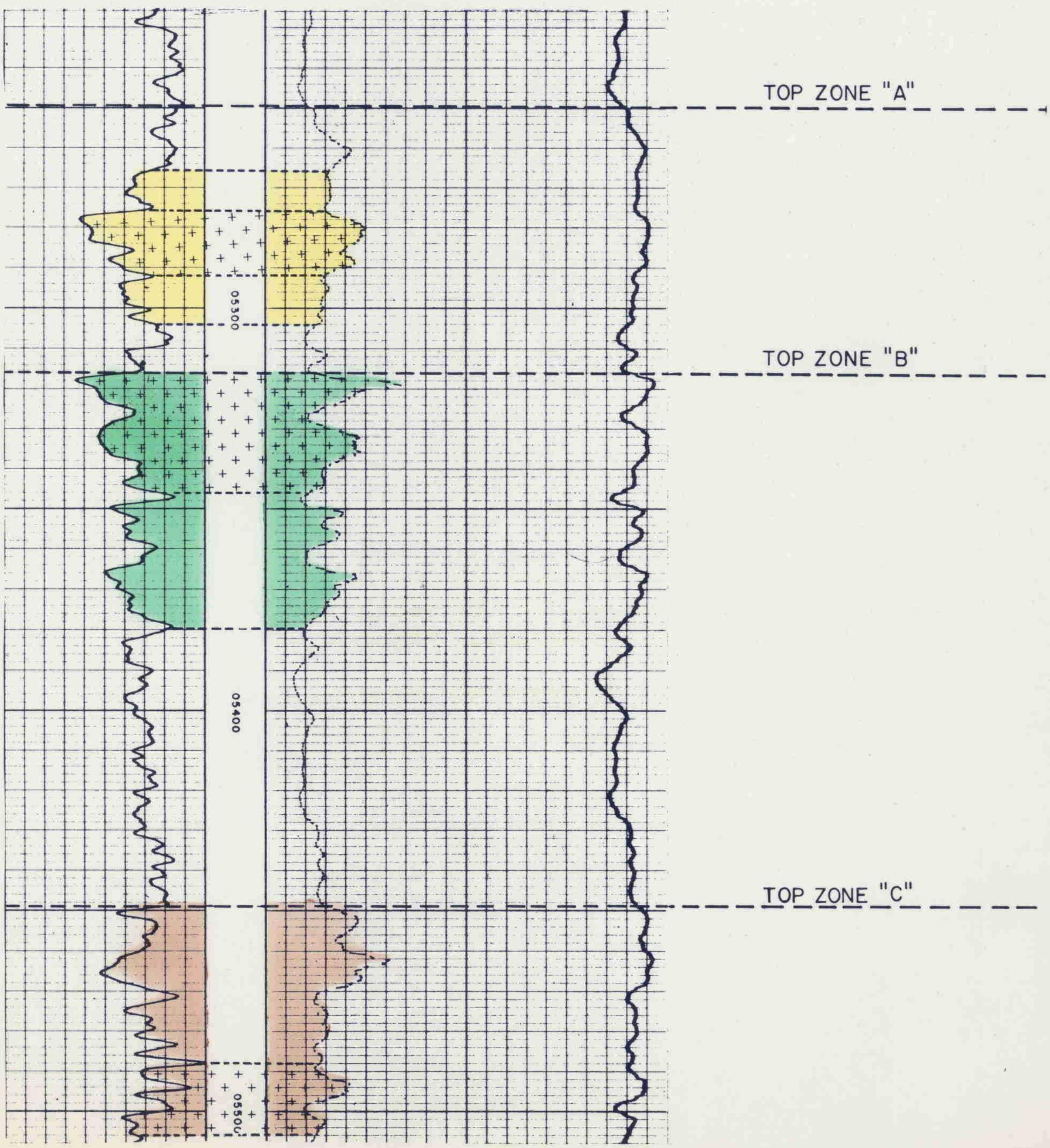
BENSON-MONTIN-GREER DRILLING CORP.
EXHIBITS IN CASE NOS. 8946 & 8950
BEFORE THE OIL CONSERVATION DIVISION OF THE
NEW MEXICO DEPARTMENT OF ENERGY AND MINERALS

AUGUST 7, 1986

NMOCC/NMOCD Case No. 8950
Hearing Date 8/21/86
Benson-Montin-Greer
Exhibit No. 3

IDENTIFICATION OF MAIN PRODUCING ZONES
NORTHEAST PUERTO CHIQUITO
AND
SOUTHWEST PUERTO CHIQUITO

BENSON-MONTIN-GREER DRLG. CORP.
CAÑADA OJITOS UNIT NO. B-18



PHYSICAL PRINCIPLES OF OIL PRODUCTION

By MORRIS MUSKAT, Ph.D.

DIRECTOR OF PHYSICS DIVISION
GULF RESEARCH & DEVELOPMENT COMPANY

FIRST EDITION

NEW YORK TORONTO LONDON
McGRAW-HILL BOOK COMPANY, INC.
1949

where k_o is the permeability to oil, μ_o is the oil viscosity, $\Delta\gamma$ is the density difference between the oil and gas,[1] and θ is the dip angle. If h be the thickness of the oil zone normal to the direction of dip, the volume rate

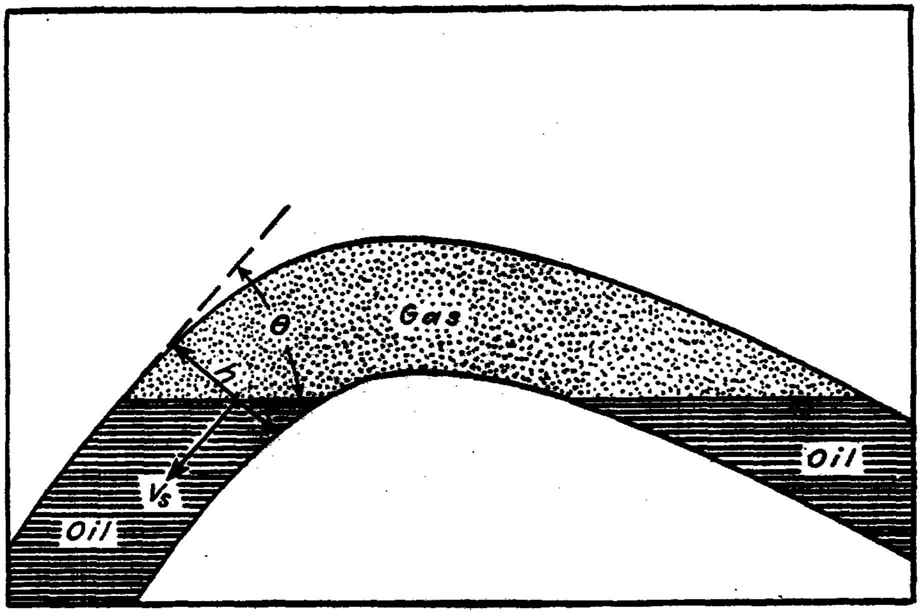


FIG. 10.39.

of oil downdip free-fall migration, in stock-tank measure, will be

$$Q_o = v_s h = \frac{k_o \Delta\gamma g h \sin\theta}{\mu_o \beta_o}, \tag{2}$$

per unit distance parallel to the strike, β_o being the formation-volume factor of the oil. The drainage per unit projected surface area of gas-oil contact is therefore

$$Q = \frac{k_o \Delta\gamma g \sin^2\theta}{\mu_o \beta_o} = 21.29 \frac{k_o \Delta\gamma \sin^2\theta}{\mu_o \beta_o} \text{ (bbl/day)/acre}, \tag{3}$$

where k_o is expressed in millidarcys and $\Delta\gamma$ as a specific gravity. The corresponding rate of vertical fall of the gas-oil-contact plane will be[2]

$$v_s = 2.744 \times 10^{-3} \frac{k_o \Delta\gamma \sin^2\theta}{\mu_o \bar{f}} \text{ ft/day}, \tag{4}$$

where $\bar{f}$ is the net porosity vacated by the oil drainage.

[1] If the gas phase is immobile and not continuous, there will be no buoyancy reaction on the oil due to the gas and $\Delta\gamma$ should be replaced by the oil density γ.

[2] In practice the gas-oil contact will not lie strictly in a plane because of permeability variations. Moreover, even if the permeability were uniform, the gas-oil contact would be a capillary transition zone rather than a sharp geometrical plane (cf. Sec. 7.9).

CASE NO. 3455
DECEMBER, 1969
B-M-G EXHIBIT 2

OIL RECOVERIES UNDER GRAVITY DRAINAGE DEPLETION AND PRESSURE MAINTENANCE AS DEPENDENT ON PHYSICAL RESERVOIR CHARACTERISTICS AND AS AFFECTED BY WELL SPACING

FRACTURED SHALE RESERVOIRS

NIOBRARA MEMBER OF THE
MANCOS SHALE FORMATION

WEST PUERTO CHIQUITO POOL
RIO ARRIBA COUNTY, NEW MEXICO

ALBERT R. GREER

DECEMBER, 1969

PART B - METHOD OF CALCULATING GRAVITY DRAINAGE RATES

Muskat (Reference No. 4) has shown the equation giving maximum possible gravity drainage rates. This equation , in terms of barrels per day per surface acre of gas-oil contact, is:

$$Q = \frac{21.29 \text{ kd } \sin^2 \theta}{\mu B} \qquad \text{(VI - 2)}$$

where Q = gravity drainage rate, barrels per day per surface acre of gas-oil contact

k = permeability to oil, md

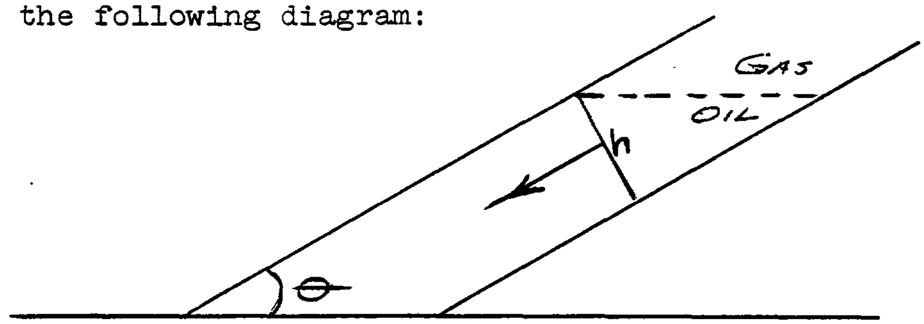
d = difference in specific gravities of oil and gas (water = 1.0)

μ = oil viscosity, cp

B = FVF of oil

θ = angle of dip of formation

The formation thickness and dip of the beds are shown schematically in the following diagram:



With reference to the above sketch, we may determine the surface area of gas-oil contact to be: (per linear mile along the strike)

$$\text{Area of contact} = \left(\frac{h}{\sin \theta}\right)\left(\frac{5,280}{43,560}\right) = .121 \frac{h}{\sin \theta} \qquad \text{(VI - 3)}$$

Multiplying Equation VI-2 by Equation VI-3, and converting to darcys, yields: $\left(\frac{BOPD}{Acre} \times \frac{Acres}{mile} = \frac{BOPD}{mile}\right)$

$$Q = \frac{2{,}580\ h\ K\ d\ \sin\theta}{\mu\ B} \qquad \text{(VI - 4)}$$

where Q - gravity drainage rate in BOPD per linear mile of gas-oil contact along the strike

which is an equation useful to us, as we now have the gravity drainage rate in terms of properties we can determine directly from well tests (transmissibility) or other readily available sources. As stated in Part II of the text, this formula is used to calculate the gravity drainage rates shown on Figure 5.

TRANSACTIONS

OF THE

AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS

(INCORPORATED)

Volume 179

PETROLEUM DEVELOPMENT AND TECHNOLOGY
1949

PETROLEUM BRANCH

PAPERS AND DISCUSSIONS PRESENTED AT MEETINGS HELD AT LOS ANGELES, OCT. 23–24, 1947; DENVER, SEPT. 28–OCT. 2, 1947; TULSA, OCT. 8–10, 1947; NEW YORK, FEB. 15–19, 1948: DALLAS, OCT. 4–6, 1948; AND LOS ANGELES, OCT. 14–15, 1948; ALSO SEVERAL NOT PRESENTED AT ANY MEETING.

PUBLISHED BY THE INSTITUTE
AT THE OFFICE OF THE SECRETARY
29 WEST 39TH STREET
NEW YORK 18, N. Y.

TRANSACTIONS
AIME 1949
VOL 179

CHAPTER IV. *Research Engineering*

Lance Creek Sundance Reservoir Performance—a Unitized Pressure-maintenance Project

By Lincoln F. Elkins,* R. W. French† and Wayne E. Glenn,‡ Members AIME

(Denver and Tulsa Meetings, September–October 1947)

Abstract

The Lance Creek Sundance reservoir provides a case history of 10 years performance of a reservoir in which unit operation has permitted effective utilization of gravity drainage augmented by primary pressure control with injection of gas into top structural wells. Detailed performance of the reservoir is presented by means of maps of well status, reservoir pressure, individual well recovery, etc., and by pool-performance charts. Analysis of reservoir performance indicates only minor water encroachment, so that gravity, injected gas, and expansion of gas are the main oil-expulsive agents.

A simplified theory of regional drainage of oil from upstructure location to downstructure location due to gravity is presented and checked by means of comparison of "reservoir" permeability and "well" permeability from the pool performance. Good order of magnitude agreement was obtained.

Individual well performance and overall reservoir performance indicate possibility that maintenance of pressure makes ineffective those parts of the reservoir in which permeability is too low to permit effective drainage of oil by action of gravity. Oil from these parts can be recovered only when pressure is reduced locally by selective withdrawal or when overall reservoir pressure is finally reduced.

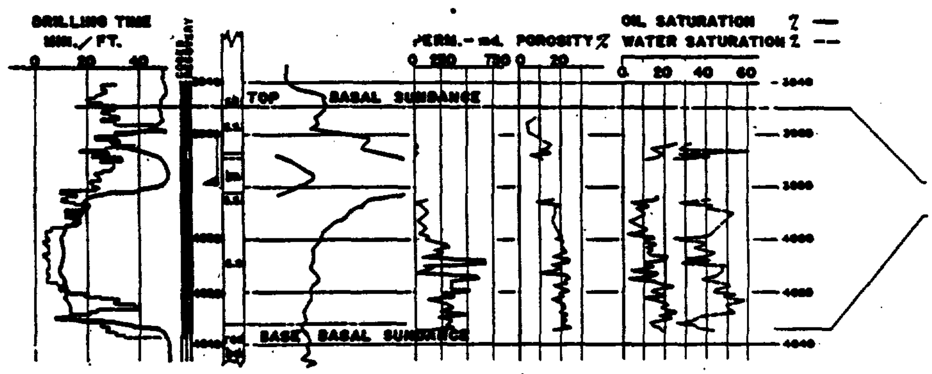


Fig 1—Columnar section and composite log, Lance Creek field.

Introduction

The Lance Creek oil field, Townships 35 and 36N, Range 65W, Niobrara County, Wyoming, was discovered in October 1918, when Ohio Well No. State 1 was

Manuscript received at the office of the Institute Sept. 7, 1947. Issued as TP 2401 in Petroleum Technology, July 1948.

* Continental Oil Co., Ponca City, Okla.; present address The Standard Oil Co. (Ohio), Oklahoma City, Okla.
† The Standard Oil Co. (Ohio), Oklahoma City, Okla.
‡ Continental Oil Co., Ponca City, Okla.

separation of oil and gas. In an underground petroleum reservoir, this is partly offset by capillary forces, which primarily control ultimate segregation, and frictional or viscosity effects, which primarily control rate of segregation. Gravity segregation can be minimized by production of upstructure wells at high gas-oil ratios; it can be made quite effective by unit operation with countercurrent flow of oil and gas; and it can be made most effective with sufficient gas injection upstructure to fill the space voided by downdip drainage of oil. Gravity drainage cannot be increased—according to the popular misconception—by "piston-like" action of high-pressure gas in a gas cap. Gas pressure can force oil to flow downdip at a rate faster than gravity drainage, but gas will flow also in accordance with effective permeabilities of the rock to gas and to oil and in accordance with potential gradients in each of gas and oil phases. Overall efficiency in terms of gas-oil ratios will be better than gas injection into a similar flat reservoir, but it will not be the same as true gravity drainage in which no gas but solution gas is produced.

Making only the one basic assumption of applicability of Darcy's law of fluid flow in porous media and using measurable physical characteristics of the reservoir rock and fluids, it is possible to calculate with reasonable accuracy the *maximum* rate at which oil can drain by gravity from upstructure to downstructure regions. Certain features of the operation of the reservoir can reduce the rate of drainage, but at least the maximum rate has practical significance in determining whether a reservoir can be exploited at a desired rate by the gravity drainage method.

Darcy's law for downdip flow of oil (essentially two-dimensional flow in the "curved" plane of the reservoir formation) may be expressed as:

$$Q_o = 1.127 \frac{K_o H L}{U_o FVF}\left(\frac{dP}{dD} - d_o \sin \alpha\right) \quad [1]$$

Where

Q_o = rate of oil flow, bbl tank oil per day.

K_o = effective permeability to oil, darcys.

H = thickness of formation exposed to flow, ft.

L = length of formation exposed to flow (measured along strike or structure contour).

U_o = viscosity of oil, centipoise.

FVF = formation volume factor of oil.

P = pressure in oil phase, psi.

D = distance along dip of formation, ft.

d_o = density gradient of oil, psi per foot.

$\sin \alpha$ = sine of dip angle.

1.127 = factor to convert darcys to barrels, feet, pounds per square inch, and day system of units.

Since maximum gravity drainage will occur in presence of static gas, and since pressure at each point in the reservoir will be the same in gas and oil phases except for a small difference in capillary pressure, the downdip pressure gradient in the gas-oil region may be calculated from the gas density gradient and will be given by the formula:

$$\frac{dP}{dD} = d_g \sin \alpha \quad [2]$$

where

d_g = density gradient of gas, psi per foot.

Combining this with Eq 1 gives:

$$Q_o = 1.127\, K_o H_o \frac{(d_o - d_g)}{U_o FVF} L \sin \alpha \quad [3]$$

for *maximum* gravity drainage. Since reservoirs are not perfectly symmetrical and fluid withdrawals are not uniformly distributed, the gas-oil contact will advance faster downdip in some areas than in others. Since the tendency exists for oil to seek a common level, there will be a lateral component of flow to compensate for the unequal advance, and the actual flow path will exceed the shortest downdip path and thus decrease the net downdip

FOR 1 MILE
* if use sp.gty (Water=1), with density .4335#/in²/ft
$Q_o = (1.127\, Kh \times .4335(S_o - S_g) \times 5280 \sin\alpha) \div \mu(FVF)$
$= (2580\, Kh(S_o - S_g)\sin\alpha) \div \mu(FVF)$

GRAVITY DRAINAGE RATES
WEST PUERTO CHIQUITO
FOR CONDITIONS OF:
OIL DENSITY 44.9#/cubic foot
GAS DENSITY 5.35#/cubic foot
OIL VISCOSITY .62 centipoises

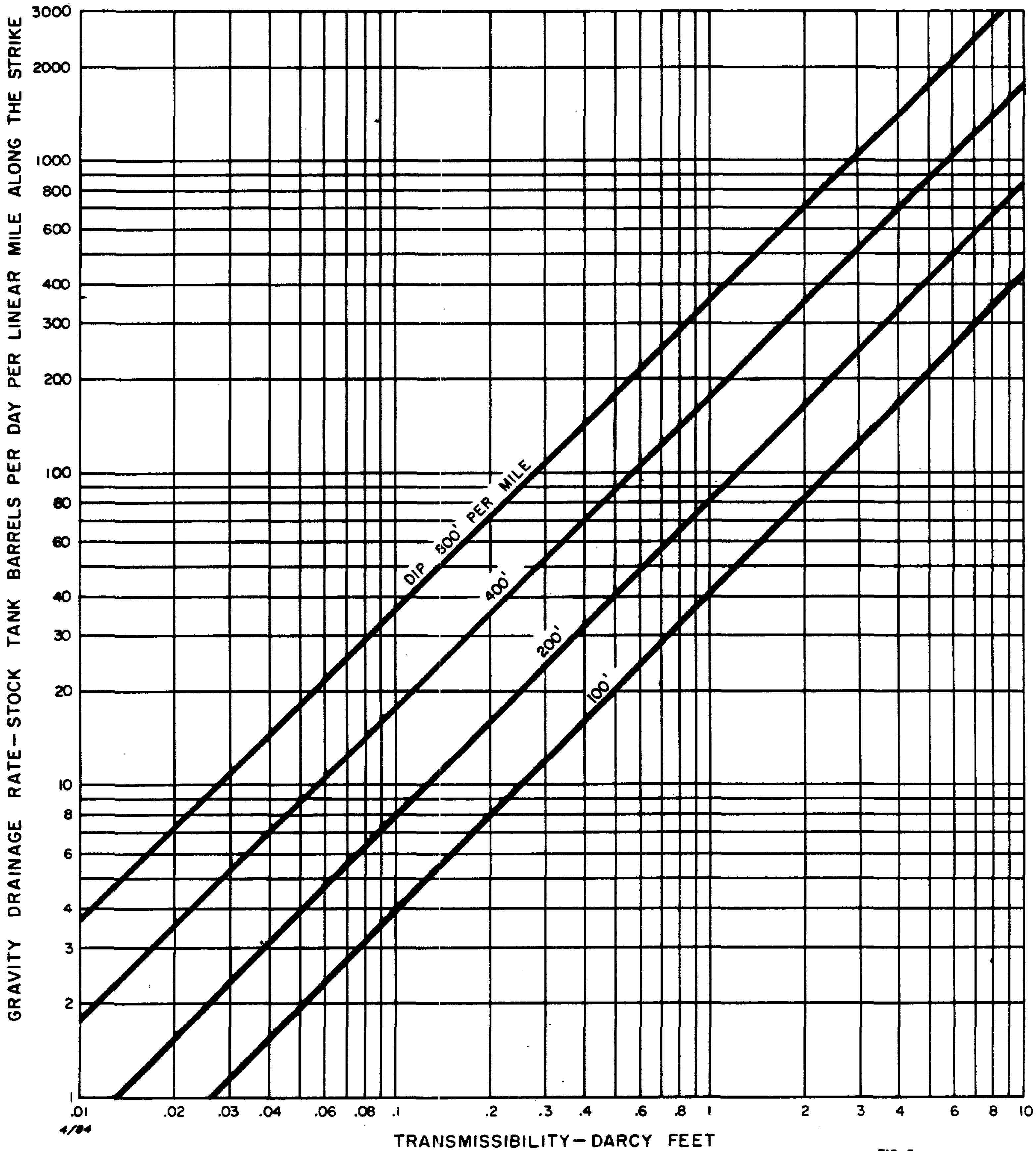


FIG. 5

COMPARISON OF GRAVITY DRAINAGE RATES FOR RESERVOIR WITH FRACTURE POROSITY WITH RESERVOIR WITH MATRIX (SAND) POROSITY

Reservoir section 1 mile wide by 3 miles down dip
Formation dip 100 feet per mile (assume vertical permeability = 0)

	Sand Reservoir	Fracture Reservoir
Transmissibility (darcy feet)	10	10
Thickness	20	?
Porosity (H.C.), percent	20	?
Permeability, horizontal (millidarcies)	500	?
Oil-in-place, STB/acre	31000	3000
Oil-in-place 3 square mile section (Mbbl)	60000	5800
<u>Solution gas drive recovery</u> Percent oil-in-place	± 20	± 6
Barrels/acre	6000	200
Barrels for 3 square mile section (Mbbls)	11500	380
<u>Gravity drainage recovery</u> At 1/2 of maximum of 55% of oil in place (bbls/acre)	8500	800
Barrels for 3 square mile section (Mbbls)	16000	1500
Gravity drainage rate BOPD/linear mile along strike	200	200
Years at gravity drainage rate to reach equivalent solution gas drive recovery	157	5.2
Years at gravity drainage rate to obtain gravity drainage reserves	220	21