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PRODUCTION PERFORMANCE SIMULATION OF GAS

AND GAS-CONDENSATE RESERVOIRS

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CHAPTER I

INTRODUCTION AND PROBLEM FORMULATION

The earliest reported transportation and use of natural gas was by the Chinese. As early as 900 A.D., the Chinese transmitted natural gas in bamboo pipes, from coal beds to their salt workings, where brine was evaporated by heat from the burning gases.[23] The Chinese were centuries ahead of the peoples in the Western hemisphere in the use of natural gas for domestic and industrial purposes.

The earliest recorded use of natural gas in the U.S. was in the town of Fredonia, N.Y., in 1827. The gas was transported in lead pipes for the short-distance usage. However, it was not until 1947 when the change in the character of the gas industry occurred. Natural gas was transported from the Southwest to the East Coast through two converted liquid pipelines. Since then the consumption of natural gas has increased rapidly in the U.S. as it has in other parts of the world. By 1970, the high pressure gas transmission network was extended into all the lower 48 states; it included 269,610 miles of pipe and 4 million horsepower of compression.[33] The consumption of natural gas increased at an average rate of approximately 6.5 per cent per year and the percentage of the Nation's energy consumption it supplied rose from 13 per cent in 1945 to 33 per cent in 1970.

Natural gas produced from gas and gas condensate reservoirs provide a portion of the nation's future energy. Therefore, the prediction of the long term deliverability of such wells is of great importance. The prediction of the decline of average field pressure during the producing life of a field and accurate calculations of pressure losses in the producing system are essential in order that reservoirs may be produced efficiently and economically. In the completion and operation of a gas or gas condensate reservoir a given deliverability must be maintained with transfer at a certain pressure at the salespoint. The engineer is often faced with the decision as how to select and size the producing equipment necessary to maintain deliverability as the reservoir pressure declines. In the cases where the wells have already been completed, it may require larger tubing strings, enlarging flowlines or installation of compressors. In some cases, soon after completion of the well, it may be known that compression will eventually be necessary for depletion of the field. Obviously, the optimal combination of the various facilities and equipment is necessary in order to acquire the maximum economic return from the producing property.

A gas or a gas condensate production system is usually composed of five distinct elements. The five elements of the system can be characterized as follows:

1. Flow through the reservoir with the pressure drop from the average reservoir pressure to the bottom-hole flowing pressure.
2. Flow through the producing strings of the wells with the pressure drop from the bottom-hole flowing pressures to the wellhead flowing pressures.
3. Flow through the surface facilities including the gathering system and the processing, control and metering equipment with the pressure drop from the wellhead flowing pressures to the compressor station inlet pressures.
4. Compression in the station with the pressure increase from compressor station inlet pressure to compressor station discharge pressure.
5. Flow through the pipeline to the sales-point with the pressure drop from compressor station discharge pressure to delivery pressure.

In previous years, extensive work has been done on the flow behavior in the five elements of the system discussed above. However, there has been no major study on the integrated performance and deliverability of such a production system.

The objectives of this investigation are:

1. To develop models to investigate the overall performance of a dry gas and a gas-condensate production system.

2. To integrate all the components of the production system into a systematic delivery model to allow for the optimal selection of (a) producing tubing or casing strings, (b) gathering system, compressor station capacity and pipeline, (c) number of completions within the reservoir (spacing).
3. To predict the well deliverability, total field deliverability and long term deliverability to a fixed pressure point.
4. To analyze the effect of the condensate on the overall performance of the gas wells, a feature which is of great importance in the deliverability of the production system.
5. To analyze the important factors included such as (a) the combined behavior of the individual elements and the interplay between them, (b) to determine the minimum amount of data required to model the system adequately.

In this thesis, schemes for the solution of the above are presented. These schemes are incorporated into a computer model which solves the problem extremely efficiently.

CHAPTER II

MATHEMATICAL MODEL

In the previous chapter five basic components of a production system were introduced. In this chapter the basic equations governing flow behavior in the five basic components are presented.

Performance Prediction for a Dry Gas Reservoir

Back-Pressure Equation. - For many years, back-pressure tests on the gas wells have been used by the oil and gas industries to determine the capacity or the open-flow potential of a gas well. The first step toward calculating the open-flow potential or capacity was made in the classic paper by Rawlins and Schellhardt[31] in 1937. They described and explained the back-pressure method of determining the capacity of a gas well to produce under various conditions of back pressure. They showed that a plot of volume-rate-of-flow versus the difference between the square of the static reservoir pressure and the square of the corresponding flowing bottom-hole pressure on log-log paper is a straight line. Figure 1 shows the back-pressure curve which is from the calculated values of P_{ws} and P_{wf}. The back pressure curve is represented by an empirical equation; namely,

$$q = C(P_{ws}^2 - P_{wf}^2)^n \qquad (2.1)$$

where

q = flow rate in Mscf/day

C = performance coefficient

P_{ws} = the average reservoir pressure in psia

P_{wf} = the flowing bottom hole pressure in psia

n = the reciprocal of the slope of the back-pressure curve.

From a theoretical standpoint, this equation can be considered as the steady state radial flow equation if $n = 1$, and can be stated as:

$$q = \frac{19.88\ T_{sc} kh(P_{ws}^2 - P_{wf}^2)}{ZP_{sc} T_f \mu_g [\ln(r_e/r_w)]}$$

For a particular well, the terms k, h, T_f, T_{sc}, P_{sc}, Z, and $\ln(r_e/r_w)$ may be assumed constant which yields:

$$q = C(P_{ws}^2 - P_{wf}^2)$$

where

$$C = \frac{19.88\ T_{sc} kh}{ZP_{sc} T_f \mu \ln(r_e/r_w)}$$

This is strict Darcy flow. In addition, it assumes isothermal steady state flow and requires an average compressibility factor. For a particular well neither of these assumptions holds absolutely true and thus the exponent n must be introduced.

In the monograph 7, Rawlins and Schellhardt[31] showed the relationship between absolute open flow and absolute formation pressure in the sand for different values of "n" ranging between n = 0.1 and n = 20. This is considerably beyond the practical range for n which is $0.5 \leq n \leq 1$. The variation of the exponent n between different wells has not been satisfactorily explained; however, many tests under actual field conditions and in the laboratory have shown the reliability of the back pressure equation. In low permeability reservoirs in which the wells do not stabilize quickly, it is often not possible to measure directly the stabilized performance without wasting large volumes of gas. For many tight reservoirs both economics and current focus on gas reserves preclude tests of sufficient duration to achieve stabilized flow for a sequence of flow rates. Riley[32] introduced a stabilization factor (SF) for low permeability reservoirs, where because of a short period of testing, stabilization cannot be achieved. This factor applied to the short-term flow rate will give a reasonable approximation of the stabilized flow rate at the back-pressure used in the flow test.

Performance Prediction of Gas-Condensate Reservoir

As long as the reservoir fluid remains in single phase (gas) as the reservoir is depleted, the back-pressure equation presented previously is adequate for performance prediction of the well. However, most gas reservoirs produce some hydrocarbon liquid, commonly called condensate, in the range of a few to a hundred or more bbls/day. This type of well suffers more rapid decline in productivity than that predicted by the theory for dry gas wells due to condensate accumulation within the reservoir and within the producing string. Because of high rates of liquid production, the well may not be able to produce against the required pipeline pressure which consequently necessitates compression. In other cases, the percentage of liquid at the bottom hole condition is sufficient that it loads the well and causes it to die. Figure 2 shows the percentage of liquid as a function of the reservoir pressure. This plot is the result of the laboratory analysis on the fluid sample obtained at the bottom-hole or the well-head. Most gas-condensates in fact behave in this manner, i.e. the condensate production increases as the reservoir pressure decreases. The condensate production is curtailed after a peak production is reached and the reservoir then behaves as a dry gas reservoir.

To take into account the above phenomena, the equation suggested by Fussel et al.[18] was used to predict the performance of gas-condensate reservoirs. This equation can be written in the following form:

$$q = C\left(1 - \frac{V_o Z_g}{V_g Z_o}\right)(P_{ws}^2 - P_{wf}^2)^n \qquad (2.4)$$

where V = volume percent of HCPV occupied by the gas or condensate phase. Figure 2 is a plot of V_o vs. pressure.

Flow in Wells

Single Phase (Gas) Flow in Wells. - A knowledge of the bottom-hole flowing pressure of a gas reservoir is of prime importance in predicting the reserves and deliverability of the gas in the reservoir. For this purpose, flowing sand-face pressure may be measured with a bottom-hole pressure gauge or computed from the well-head pressure. The pressure drop in the production string during gas flow is composed of two components:

1. The pressure drop across a static column of gas with the same average density as the flowing gas column.
2. Friction loss caused by flowing gas through the pipe.

Different methods for calculating and combining the values for the two components have been suggested.[13,23,27,35] The equations commonly used in practice for calculating the flow of gas in a gas well are based on the following assumption:

A. The kinetic energy change is negligible.

B. The flow is isothermal.

C. There is no work done by the gas in flow.

The most realistic equation which has received the most widespread use for calculating the pressure drop in the flowing gas well is that of Smith.[35] Smith gave the equation for calculating pressure in a dry gas well (neglecting kinetic energy change, and assuming that temperature and compressibility are constant at their average value) as:

$$q = \left[\frac{c_f d^5 (P_{wf}^2 - e^s P_{tf}^2)}{f T_{avg}^2 Z_{avg}^2 (e^s - 1)}\right]^{0.5} \tag{2.5}$$

Rearranging would yield:

$$P_{wf} = \left[P_{tf}^2 + \frac{(f q_g^2 T_{avg}^2 Z_{avg}^2)(e^s - 1)}{c_f d^5 e^s}\right]^{1/2} e^{s/2} \tag{2.6}$$

$$s = \frac{0.0375\ GD}{T_{avg}\ Z_{avg}}$$

Multiphase Flow (Gas and Condensate in Wells. - In the petroleum industry the production of gas-condensate through wells involves the flow of mixed fluid phases. In this case, natural gas with light liquid hydrocarbons are produced simultaneously and the flow mixture is two-phase. Several methods[1,3,4,9,15,17,22,29,30] have been developed to compute and predict the flow patterns, liquid hold-up and pressure losses occurring during two-phase flow through vertical pipe. These pressure-loss prediction methods are made up of a combination of pressure-loss correlations and various fluid physical property correlations.

The general pressure gradient equation[30] for a vertical flow can be written as:

$$\frac{dP}{dZ} = \left(\frac{dP}{dZ}\right)_{elev} + \left(\frac{dP}{dZ}\right)_{fric} + \left(\frac{dP}{dZ}\right)_{acc} \qquad (2.7)$$

where:

$\left(\frac{dP}{dZ}\right)_{elev}$ = pressure drop caused by elevation change,

$\left(\frac{dP}{dZ}\right)_{fric}$ = pressure drop caused by friction,

$\left(\frac{dP}{dZ}\right)_{acc}$ = pressure drop caused by acceleration.

The $(dP/dZ)_{elev}$ depends on the density of the two-phase mixture and is usually calculated by a liquid holdup value. The $(dP/dZ)_{fric}$ is due to the friction losses and a two phase friction factor must be evaluated. The $(dP/dZ)_{acc}$ depends on the flow velocity and is considered negligible except in the cases of high flow velocity. Except for the latter case, most of the pressure drop is attributed to elevation. These components can be evaluated by many different types of correlations. Beggs and Brill[6] classified the correlations according to their complexity and the methods used to evaluate each of the components as follows:

1. No Slip, No Flow regime:[3,17,30] liquid holdup is not considered in the computation of the density. The liquid holdup and the friction losses are computed empirically. No distinctions are made among flow regimes.

2. Slip considered, No Flow regime:[22] liquid holdup is considered in the computation of the density. The friction losses are based on the composite properties of the liquid and gas. No distinctions are made among flow regimes.
3. Slip considered, Flow regime considered:[1,4,9,15,29] The calculated density term considers liquid holdup. Liquid holdup is determined from the difference between gas and liquid velocities (slip velocity). The friction losses are determined from the fluid properties of the continuous phase. Distinct flow regimes are considered.

Orkiszewski[29] presented a method in which the two-phase pressure drops can be accurately predicted over a wide range of well conditions and it considered the slip and the flow regime. Orkiszewski's work is a composite of several methods tabulated below:

METHOD	FLOW REGIME
Griffith[19]	Bubble
Griffith and Wallis[20]	Slug (density term)
Orkiszewski[29]	Slug (friction gradient term)
Duns and Ros[15]	Transition
Duns and Ros[15]	Mist

Figure 3 shows the flow regimes of two-phase flow considered by Orkiszewski[29] and can be briefly described as follows:

1. Bubble Flow (Fig. 3-A)

   In this regime the pipe is almost completely filled with the liquid phase and the free gas phase is small. Free gas is present as small bubbles and the liquid is the continuous phase.

2. Slug Flow (Fig. 3-B)

   In this flow pattern more gas bubbles coalesce to form larger, bullet shaped bubbles. These bubbles are separated by a slug of liquid and are surrounded by a thin liquid film.

3. Transition Flow (Fig. 3-C)

   In this regime the change from a continuous liquid phase to a continuous gas phase occurs. Although the liquid effects are significant, the gas phase effects are predominant.

4. Mist Flow (Fig. 3-D)

   In this regime the liquid droplets are carried in the continuous gas phase. The pipe wall is coated with a liquid film and the gas phase predominantly controls the pressure gradient.

In two phase flow, both the friction loss gradient and the fluid density are influenced by the flow regime type, and all three terms (equation 2.7) are a function of temperature and pressure. Therefore, to use equation 2.7 the following procedure must be followed:

1. Increment the flow string so that the fluid properties do not markedly change within any of the increments.
2. For each increment, determine the flow regime and compute the friction loss and average fluid density.
3. Each increment must be evaluated by using an iterative method.

Equation 2.7 can be written in the following form:

$$\Delta P = \left[\frac{1}{144}\,\frac{\bar{\rho} + \tau_f}{1 - W_t q_g/4637\, A_p^2\, \bar{P}}\right]_k \Delta Z_k \qquad (2.8)$$

Determination of Flow Regime

Griffith and Wallis[20] defined the boundary between bubble and slug flow and Duns and Ros[15] defined the boundaries for the slug, transition and the mist flow. The flow regimes are determined by testing whether the variable q_g/q_T or $\bar{V}_g$ or both fall within the limits tabulated below:

Limits	Flow Regime
$q_g/q_T < (L)_B$	Bubble
$q_g/q_T > (L)_B,\ \bar{V}_g < (L)_S$	Slug
$(L)_M > \bar{V}_g > (L)_S$	Transition
$\bar{V}_g > (L)_M$	Mist

where

$$\bar{V}_g = q_g(\sqrt[4]{\rho_\ell / g\sigma})/A_p \tag{2.9}$$

$$(L)_B = 1.071 - (0.2218\ V_t^2/D_h),\ \text{with limit}\quad (L)_B \geq 0.13 \tag{2.10}$$

$$(L)_s = 50 + 36\ \bar{V}_g q_\ell / q_g \tag{2.11}$$

$$(L)_M = 75 + 84\ (\bar{V}_g q_\ell / q_g) \tag{2.12}$$

$\bar{V}_g$ = dimensionless gas velocity

Gathering System

Flow of gas through gas gathering system. - The design of pipelines for gathering natural gas in the oil field has been extensively studied and a number of equations have been used to predict the pressure drop in the gas gathering system.[5,7,28,36]

The Weymouth[38] formula is most commonly used for this purpose within the oil and gas industry and has been found to be adequate. The Weymouth formula, in its most common form, may be expressed as:

$$q = 433.45\ \frac{T_s}{P_s}\ d^{2.667} \left(\frac{P_1^2 - P_2^2}{GT_a L Z_a}\right)^{0.5} \tag{2.13}$$

Flow of two-phase in the gathering system. - Two-phase flow has been of considerable interest in the petroleum industry due to the desirability of accurately calculating the pressure losses that occur in the gathering system.

Gas-liquid mixtures have been transported over relatively long distances in a common line due to centralized gathering systems, particularly in offshore operations. Large pressure drops occur in long two-phase flow lines. Pressure losses in two-phase gas-liquid flow vary considerably from those encountered in single-phase flow; in most cases, an interface exists and the gas slips past the liquid. Several published methods exist for prediction of pressure drop in two-phase flow through horizontal pipe.[4,14,21,25,39] Many of the correlations use a holdup value in calculating the density term used in the friction and acceleration pressure drop components.

Eaton[16] developed correlations for liquid holdup and the two-phase friction factor. Equation 2.7 can be written for multiphase horizontal flow in the following form:

$$\frac{dP}{dL} = \left(\frac{dP}{dL}\right)_f + \left(\frac{dP}{dL}\right)_{acc} \tag{2.14}$$

where Eaton's[16] friction factor is:

$$\left(\frac{dP}{dL}\right)_f = \frac{f\rho_n V_{mix}^2}{2g_c d} = \frac{fW_{mix}^2}{2g_c dA^2\rho_n} \tag{2.15}$$

and Eaton's[16] acceleration term is:

$$\left(\frac{dP}{dL}\right)_{acc} = \frac{W_{liq}\Delta V_{liq}^2 + W_{gas}\Delta V_{gas}^2}{2g_c q_{mix} dX} \tag{2.16}$$

Note that in equation 2.14 the term for potential energy or elevation change is zero.

Compression

Compression is an important element of the production system, and the station inlet pressure at a given deliverability determines the remaining parameters for the reservoir and the production system. The suction pressure of the compressor reflects back to the producing string pressure at the wellhead. The producing string pressure influences the back pressure on the sandface which directly influences feed-in rate.

The engineer in the field is frequently required to determine the approximate horsepower required to handle a certain volume of gas at some intake conditions to a given discharge pressure. Therefore, the selection of proper compressor size is of great importance. Many compression requirements involve conditions beyond the practical capability of a single compression stage. Too great a compression ratio (absolute discharge pressure divided by absolute suction pressure) causes excessive discharge temperature and other design problems. It, therefore, may become necessary to combine elements or groups of elements in series to form a multistage unit, in which there will be two or more stages of compression. The gas is frequently cooled between stages to reduce the temperature and volume entering the following stage. Each stage involves an individual compression. It is sized to operate in series with one or more additional compressors and even though they may all operate from one power source, each is still separate.

The behavior of the compressor station can be represented by two methods: Isothermal Compression and Adiabatic (Isentropic) Compression. Isothermal compression occurs when the temperature is kept constant as the pressure increases. This requires continuous removal of the heat of compression. Adiabatic (isentropic) compression is obtained when there is no heat added to or removed from the gas during compression. Adiabatic compression calculations give the maximum theoretical work or horsepower necessary to operate the compressor between any two pressure limits, whereas isothermal compression calculations give the minimum theoretical work or horsepower necessary to compress a gas.

In this study, the equation of adiabatic theoretical horsepower given by Katz _et al._[23] was used. This equation, which is to find the adiabatic theoretical horsepower to compress 1 mmcf/day at 60°F. and 14.65 psia, is written as follows:

$$ATHP = 0.08531 \frac{k}{k-1} T_{suc} \left[r^{Z_{suc}\left(\frac{k-1}{k}\right)} - 1 \right] \qquad (2.17)$$

where:

$r = P_{dis}/P_{suc}$

P_{dis} = discharge pressure of gas, psia

P_{suc} = suction pressure of gas, psia

$k = c_p/c_v$ = ideal-gas specific-heat ratio

The total brake horsepower (BHP) required is given by

$$BHP = \left(\frac{ATHP}{E}\right) q_{sc} \left(\frac{14.73}{14.65}\right) \qquad (2.18)$$

where

E = overall efficiency

<u>Flow of Gas Through Pipeline</u>

<u>The Panhandle A[8] Formula</u>. - As previously discussed in the gas gathering section of this chapter, the Weymouth[38] formula is suitable for use in the design of gathering system and short pipelines. For larger diameter long lines designed for transmission and gas delivery, the panhandle is used. The formula can be written in the following form:

$$Q = 435.87\ E \left(\frac{T_s}{P_s}\right)^{1.0788} \left(\frac{P_1^2 - P_2^2}{T_f L Z_a}\right)^{0.5394} \left(\frac{1}{G}\right)^{0.4606} d^{2.6182} \qquad (2.19)$$

where E = efficiency factor.

CHAPTER III

TOTAL FIELD DELIVERABILITY

The total field or reservoir back-pressure equation can be obtained by merely summing the performance coefficient (C) for all the wells in the reservoir. This can be shown as follows:

$$\text{Reservoir Deliverability} = q_{reservoir} = (\sum_{j=1}^{N_w} C_j)(P_{ws}^2 - P_{wf}^2)^n$$

where

C_j = performance coefficient of well j

N_w = number of wells

The above equation can be written on an average per well basis, which is:

$$(q_{sc})_{avg} = C_{avg}(P_{ws}^2 - P_{wf}^2)^n$$

Note that the value of "n", the exponent of the back-pressure equation, is assumed the same for all wells. In most cases this is a very reasonable assumption and the value of "n" observed in practice turns out to be very nearly constant in many individual reservoirs. In fact, it is often adequate for field calculations to consider "n" to be constant on a regional basis.

CHAPTER IV

PREDICTION OF RESERVOIR PERFORMANCE

In order to forecast the deliverability of a gas and gas-condensate production system, the system deliverability must be coupled with a material balance equation for the reservoir. The following equations are obtained on the basis of a material balance technique[12] for reservoirs in which there is no water influx or water production.

Gas initially in reservoir = gas produced + gas remaining

thus,

$$G = G_p + (G - G_p) \qquad (3.1)$$

If PV = 379 GZRT, then

$$\frac{P_i V_i}{379\ Z_i RT} = G_p + \frac{PV_i}{379\ ZRT} \qquad (3.2)$$

and

$$\frac{P}{Z} = \frac{P_i}{Z_i} - \frac{379\ RT}{V_i} G_p \qquad (3.3)$$

Solving for G_p would yield

$$G_p = \frac{V_i}{379\ RT}\left(\frac{P_i}{Z_i} - \frac{P}{Z}\right) \qquad (3.4)$$

or

$$G_p = G \frac{Z_i}{P_i}\left(\frac{P_i}{Z_i} - \frac{P}{Z}\right) \tag{3.5}$$

Then

$$G_p = G\left(1 - \frac{P/Z}{P_i/Z_i}\right) \tag{3.6}$$

or

$$G_p = G\left(\frac{P_i/Z_i - P/Z}{P_i/Z_i}\right) \tag{3.7}$$

Equation 3.7 is used to calculate the cumulative gas production during any period of production. Equation 3.7 can also be written in terms of the recovery factor (RF):

$$G_p = G \times RF$$

where the recovery factor is defined as follows:

$$RF = \frac{P_i/Z_i - P/Z}{P_i/Z_i} \tag{3.8}$$

At abandonment conditions the recovery factor is given as follows:

$$RF = \frac{P_i/Z_i - P_a/Z_a}{P_i/Z_i}$$

P_a/Z_a corresponds to the minimum rate at which gas production will no longer be economical (abandonment rate).

Decline rate production. - In the prediction of the long term reservoir deliverability, we must estimate the start of decline in the production rate. This can be simply computed by the following relation:

$$\text{Time to decline} = \frac{\text{Cumulative gas production}}{\text{Constant rate production}} \qquad (3.9)$$

The important point is that the time to decline results from the joint solution of the material balance equation for the reservoir and the overall system flow equations.

CHAPTER V

SOLUTION TECHNIQUES

A constant volume gas expansion type of reservoir is considered. There is no water production nor water encroachment. The objectives of this study are to determine:

I. The maximum deliverability of a production system

II. Based on the predicted deliverability of the system:

1. the life of the well
2. the cumulative gas production as a function of time.
3. the average reservoir pressure as a function of time.
4. the average delivery rate as a function of time

III. The effect on the above with the change of the following parameters:

1. size of the producing string
2. size of the compressor
3. number of the wells
4. flow rate

IV. Repeat the above procedure for a gas-condensate system.

V. Compare the results of the production performance for the dry gas reservoir with the production performance of the gas-condensate reservoir.

The equations used to describe the behavior of the various components to calculate the deliverability of the gas and the gas-condensate production system were the following:

I. Reservoir

1. Dry Gas: back-pressure equation

2. Gas-Condensate: Fussel *et al.* equation

II. Production String

1. Dry Gas: Smith equation

2. Gas-Condensate: Orkiszewski correlation

III. Gathering System

1. Dry Gas: Weymouth equation

2. Gas-Condensate: Eaton correlation

IV. Compressors: Adiabatic compression equation

V. Pipeline: Panhandle A formula

The calculation of the maximum deliverability for a production system involves a trial and error solution. A flow rate, Q, is assumed and the flowing bottom-hole pressure will be calculated in two ways: (1) from the pipeline side, and (2) from the reservoir side. The calculation of the bottom-hole pressure from the line side is as follows:

1. With the assumed value of Q, and the designated delivery pressure, use the panhandle formula to compute the inlet pressure of the pipeline (this inlet pressure calculated is the P_{dis} of the compressor).
2. With the discharge pressure computed in step 1, use the adiabatic compression equation to evaluate the suction pressure at the compressor (this calculated P_{suc} is the outlet pressure of the gathering system).

3. With the gathering system outlet pressure computed in step 2, use the Weymouth equation (Eaton correlation for gas-condensate systems) to calculate the inlet pressure of the gathering system (the inlet pressure calculated is the wellhead flowing pressure).
4. With the wellhead flowing pressure computed in step 3, use the Smith equation (Orkiszewski correlation for gas-condensate systems) to calculate the bottom-hole flowing pressure.

The calculation of the bottom-hole pressure from the reservoir side is as follows:

With the assumed value of Q coupled with other reservoir properties, use the back-pressure equation (Fussel et al. equation for gas-condensate systems) to calculate the bottom-hole flowing pressure.

If the computed pressure from the line side is greater than the computed pressure from the reservoir side, the value of Q is too high and the above procedure must be repeated with a smaller Q. The iterative process is continued until a value of Q is obtained for which the bottom-hole pressures computed from both sides are in close agreement. The method of false position was used to accelerate the iterative procedure.

If there is more than one completion in the reservoir, it is assumed that all wells are identical in every respect, and that the production rates are the same.

Production Performance Under a Prescribed Production Rate or Capacity Production Rate

If the maximum delivery rate computed is higher than the prescribed flow rate, it indicates that the production system can meet the specified requirements. Thus for a given system, the time intervals over which the requirements can be met and those over which they cannot must be identified. In the former, the performance under the specified schedule is determined and in the latter the performance under capacity production is determined (capacity production is a steady decline in deliverability).

Equation 3. is used to calculate the time-to-decline under the specified shcedule. The performance under capacity production at any time step J can be computed as follows:

1. Specify the system deliverability, Q_J.
2. Calculate the average reservoir pressure required to maintain the production rate Q_J.
3. Calculate the average system deliverability $(Q_{avg})_J$:

$$(Q_{avg})_J = \sqrt{Q_J Q_{J-1}}$$

4. Calculate the cumulative production, $(G_p)_J$, at the end of time step J as follows:

$$(G_p)_J = G\left[\frac{\left(\frac{P_{res}}{Z}\right)_i - \left(\frac{P_{res}}{Z}\right)_J}{\left(\frac{P_{res}}{Z}\right)_i}\right]$$

5. Calculate the incremental gas production:

$$(\Delta G_p)_J = (G_p)_J - (G_p)_{J-1}$$

6. Calculate the incremental time:

$$\Delta t_J = \frac{(\Delta G_p)_J}{(Q_{avg})_J(365)}$$

7. Calculate cumulative time at the end of time step J:

$$(t_{cum})_J = t_{J-1} + \Delta t_J$$

The simulation of the production performance and deliverability of gas and gas-condensate reservoirs was carried out on a digital computer, since performing such a heavy load of mathematical operations either by hand or on a desk calculator is not feasible. The computer model is written in FORTRAN IV language for the IBM system/370. The FORTRAN IV language is especially useful in writing programs for applications that involve mathematical computation and other manipulations of numerical data.

The computer model was made completely flexible. Any type of production system can be incorporated, and any number of wells can be investigated within the same reservoir. The model can be run without a portion or portions of the production system such as pipeline, compressor and gathering system.

Thus, fifteen subroutines were prepared, each performing a specific task. Subroutine QCALC coupled with BHP were designed to calculate the optimum deliverability of the production system. Following is the list of the remaining subroutines and their functions:

FRIFAC	Friction factor calculation (Colebrook and White[11])
GASVIS	Gas viscosity calculation (Lee _et al._[24] correlation)
MUFF	Two-phase flow in vertical pipe (Orkiszewski[29] correlation)
MUFFIH	Two-phase flow in horizontal pipe (Eaton _et al._[16] correlation)
OWLVIS	Live oil viscosity calculation (Chew and Connally[10])
OILRAT	Condensate production rate (see Appendix D)
RESP	Reservoir pressure calculation
SOLZ	Iterative method of linear inverse interpolation (method of false position)
SURFAC	Live oil surface tension (gas-oil system)(Baker and Swerdloff[2])
ZFAC0 ZFAC1 ZFAC2	Compressibility factor (Z) calculation (Sarem[34])

CHAPTER VI

RESULTS AND DISCUSSION

This investigation involved a novel technique which determined the maximum production capacity and predicted the long-term deliverability of the integrated production system for a gas and a gas-condensate reservoir. The solution method and the organization of the computer models were presented in Chapters II through V. The data used to obtain the tables and the curves, referred to in this discussion, are presented in Table 1 of Appendix A. The method of investigation involved the interpretation of a series of runs which were made for all cases listed in Table 2, Appendix A.

The size of the producing tubing strings, the compressor station capacity, the number of well in the reservoir and the flow rate were varied in a series of simulation runs and the system production performance were obtained.

Simulation Results of the Dry Gas Model

The results of the simulation study are shown in Tables 3 and 4 and Figures 4 through 19 in Appendix B and C, respectively.

Table 3 indicates the flow behavior of a reservoir with 10 wells producing through (1) 2-1/2-inch tubing and (2) 7-inch casing with station capacities of 3325, 6650, and 8300 HP. Note that the magnitude of the total field deliverability and compressor discharge pressure of the systems increase, and the bottom-hole flowing pressure, the well-head flowing pressure and the compressor station suction pressure decrease as the size of the production string and the compressor station capacity increase.

Similarly, Table 4 shows the flow behavior of a reservoir with (1) 10 wells, (2) 20 wells, and (3) 30 wells, producing through 2-1/2-inch tubing at a station capacity of 8300 HP. The comparison of these three systems shows that the total field deliverability, the bottom-hole flowing pressure, the well-head flowing pressure, the compressor station suction pressure and the compressor station discharge pressure increase as the number of completions increases (well spacing decreases). The system deliverability increased by 41.8% when the number of wells increased from 10 to 20; however, it only increased by 8.59% when the number of wells increased from 20 to 30.

Figures 4 through 7 of Appendix C show the total field deliverability vs time for 10 wells producing through 2-1/2-inch tubing and 7-inch casing at station capacity of 6650 HP. Flow rates of 50, 100, 150 and 200 MMscf/day are prescribed. The deliverabilities of the wells are represented by their respective deliverability curves. The comparison of these figures indicates that the maximum deliverability for 2-1/2-inch completions and 7-inch completions are 134.82 and more than 200 MMscf/day respectively. The increase in total field deliverability is due to the reduced friction losses resulting from the larger area available for flow in the producing string.

Figure 4 shows that in the 2-1/2-inch completions the total field deliverability declines below 50 MMscf/day in the third quarter of the ninth year while in 7-inch completions the total field deliverability does not decline until the last quarter of the thirteenth year. However, the latter reaches the abandonment rate over a year earlier. Figure 5 shows similar behavior except the decline production is reached earlier because of the twofold increase in the production rate.

Figures 6 and 7 indicate that the 2-1/2-inch completions are performing under capacity production and that the total field deliverability is declining in spite of the use of compression throughout its productive life.

Figures 8-11 illustrate the behavior of a reservoir with 10 wells producing through 2-1/2-inch tubing and 7-inch casing at 3325, 6650, and 8300 HP capacities. Prescribed flow rates of 100 and 200 MMscf/day are shown. Figures 8 and 10 indicate that the total field deliverability of the production systems (2-1/2-inch and 7-inch completions) with 3325 HP station capacity would decline earlier than the other systems with larger compressor size. The production system with larger compressor station capacity reaches the abandonment rate earlier than the other systems. Figures 9 and 11 exhibit the performance of the systems described above under capacity production.

Figure 12 shows that the total field deliverability is increased as the larger production string is installed. It is further increased as the size of the compressor is increased.

Figures 13-15 illustrate the effect of the compressor horsepower on the total field deliverability. The curves show the behavior of the production system (2-1/2-inch tubing and 7-inch casing) as the compressor station capacity is increased. In Figure 13 the curve indicates that as the compressor station capacity increases the deliverability of the system increases rapidly. However, the rate of increase in the deliverability decreases when a compressor station capacity of 4000 HP is reached. Furthermore, there will be a point in the curve where the slope of the line will be zero which illustrates that there will be no more increase in the deliverability of the system in spite of the use of a larger compressor.

Figure 16 shows the behavior of a reservoir with 10 wells producing through 2-1/2-inch tubing with station capacity of 3325 and 6650 HP; 10 wells producing through 7-inch casing and 6650 HP station capacity; and 20 wells producing through 2-1/2-inch tubing and 6650 HP capacity. These curves illustrate the effects of the size of the compressor, the size of the production string and the number of completions.

Figure 17 is a graph of the cumulative gas production versus time for 2-1/2-inch tubing and 7-inch casing completions. This curve indicates that the 7-inch casing completions have higher recovery factors than 2-1/2-inch completions. However, the abandonment rate is reached 1.75 years later in the latter case.

Figure 18 shows the overall system deliverability for the cases discussed in Figure 16. This curve shows the deliverability of the system versus the average reservoir pressure. This curve illustrates the maximum deliverability of the system as a function of the average reservoir pressure or gas in place. This curve is of prime importance because it exhibits the deliverability under the influence of all the components of the system.

Figure 19 shows the total field deliverability as a function of the compressor station suction pressure for 10 wells producing through 2-1/2-inch tubing at 6650 and 8300 HP capacity. This curve is also of prime importance since the sunction pressure of the compressor will reflect back to the well-head flowing pressure, which in turn will reflect back to the bottom-hole flowing pressure and consequently affect the feed-in rate.

Simulation Results of the Gas-Condensate Model and Comparison of the Production Performance of the Gas and Gas-Condensate Reservoirs

The effect of the compressor size on the flow behavior of the production system was first studied for 10 wells producing through 2-1/2 inch tubing at 3325, 6650 and 8300 HP capacity (see Table 5, Appendix B). Second, the effect of the number of completions on the flow behavior and system deliverability was investigated for 10, 20, and 30 wells producing through 2-1/2 inch tubing at 6650 HP compressor station capacity. Third, the effect of the size of the production string on the total field deliverability was studied for 10 wells producing through 2-1/2 inch tubing and 7 inch casing at 6650 HP station capacity.

Table 5 shows that the maximum total field deliverabilities increased as the compressor size increased. The maximum deliverability of the system with 3325 HP compressor was predicted to be 23.6 MMscf/day and 192 bbls/day condensate while the maximum deliverability of the system with 8300 HP compressor is computed to be 35.6 MMscf/day and 290.9 bbls/day condensate. In these runs the assumption is made that the gas and the condensate are separated by the separator at the well head, and that there is no pressure loss through the separator. However, in actual field operation there is a pressure drop through the separator with the pressure drop being in the range of a few psia. Table 5 also shows the pressure drop through the production string.

This significant pressure drop is due to the multiphase flow through the pipe.

Table 6 illustrates the effect of an increase in the number of completions in the reservoir. It indicates that as the number of completions in the reservoir increases the gas deliverability and the condensate production of the system increases.

Figure 20 shows the effect of increasing the diameter of the production string on the total field deliverability. It indicates that as the size of the production string increases, the total field deliverability increases.

Figure 21 compares the total field deliverability for 10 wells producing through 2-1/2 inch tubing at 3325 HP and 8300 HP station capacity; 20 wells producing through 2-1/2 inch tubing at 8300 HP capacity; and 10 wells producing through 7-inch casing at 8300 HP capacity. In all the systems investigated (Tables 5 and 6 and Figures 20 and 21) and discussed above, the prescribed flow rate was 50 MMscf/day of gas and 400 bbls/day of condensate. It is apparent that the reservoir and the production system described will not produce under the prescribed production rates.

Comparison of the Production Performance of the Gas and Gas-Condensate Reservoirs

The results of the simulation studies and their comparison are illustrated in Tables 7 and 8 (Appendix B) and Figures 22-28 (Appendix C). The comparison of the results from simulation of the dry gas and the gas-condensate models shows some noticeable differences.

Table 7 shows the fluid flow behavior for 10 wells producing through 2-1/2 inch tubing and 7-inch casing with compressor capacity of 3325 HP. The prescribed flow rate is 50 MMscf/day of gas for the dry gas case and 50 MMscf/day of gas and 400 bbls/day condensate for the gas-condensate system. This table shows the difference in the behavior of the reservoirs and the effect of each element of the system on the overall production performance. For the case of 2-1/2 inch completions the maximum total field deliverability of a dry gas system is decreased from 118 MMscf/day to 23.6 MMscf/day. Similarly, in the case of the 7-inch completions the total field deliverability is decreased from 164.7 MMscf/day to 24 MMscf/day. Also, note that there is no marked difference in the overall performance of the 2-1/2 inch completions and the 7-inch completions of the gas-condensate system. The significant reduction in the total field deliverability and large increase in the pressure losses through the producing equipment is primarily the result of multiphase flow phenomena in the producing string and not deterioration of reservoir deliverability.

Table 8 shows the comparison of the 7-inch completions in the dry gas and the gas-condensate reservoir with the compressor station capacity of 8300 HP.

Figures 22 through 25 show the comparison of the performance of the dry gas and the gas-condensate reservoirs for 10 wells producing through 2-1/2 inch tubing and 7-inch casing at a station capacity of 6650 HP. The prescribed gas flow rates are 50 and 100 MMscf/day and 400 bbls/day of condensate.

In figure 22, in the case of the dry gas, the total field deliverability declines below 50 MMscf/day (prescribed flow rate) in the last quarter of the ninth year. However, in the case of the gas-condensate, the flow system cannot sustain a production rate of 50 MMscf/day initially and its entire production life is characterized by capacity decline. The abandonment rate is reached six years earlier in the gas-condensate reservoir.

Figure 23 indicates that for the 7-inch completions in the gas-condensate reservoir, the total field deliverability declines below 50 MMscf/day in the first quarter of the first year and that total field deliverability of the dry gas system does not decline until the thirteenth year of production is reached.

Figures 24 and 25 show the comparison of the same systems with the prescribed flow rate of 100 MMscf/day.

Figure 26 shows the effect of the size of the production string on the total field deliverability of both dry gas and gas-condensate systems. It indicates that the size of the producing string has greater influence on the overall behavior of the dry gas system than that of the gas-condensate system.

Figures 28 and 29 show the effect of the compressor station capacity on the total field deliverability of the dry gas and gas-condensate systems.

CHAPTER VII

SUMMARY AND CONCLUSIONS

A mathematical simulation procedure for computing the dry gas and the gas-condensate field deliverability to a set delivery pressure at some terminal point has been developed.

The features of these procedures can be summarized as follows: (1) They provide simulations of the existing field producing system and prediction of the future performance. (2) The models allow the study of a system composed of several wells within a reservoir. (3) Models developed show the significance of the individual elements of the production system and the interplay between them. (4) Models show the significance of the flow behavior in the technology of the production, especially two-phase flow.

Conclusions from the results presented are:

1. The system deliverability could be increased by analyzing all parts of the system simultaneously in an integrated manner. In some cases, the situation may dictate the use of larger tubing strings and gathering flow lines. In other cases, a larger compressor may be desired. The method presented allows one to maximize deliverability by the design of the production strings, gathering system, compressor station

capacity and pipeline. The optimal design can be determined by computing the effects of the parameters, size of tubular goods and production strings, on reservoir behavior.

2. The scheme allows optimal gas well spacing by the selection of the number of wells within the field required to meet given production targets.

3. Comparisons made between the dry gas flow and two-phase flow production systems show that the deliverability of the gas-condensate, compared to that of a dry gas, is greatly reduced. This is due to condensate accumulation in the region of the producing wells and the pressure losses through the producing strings and gathering system attributed to multiphase flow.

4. The techniques described here provide important information such as (a) maximum well deliverability, (b) total field deliverability, (c) overall system deliverability, and (d) the production life of the reservoir. This information allows the selection of appropriate producing strings and tubular goods which will achieve a maximum cash flow or maximize some similar type criterion over the life of the field.

5. The simulation studies in this report will not account for erratic and unpredictable production problems, such as scale, corrosion, equipment failure and other problems which may become more serious as abandonment conditions are approached.

6. Methods using the simulation of mathematical models are very powerful and useful and could be used to predict the system performance of a reservoir in an economical amount of computer time.

CHAPTER VIII

RECOMMENDATIONS

Further considerations that must be taken into account before determining the optimum sizing of the production system and optimal well spacing include: the availability of equipment, operating cost and agreements, governmental rules and regulations, cost of equipment and many other limitations.

Therefore, the design of the project must be fully evaluated and the results of such an engineering study should be combined with (1) reservoir production optimization solved effeciently by using a dynamic programming approach and (2) economic analysis of the project to arrive at the most profitable operation.

NOMENCLATURE

A_p	area of pipe, sq. ft.
ATHP	adiabatic theoretical horsepower, HP
B_g	gas formation volume factor, bbl/SCF
C	performance coefficient
C_f	constant, 1.5×10^3
d	inside diameter of production string, in.
D	formation depth, ft.
D_h	hydraulic pipe diameter ($4 \times A_p$/wetted diameter), ft.
E	efficiency
f	friction factor, dim.
g	acceleration of gravity, ft/sec^2
g_c	gravitational constant, ft-lb(mass)/lb(force)-sec^2
G	gas gravity (air = 1)
h	formation thickness, ft.
HCPV	hydrocarbon pore volume, ft.^{3}
k	formation permeability, md
L	length of the pipe, ft.
$(L)_B$	bubble-slug boundary, dim.
$(L)_M$	transition-mist boundary, dim.
$(L)_s$	slug-transition boundary, dim.
n	the reciprocal of the slope of the back-pressure curve

N_w	number of wells, dim.
P	pressure, psi
$\bar{P}$	average pressure, psia
ΔP	pressure drop, psi
P_{tf}	flowing tubing or casinghead pressure, psi
P_{wf}	flowing bottomhole pressure, psi
P_{ws}	average reservoir pressure, psi
q	volumetric flow rate, cu. ft./sec
Q	volumetric flow rate, cu. ft./day
r	compression ratio
r_e	outer radius, ft.
r_w	well bore radius, ft.
R	universal gas constant (per mole), psi-ft^3/(lb. mole R°)
T	temperature, °R
Δt	time increment, year
V	fluid velocity, ft./sec
ΔV_g^2	$V_g^2(P_1,T_1) - V_g^2(P_2,T_2)$
ΔV_L^2	$V_L^2(P_1,T_1) - V_L^2(P_2,T_2)$
W	mass flow rate, lb/sec
Z	compressibility factor
Z	depth from wellhead, ft.
ΔZ	increment of depth, ft.
μ	viscosity, cp
$\bar{\rho}$	average flowing density, lb/cu.ft.
ρ_n	two phase density, lb/cu.ft.
σ	surface tension, lb/sec^2

τ_f	friction loss gradient, psf/ft
$\bar{V}$	$q_g(\sqrt[4]{\rho_\ell/g\sigma})$, dimensionless gas velocity

<u>Subscripts</u>

a	average, abandonment
cum	cumulative
dis	discharge
f	flowing, friction
g	gas
i	initial
J	time step
k	increment
ℓ	liquid
Liq	liquid
Mix	mixture
o	oil
p	production
res	reservoir
s, sc	standard condition
suc	suction
T	total

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APPENDIX A

TABLE 1

DATA USED IN THIS STUDY

Gas Properties

γ_g = .64, gas sp. gravity

μ_g = 0.0175 cp, gas viscosity

Condensate Properties

γ_o = 0.8, condensate sp. gravity

μ_o = 1.419 cp, condensate viscosity

σ_o = 32 dynes/cm, condensate surface tension

ρ_o = 42.45 lbm/ft^3, condensate density

B_o = 1.419 bbls/stb, condensate formation volume factor

Reservoir Data

N_w = 10, number of wells (well spacing)

C_{avg} = 0.0742 (MMscf/day)/psia$^{2/n}$, performance coefficient

n = 0.747, exponent of the back pressure equation

P = 1500 psia, average reservoir pressure

T = 120°F, 580°R, reservoir temperature

G = 250,000 MMscf, gas in place

Producing Tubing Strings Data

D = 5000 ft, well depth

d = 2-1/2 inch, size of the tubing

T_{avg} = 95°F = 555°R, average flowing temperature

Z_{avg} = 0.95, average compressibility factor

Surface Facilities Data

C_3 = 7.63 x 10^5 (scf/day)/psia^2, the average flow conductivity of the gathering system

TABLE 1 (Continued)

Compressor Station Data

BHP = 6650 HP, compressor station capacity

E = 0.80, overall efficiency

k = 1.25, c_p/c_v, ratio of the molar heat capacities of the gas

T_{suc} = 60°F, 520°R, suction temperature

Z_{suc} = 1.0, suction compressibility factor

Pipeline Data

d = 13 inches, pipeline diameter

L = 100 miles, pipeline length

T_{avg} = 70°F = 530°R, pipeline average flowing temperature

E = 0.92, pipeline efficiency factor

P_b = 14.73 psia, base pressure

T_b = 60°F = 520°R, base temperature

P_L = 300 psia, pipeline delivery pressure

TABLE 2

GAS AND GAS-CONDENSATE PRODUCTION SYSTEM

2-1/2 INCH TUBING

Constant Rate (MMscf/day)	Station Capacity (HP)	Number of Wells	Constant Rate (MMscf/day)	Station Capacity (HP)	Number of Wells
50	3325	10	50	6650	30
100	3325	10	100	6650	30
150	3325	10	150	6650	30
200	3325	10	200	6650	30
50	3325	20	50	8300	10
100	3325	20	100	8300	10
150	3325	20	150	8300	10
200	3325	20	200	8300	10
50	3325	30	50	8300	20
100	3325	30	100	8300	20
150	3325	30	150	8300	20
200	3325	30	200	8300	20
50	6650	10	50	8300	30
100	6650	10	100	8300	30
150	6650	10	150	8300	30
200	6650	10	200	8300	30
50	6650	20	50	100	10
100	6650	20	50	500	10
150	6650	20	50	1000	10
200	6650	20	50	2000	10

TABLE 2 (Continued)

GAS AND GAS-CONDENSATE PRODUCTION SYSTEM

7 INCH CASING

Constant Rate (MMscf/day)	Station Capacity (HP)	Number of Wells	Constant Rate (MMscf/day)	Station Capacity (HP)	Number of Wells
50	3325	10	50	6650	30
100	3325	10	100	6650	30
150	3325	10	150	6650	30
200	3325	10	200	6650	30
50	3325	20	50	8300	10
100	3325	20	100	8300	10
150	3325	20	150	8300	10
200	3325	20	200	8300	10
50	3325	30	50	8300	20
100	3325	30	100	8300	20
150	3325	30	150	8300	20
200	3325	30	200	8300	20
50	6650	10	50	8300	30
100	6650	10	100	8300	30
150	6650	10	150	8300	30
200	6650	10	200	8300	30
50	6650	20	50	100	10
100	6650	20	50	500	10
150	6650	20	50	1000	10
200	6650	20	50	2000	10

APPENDIX B

TABLE 3

COMPARISON OF THE PERFORMANCE OF A DRY GAS PRODUCTION SYSTEM

Compressor Station Capacity:	3325 HP		6650 HP		8300 HP	
	2½" Tubing	7" Casing	2½" Tubing	7" Casing	2½" Tubing	7" Casing
Deliverability (MMCF/DAY)	118	164.7	134.82	209.8	139.45	228.5
Average Reservoir Pressure (psia)	1500	1500	1500	1500	1500	1500
Bottom-hole Flowing Pressure (psia)	1485	1472	1481	1453	1480	1443
Well-head Flowing Pressure (psia)	809	1263	607	1244	530	1235
Compressor Station Suction Pressure (psia)	794	1244	581	1214	498	1198
Compressor Station Discharge Pressure (psia)	1415	1899	1586	2367	1635	2558
Delivery Pressure (psia)	300	300	300	300	300	300

TABLE 4

COMPARISON OF THE PERFORMANCE OF A DRY GAS PRODUCTION SYSTEM

	Production from 10 Wells	Production from 20 Wells	Production from 30 Wells
Deliverability (MMcf/day)	139.45	197.75	216.35
Average Reservoir Pressure (psia)	1500	1500	1500
Bottom-hole Flowing Pressure (psia)	1480	1490	1495
Well-head Flowing Pressure (psia)	530	977	1132
Compressor Station Suction Pressure (psia)	498	942	1096
Compressor Station Discharge Pressure (psia)	1635	2242	2433
Delivery Pressure (psia)	300	300	300

TABLE 5

COMPARISON OF THE PERFORMANCE OF A GAS-CONDENSATE PRODUCTION SYSTEM

Production Through 2-1/2" Tubing

Compressor Station Capacity:	3325 HP	6650 HP	8300 HP
Deliverability (MMcf/day)	23.6	33.6	35.65
Condensate Production (bbls/day)	192	274	290.9
Average Reservoir Pressure (psia)	1500	1500	1500
Bottom-hole Flowing Pressure (psia)	1499	1499	1498
Well-head Flowing Pressure (psia)	50	49.10	49.0
Compressor Station Suction Pressure (psia)	39.25	21.65	15.0
Compressor Station Discharge Pressure (psia)	431.4	524.3	544
Delivery Pressure (psia)	300	300	300

TABLE 6

COMPARISON OF THE PERFORMANCE OF A GAS-CONDENSATE PRODUCTION SYSTEM

D = 2-1/2" Tubing, Compressor Station Capacity = 8300 HP

	Production from 10 Wells	Production from 20 Wells	Production from 30 Wells
Deliverability (MMcf/day)	35.6	47.3	59
Condensate Production (bbls/day)	290.9	385.7	462
Average Reservoir Pressure (psia)	1500	1500	1500
Bottom-hole Flowing Pressure (psia)	1498	1499	1499
Well-head Flowing Pressure (psia)	49	50.2	50.5
Compressor Station Suction Pressure (psia)	15	16	16.2
Compressor Station Discharge Pressure (psia)	544	551	552
Delivery Pressure (psia)	300	300	300

TABLE 7

COMPARISON OF DRY GAS AND GAS-CONDENSATE PRODUCTION SYSTEMS

Compressor Station Capacity 3325 HP

	Production Thru 2½" Tubing		Production Thru 7" Casing	
	Dry Gas	Gas-Condensate	Dry Gas	Gas-Condensate
Deliverability (MMcf/day)	118	23.6	164.7	24
Condensate Production (bbls/day)	--	192	--	192
Average Reservoir Pressure (psia)	1500	1500	1500	1500
Bottom-hole Flowing Pressure (psia)	1485	1499	1472	1498.9
Well-head Flowing Pressure (psia)	809	50	1263	50
Compressor Station Suction Pressure (psia)	794	39.25	1244	39.25
Compressor Station Discharge Pressure (psia)	1415	431.4	1899	431.5
Delivery Pressure (psia)	300	300	300	300

TABLE 8

COMPARISON OF DRY GAS AND GAS-CONDENSATE PRODUCTION SYSTEMS

Production Thru 7" Casing

Compressor Station Capacity 8300 HP

	Dry Gas	Gas-Condensate
Deliverability (MMcf/day)	228.5	35.65
Condensate Production (bbls/day)	--	290.9
Average Reservoir Pressure (psia)	1500	1500
Bottom-hole Flowing Pressure (psia)	1443	1498
Well-head Flowing Pressure (psia)	1235	49
Compressor Station Suction Pressure (psia)	1198	15
Compressor Station Discharge Pressure (psia)	2558	544
Delivery Pressure (psia)	300	300

APPENDIX C

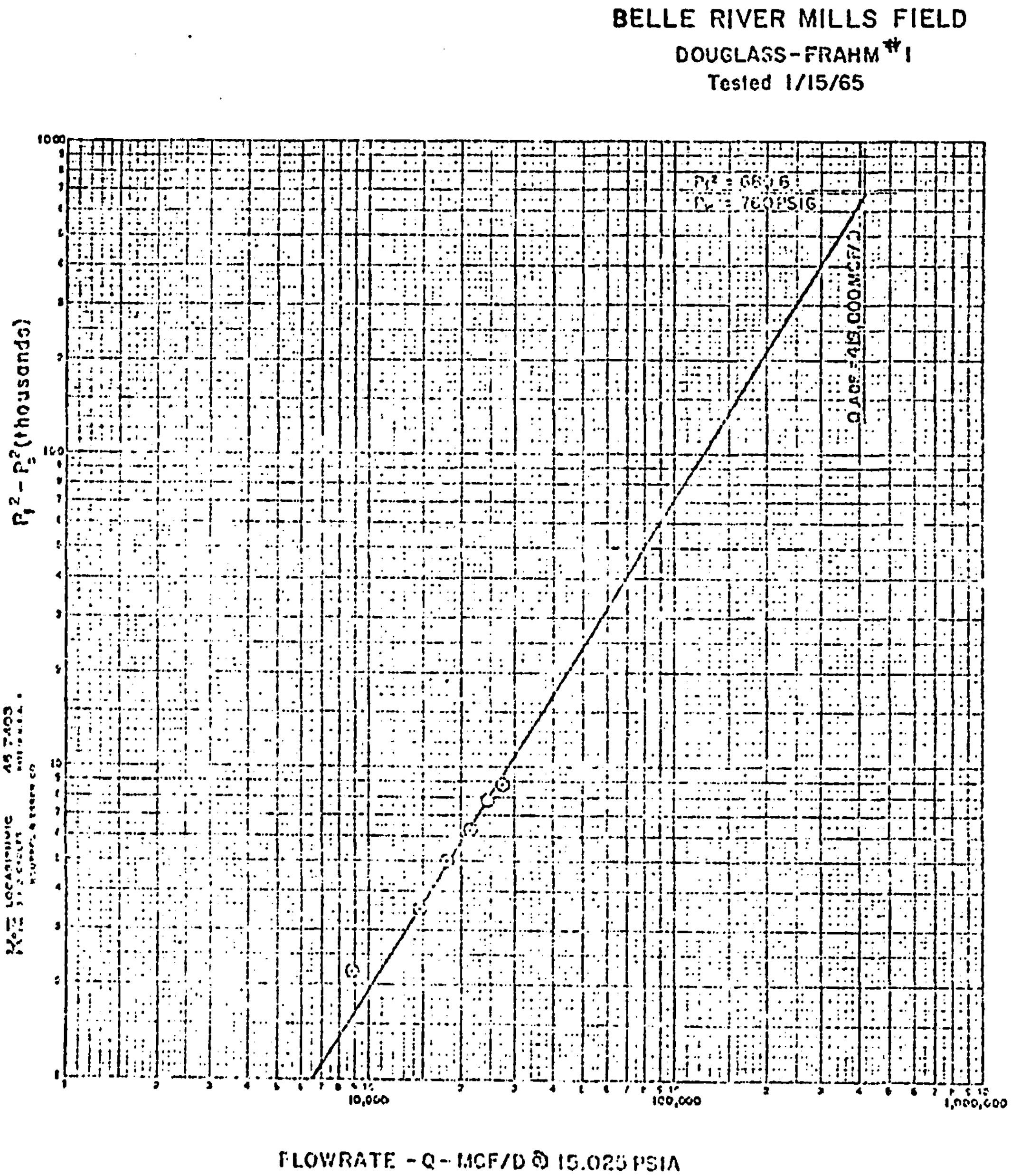
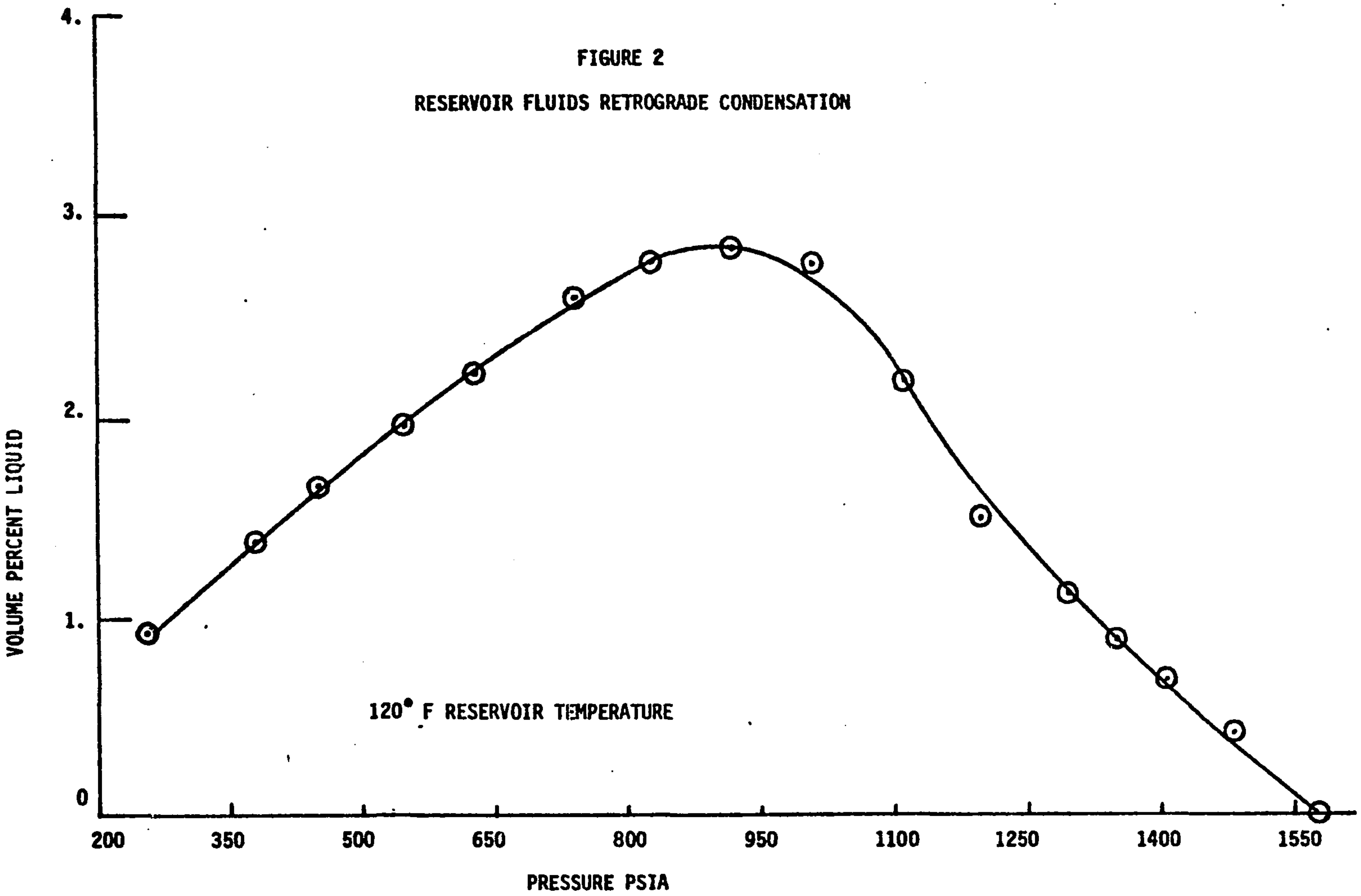


FIGURE 1

Backpressure test - Belle River Mills Field.
(Courtesy Michigan Consolidated Gas Co.)

FIGURE 2

RESERVOIR FLUIDS RETROGRADE CONDENSATION



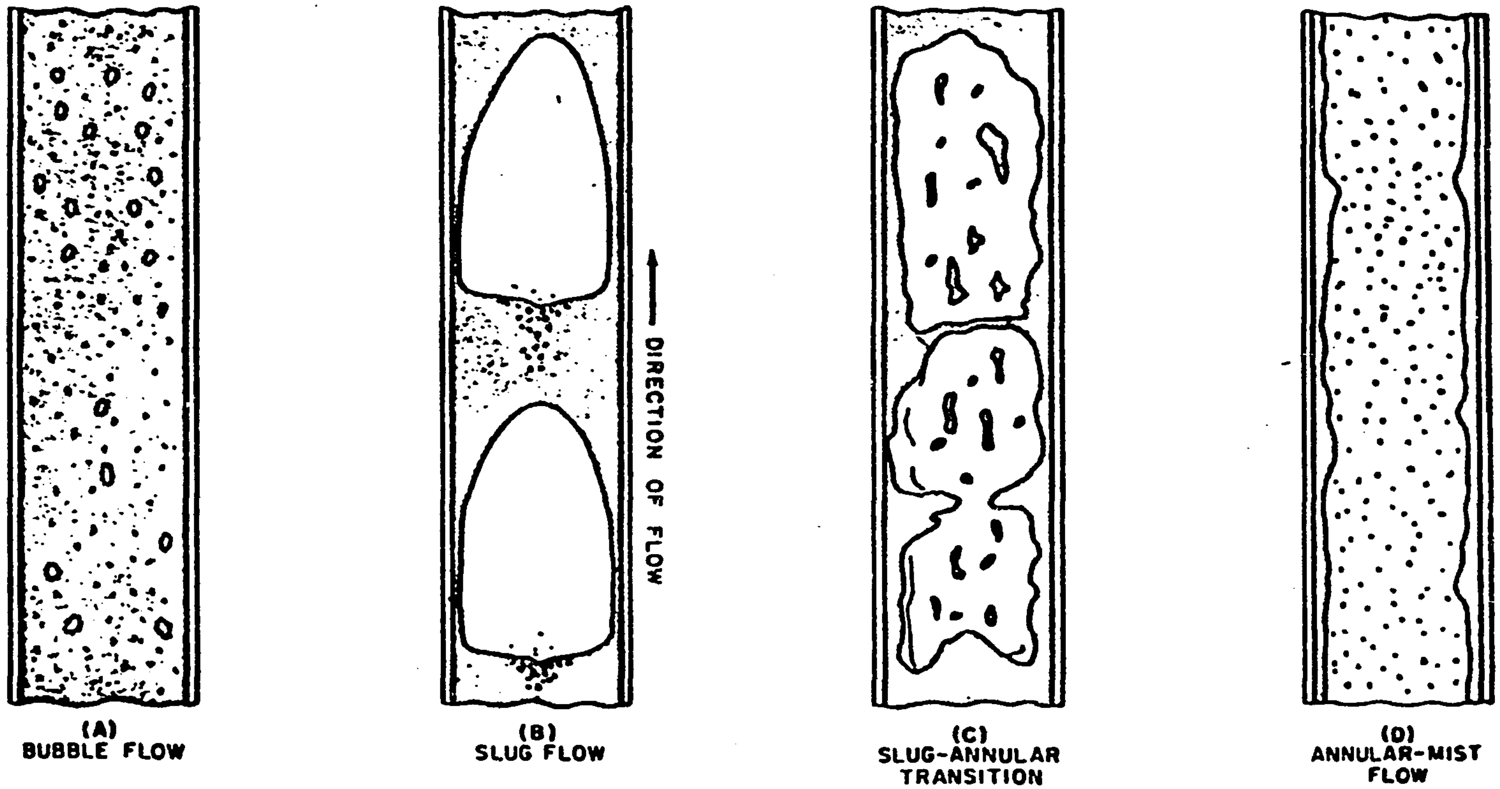


FIGURE 3. GEOMETRICAL CONFIGURATIONS IN VERTICAL FLOW.[29]

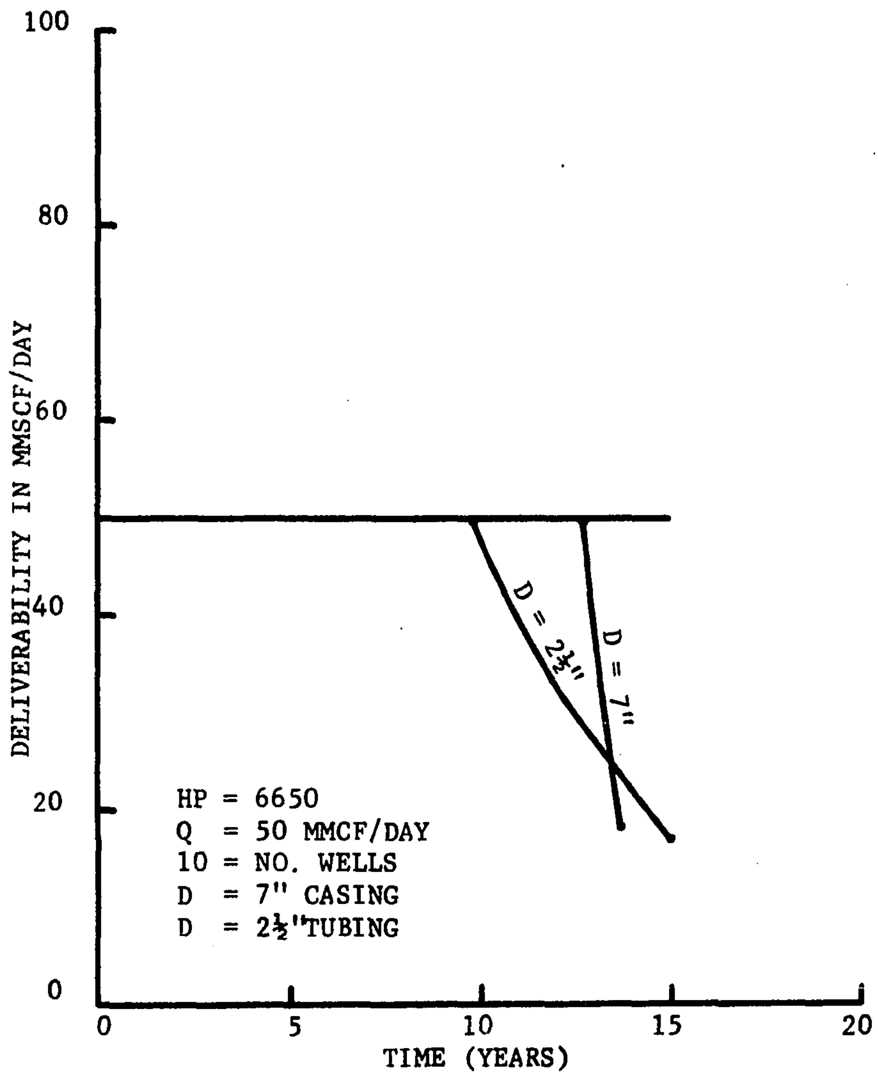


FIGURE 4. Total field deliverability vs. time for a dry gas production system.

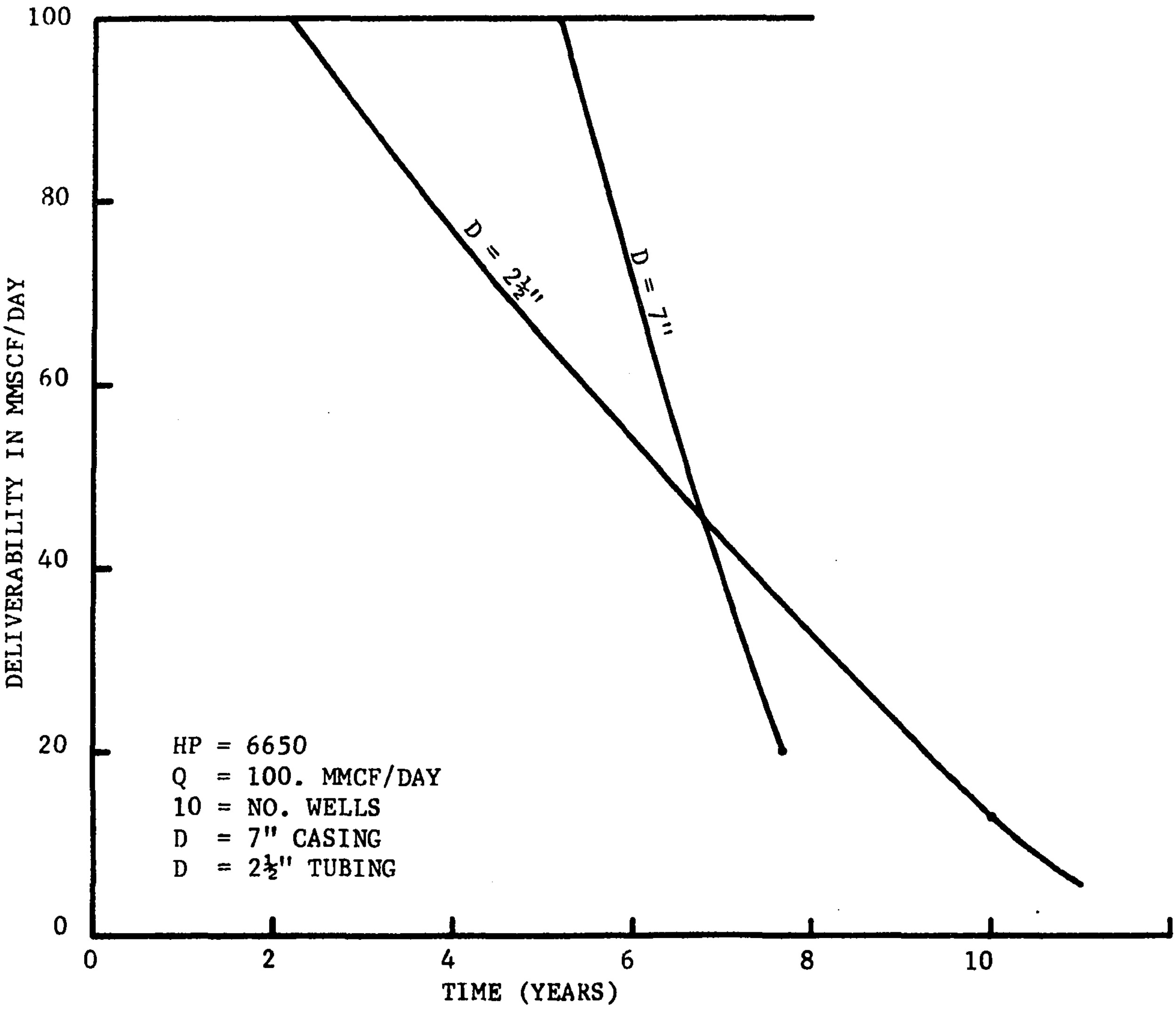


FIGURE 5. Total field deliverability vs. time for a dry gas production system.

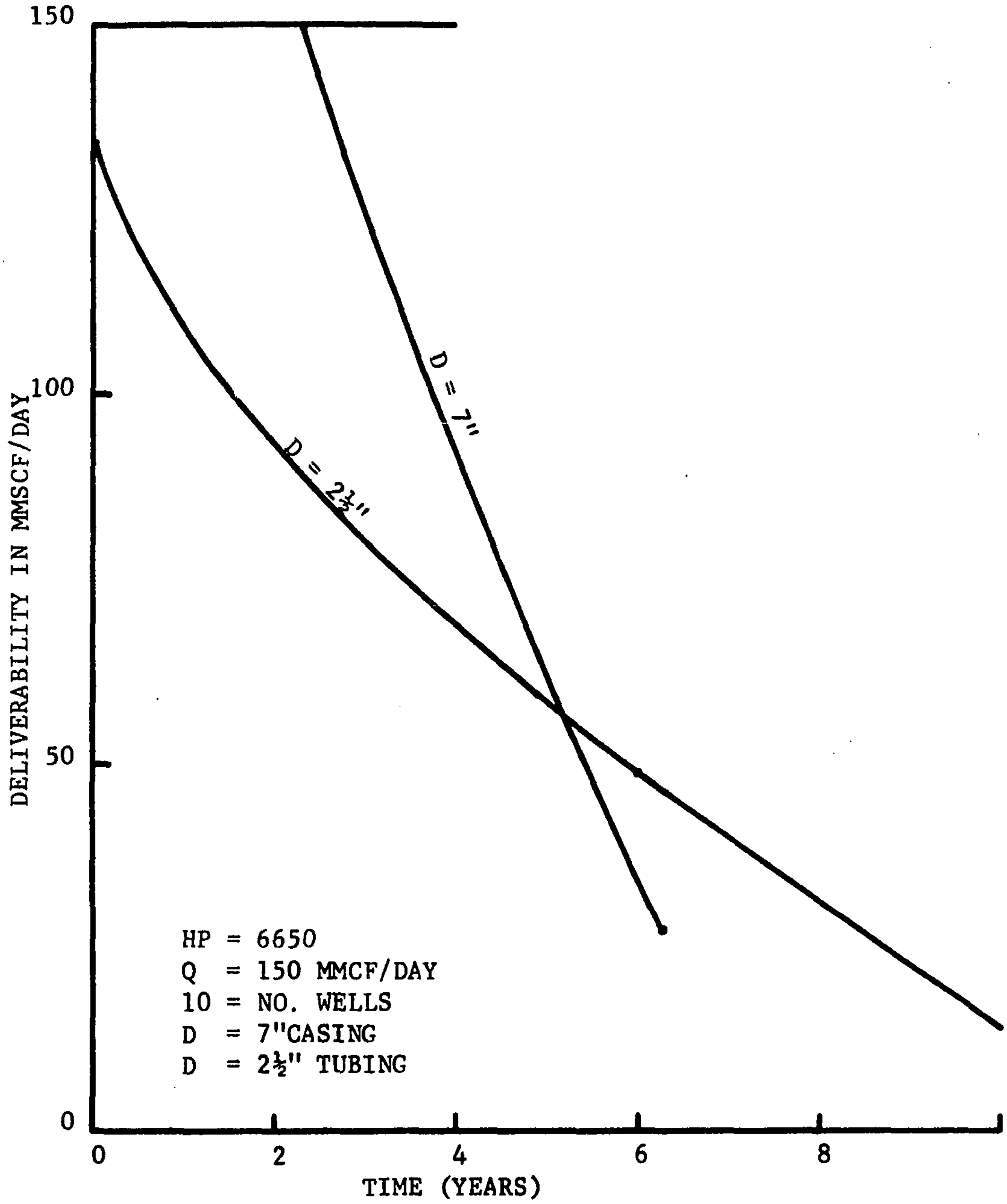


FIGURE 6. Total field deliverability vs. time for a dry gas production system.

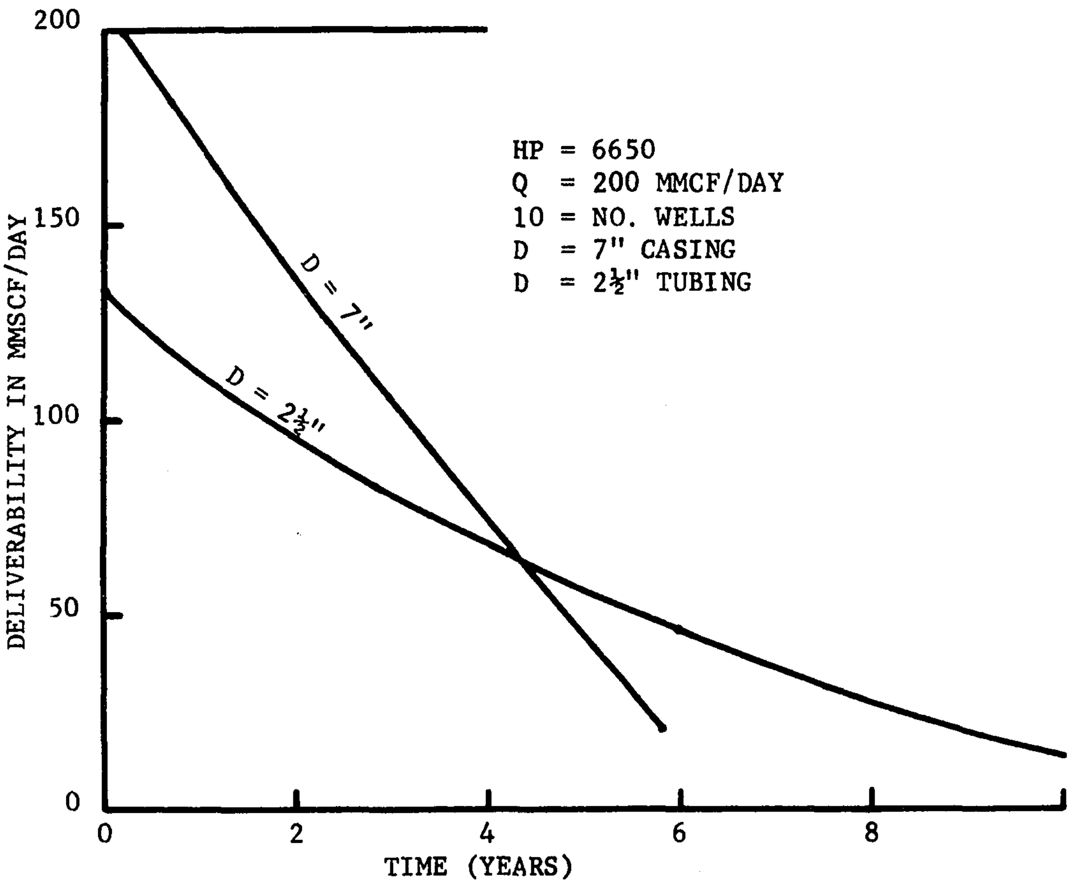


FIGURE 7. Total field deliverability vs. time for a dry gas production system.

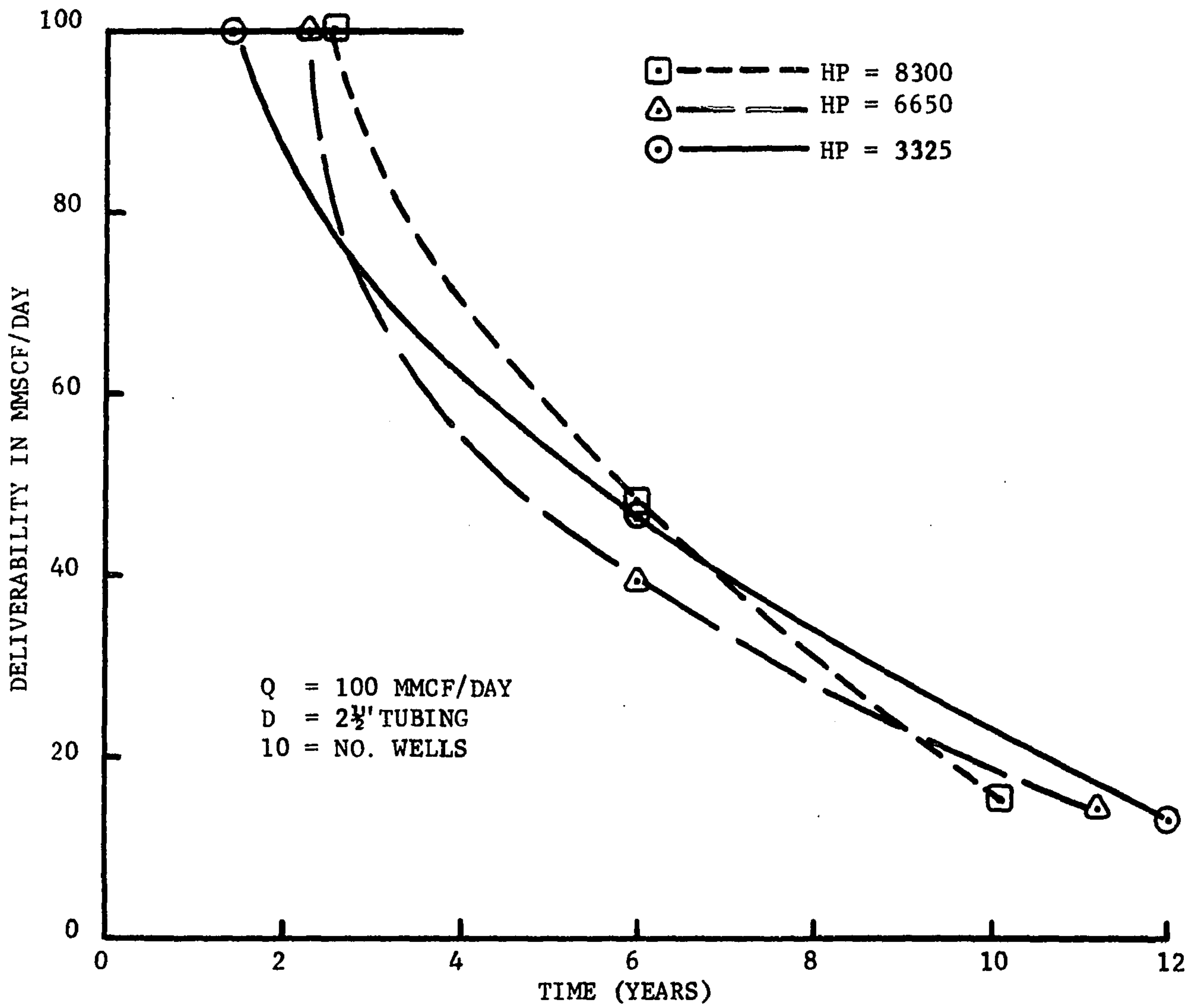


FIGURE 8. Total field deliverability and compressor station capacity for a dry gas production system.

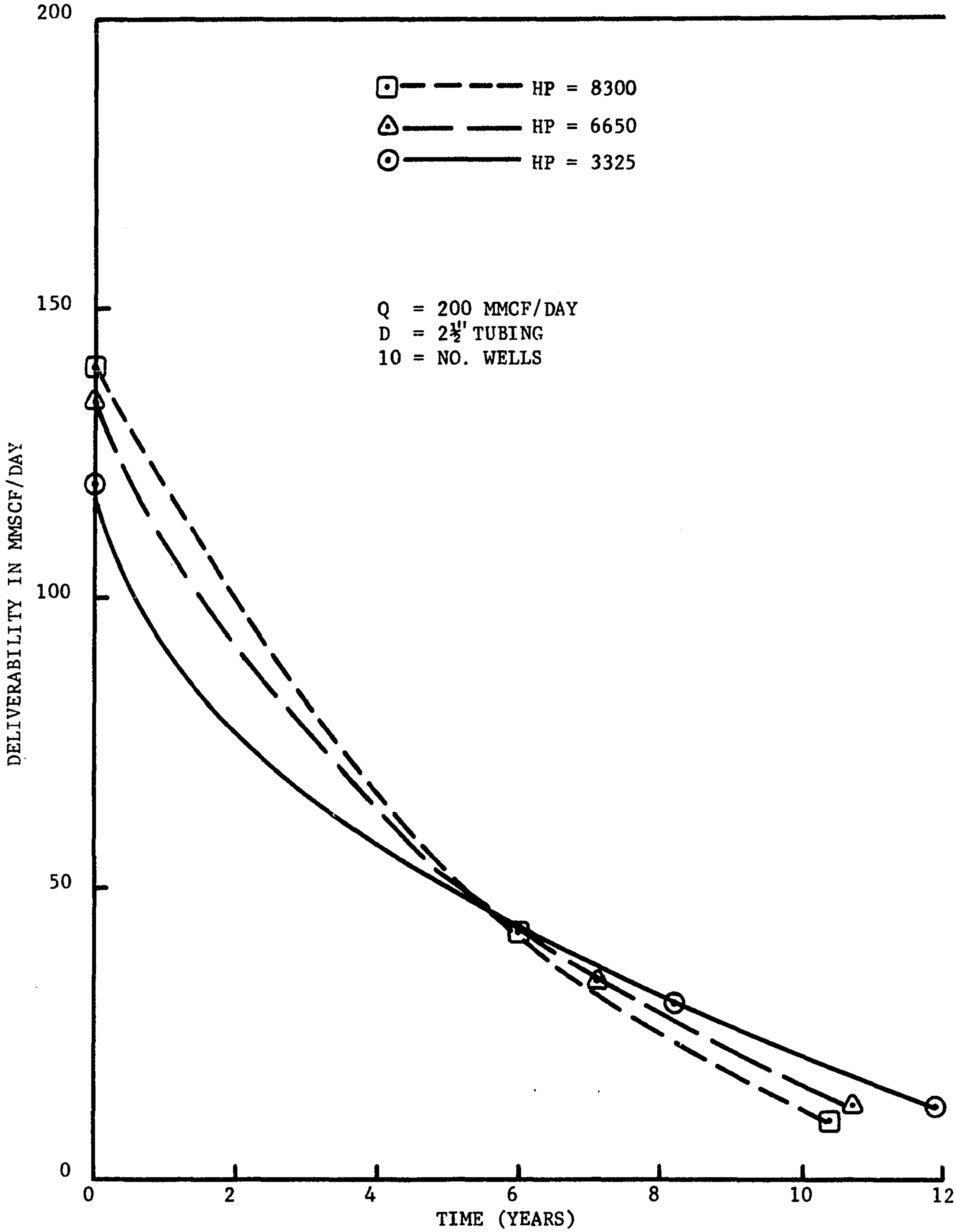


FIGURE 9. Total field deliverability and compressor station capacity for a dry gas production system.

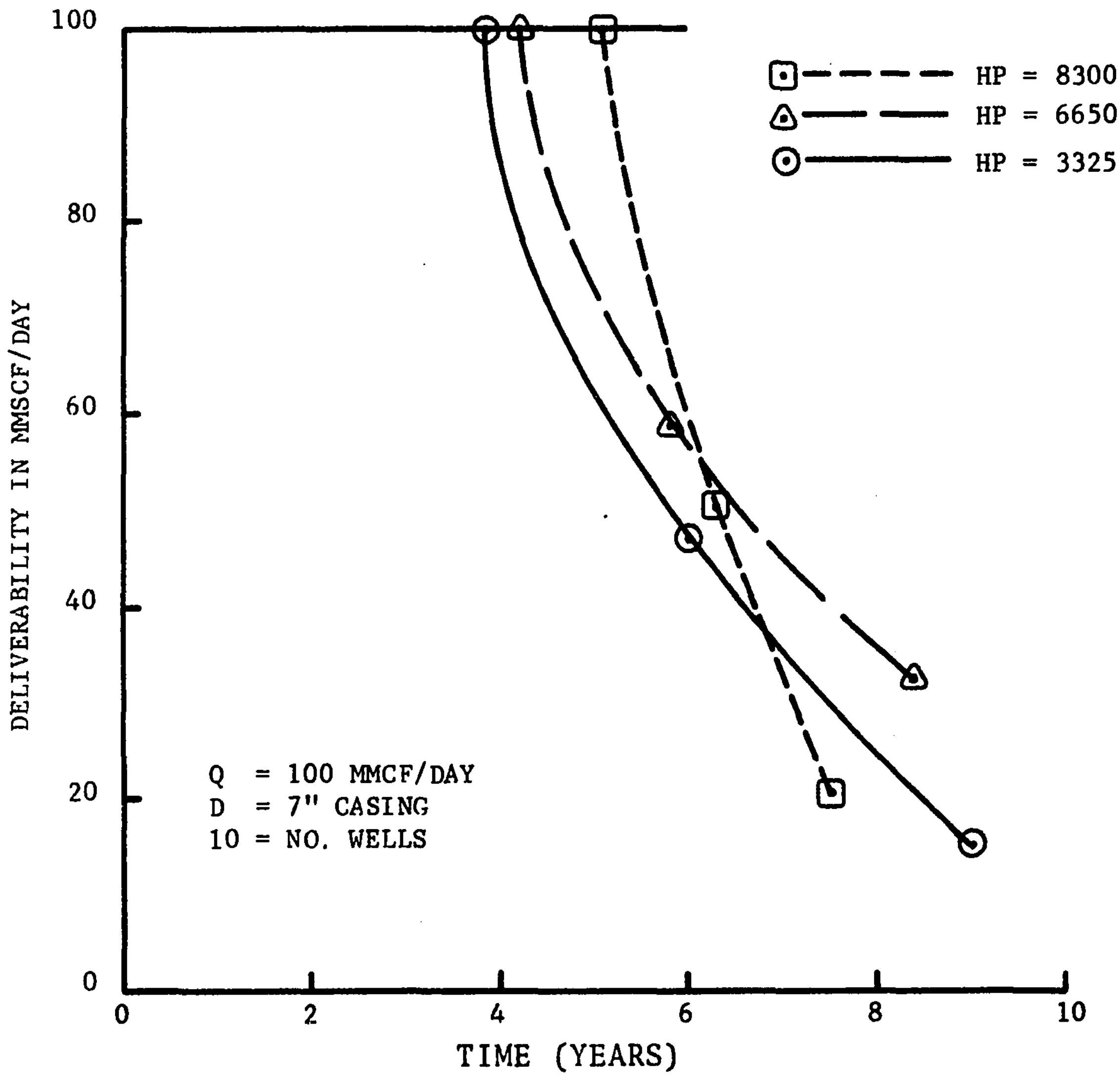


FIGURE 10. Total field deliverability and compressor station capacity for a dry gas production system.

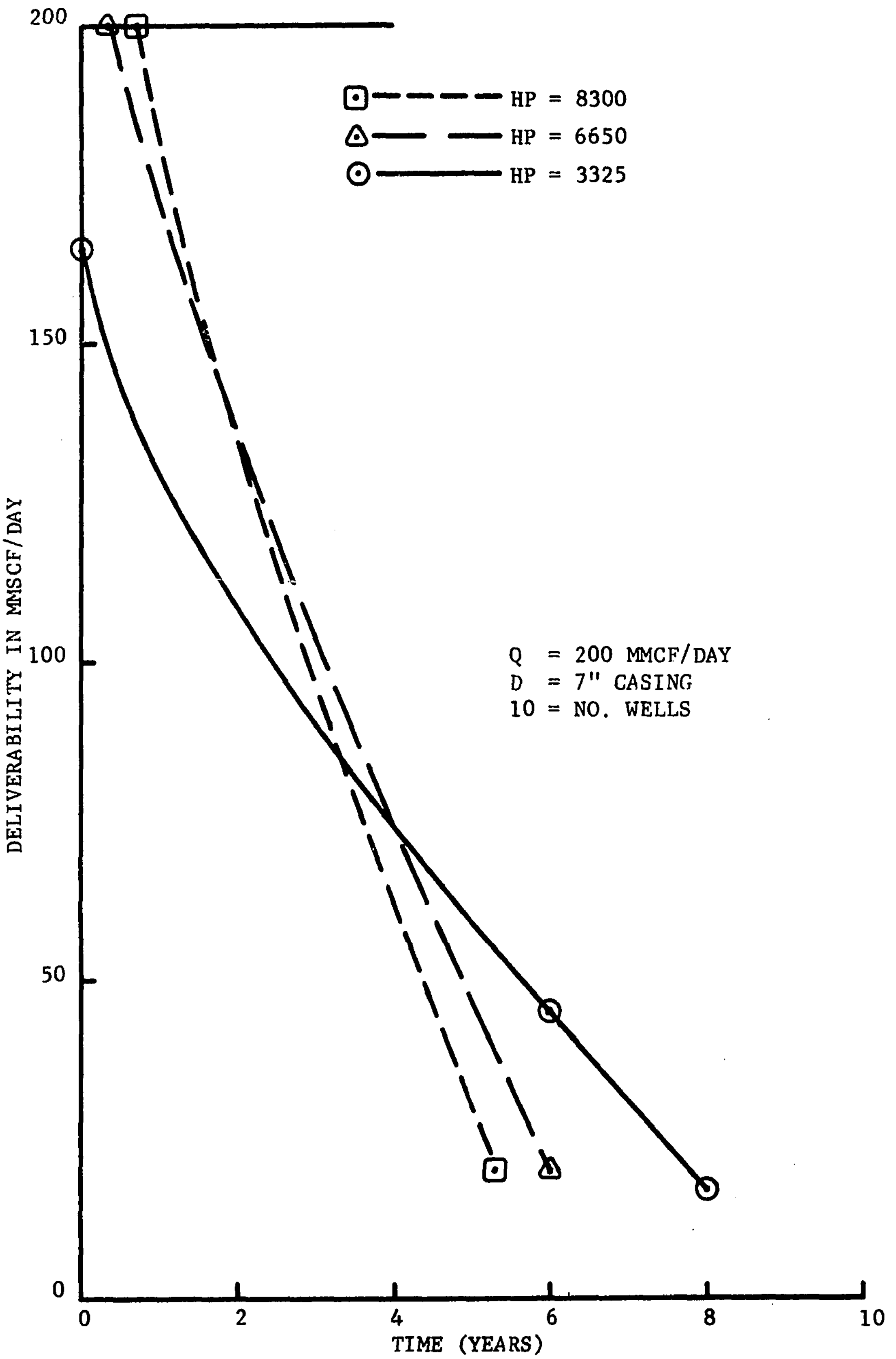


FIGURE 11. Total field deliverability and compressor station capacity for a dry gas production system.

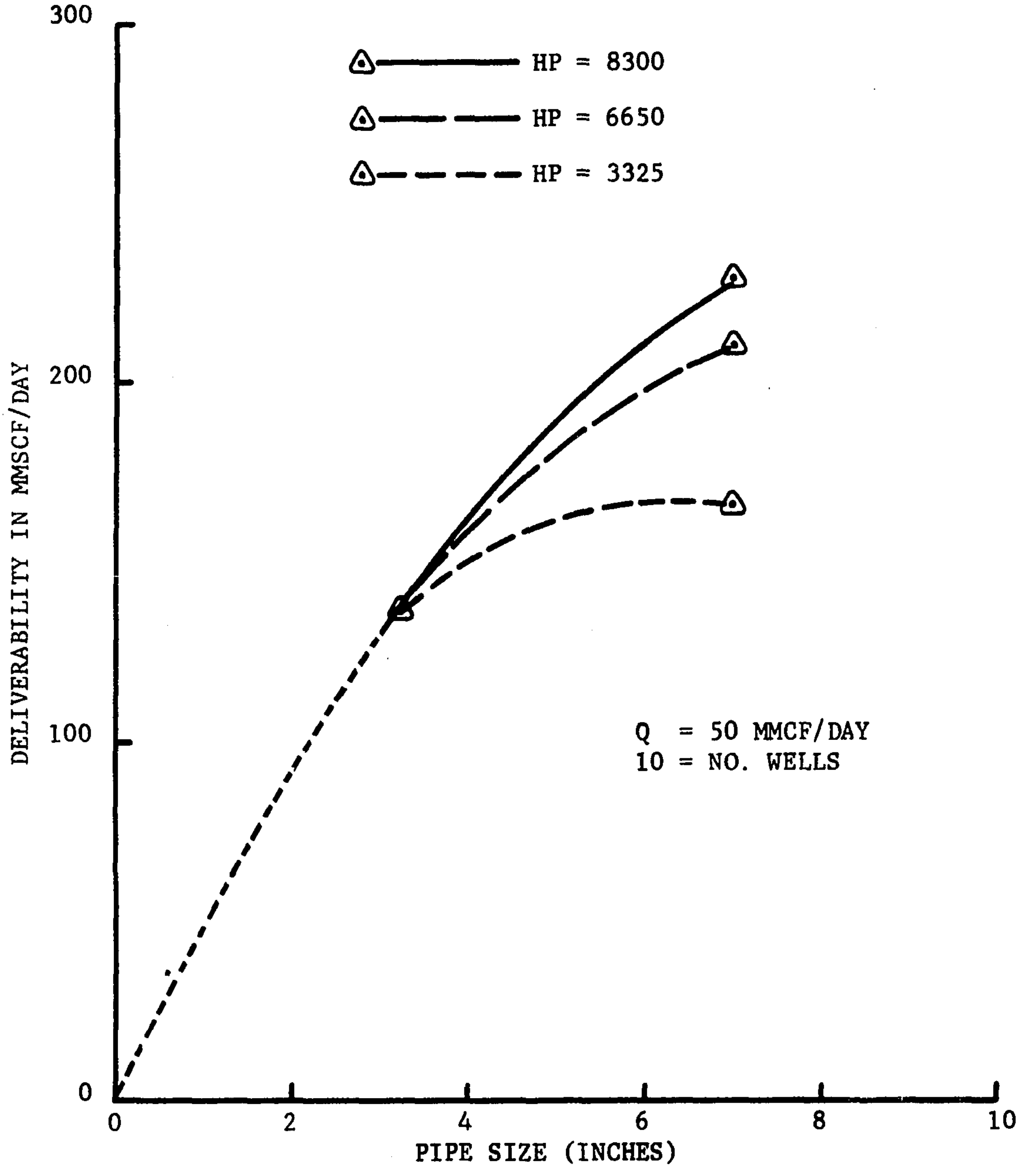


FIGURE 12. Total field deliverability vs. the size of the producing tubing strings for a dry gas production system.

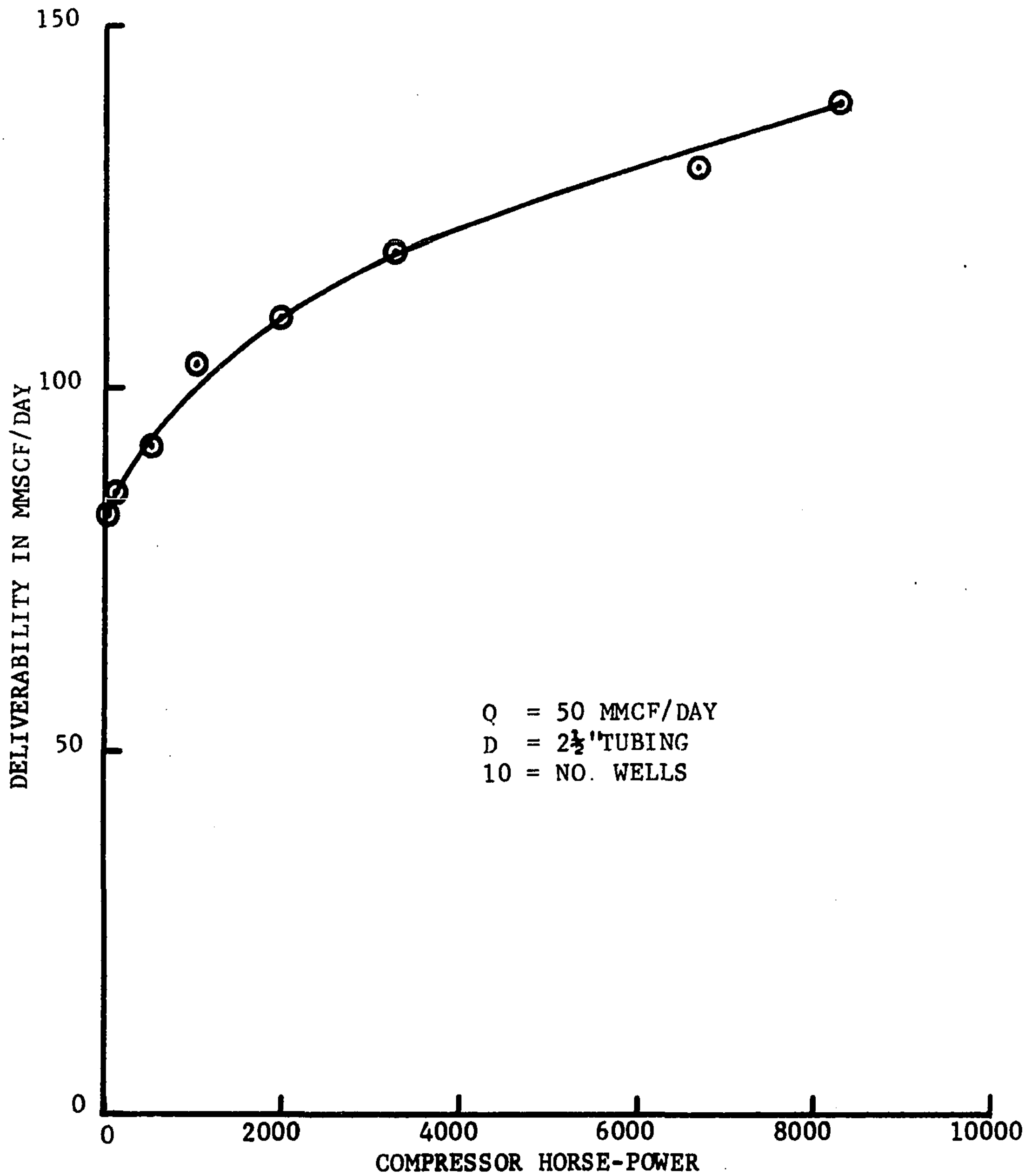


FIGURE 13. Total field deliverability vs. compressor station capacity for a dry gas production system.

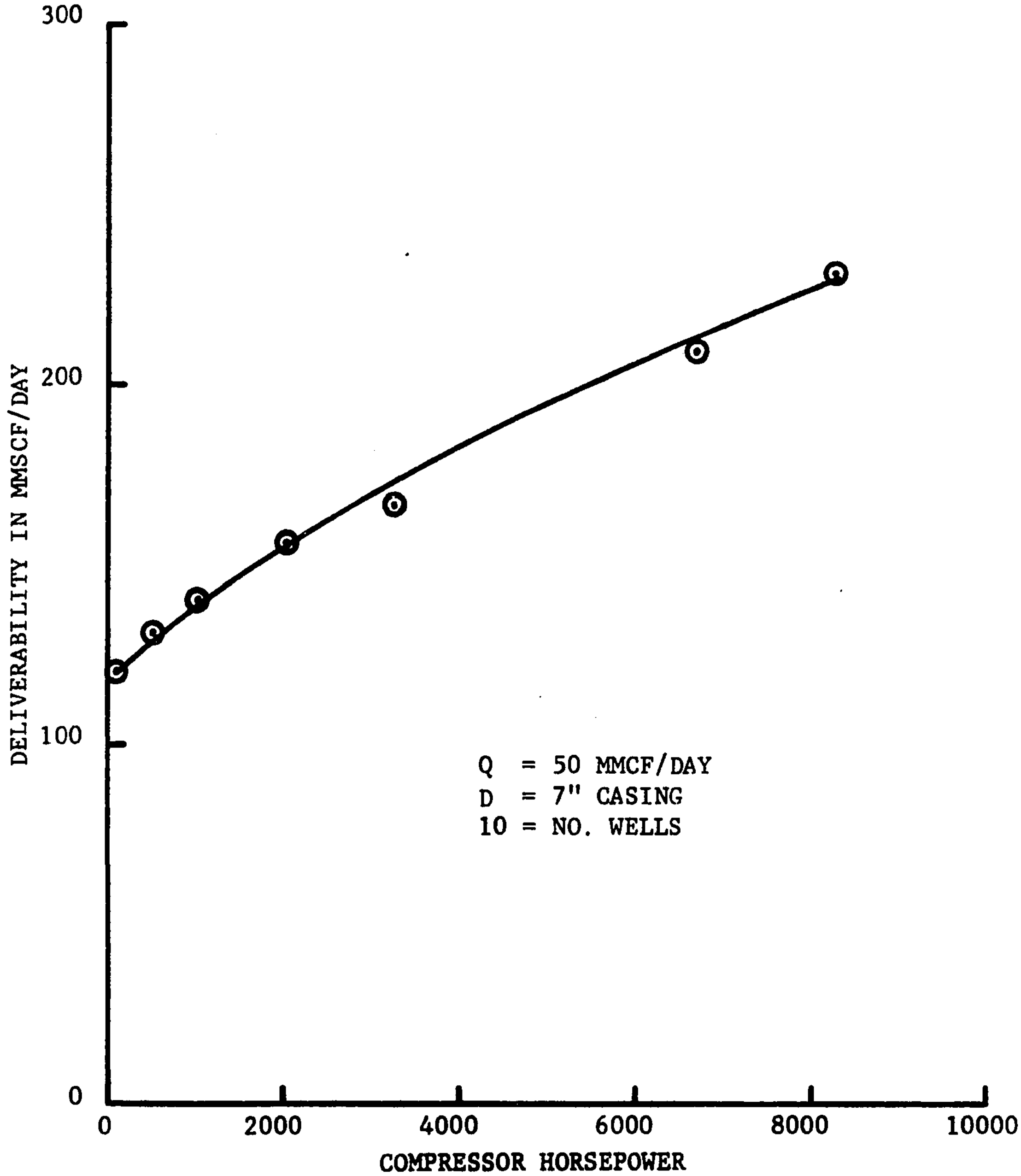


FIGURE 14. Total field deliverability vs. compressor station capacity for a dry gas production system.

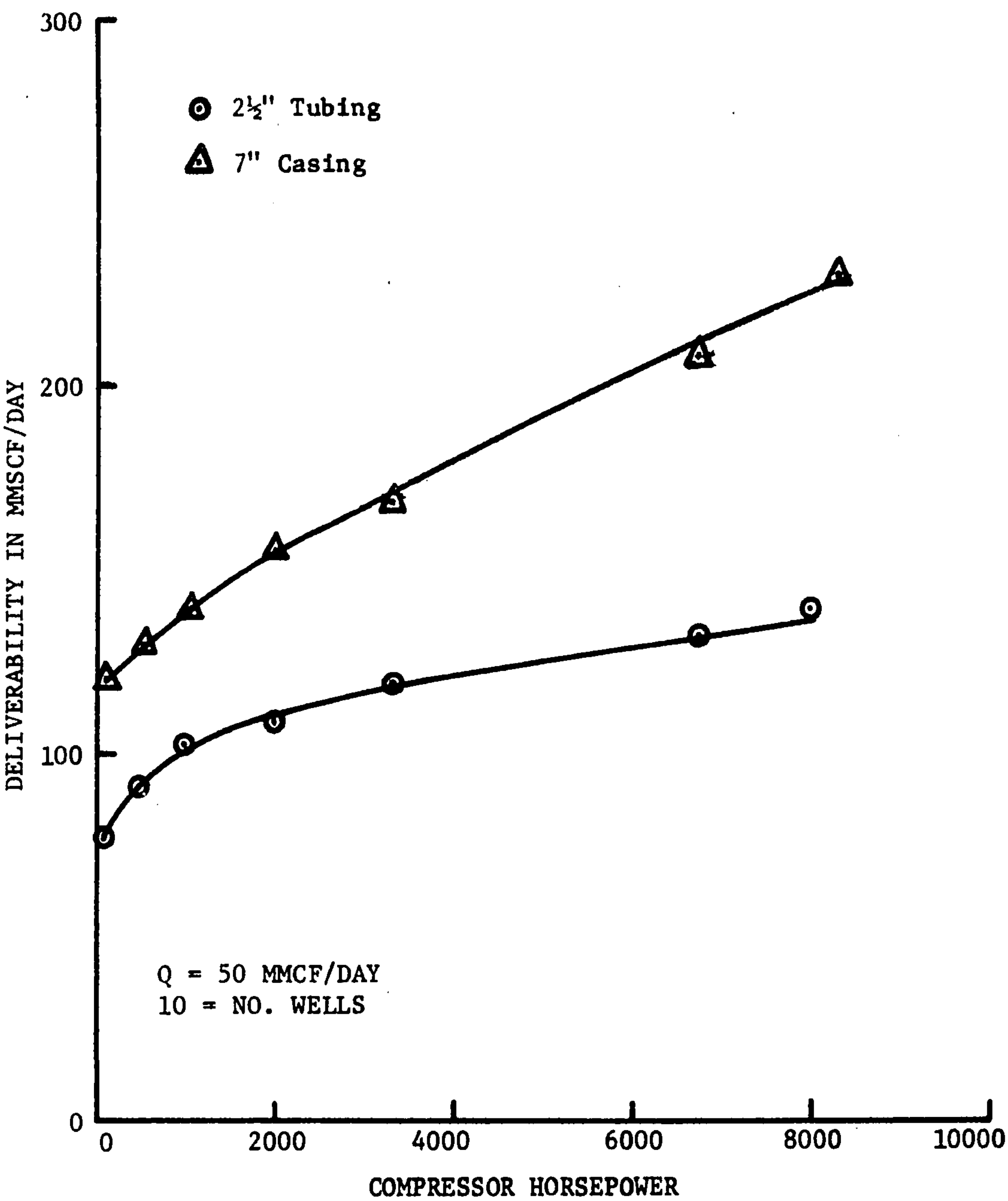


FIGURE 15. Comparison of the total field deliverability vs. the compressor station capacity for a dry gas production system.

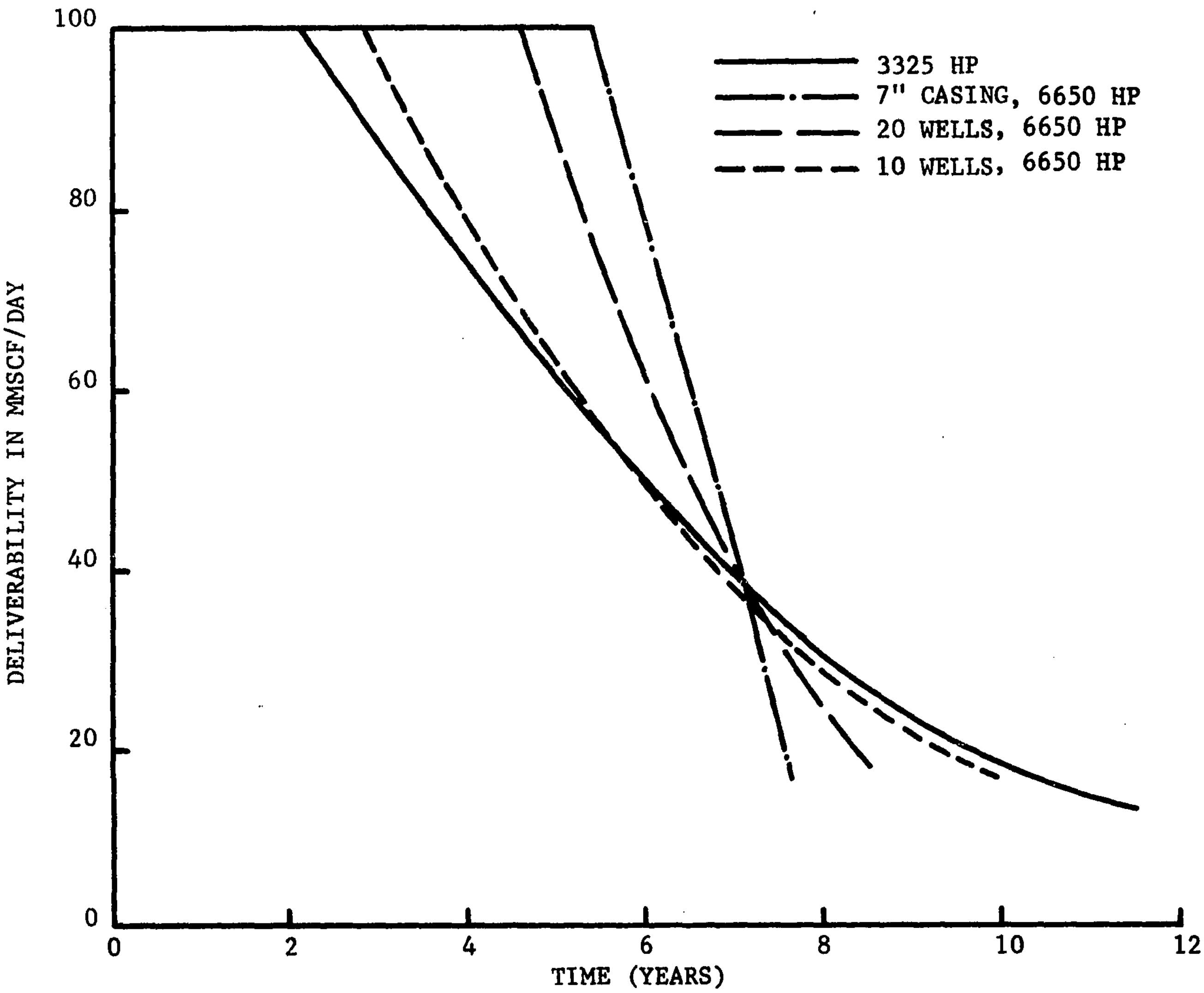


FIGURE 16. Comparison of the total field deliverability vs. time for a dry gas production system.

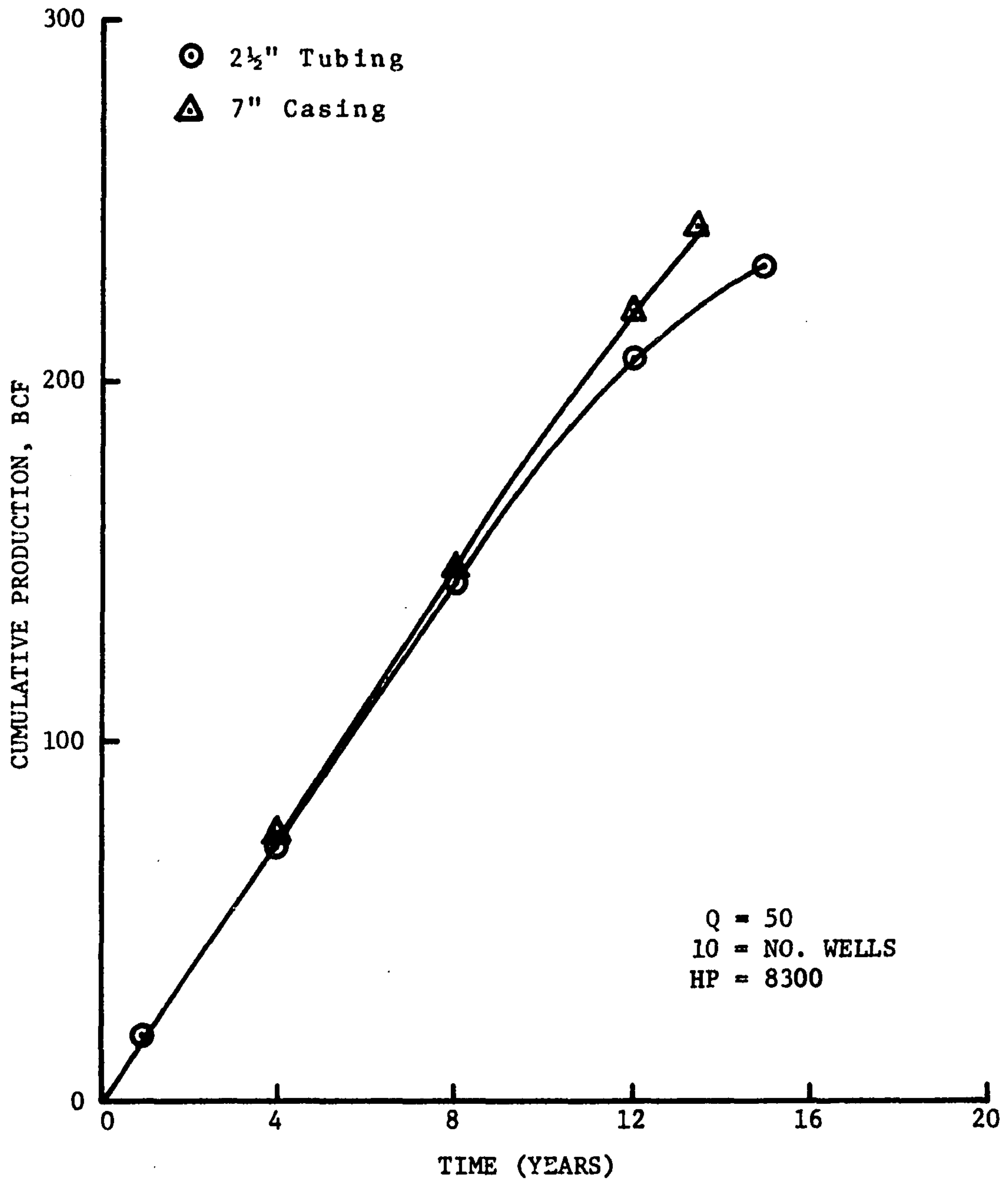


FIGURE 17. Comparison of the cumulative production vs. time for a dry gas production system.

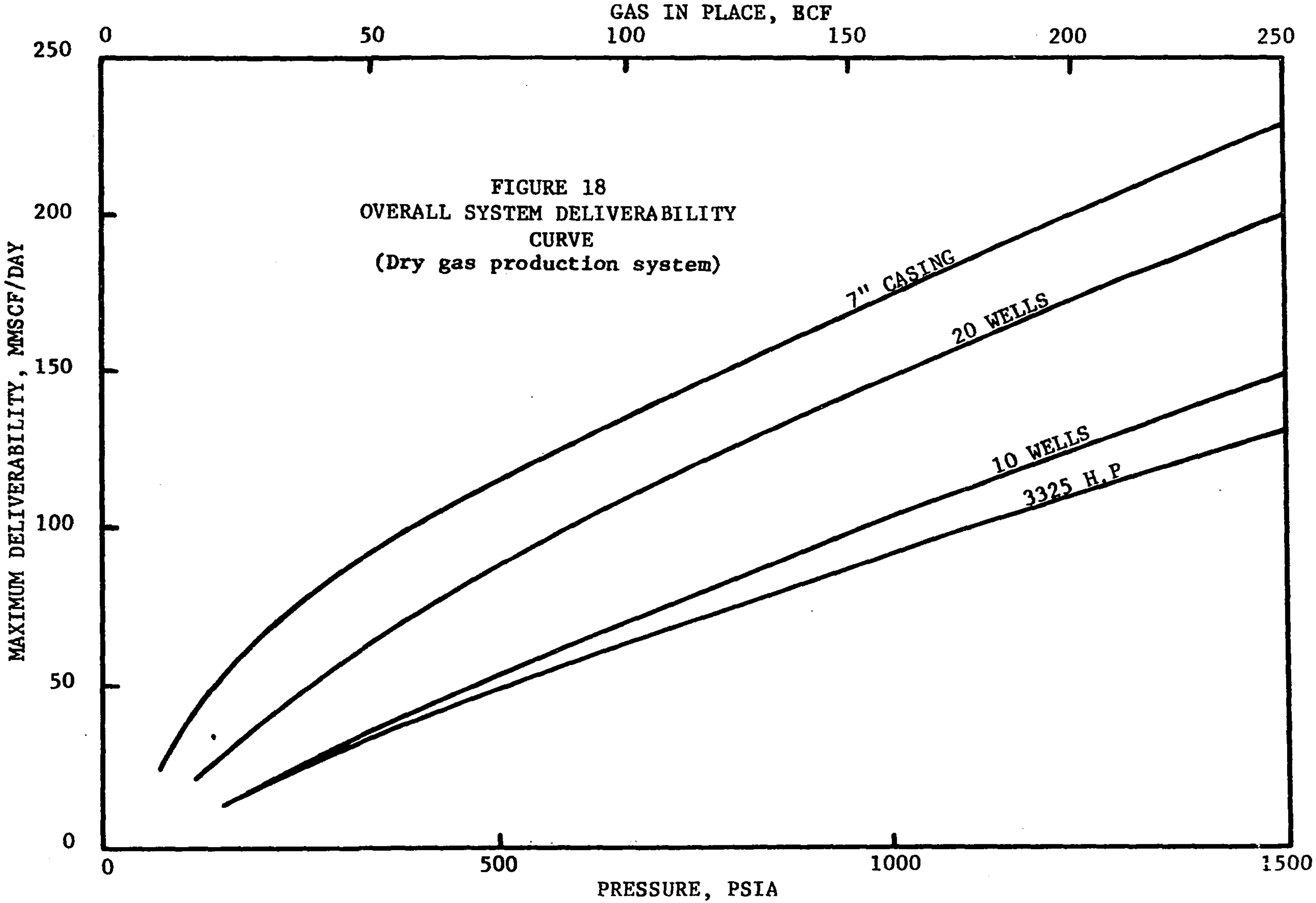


FIGURE 18
OVERALL SYSTEM DELIVERABILITY
CURVE
(Dry gas production system)

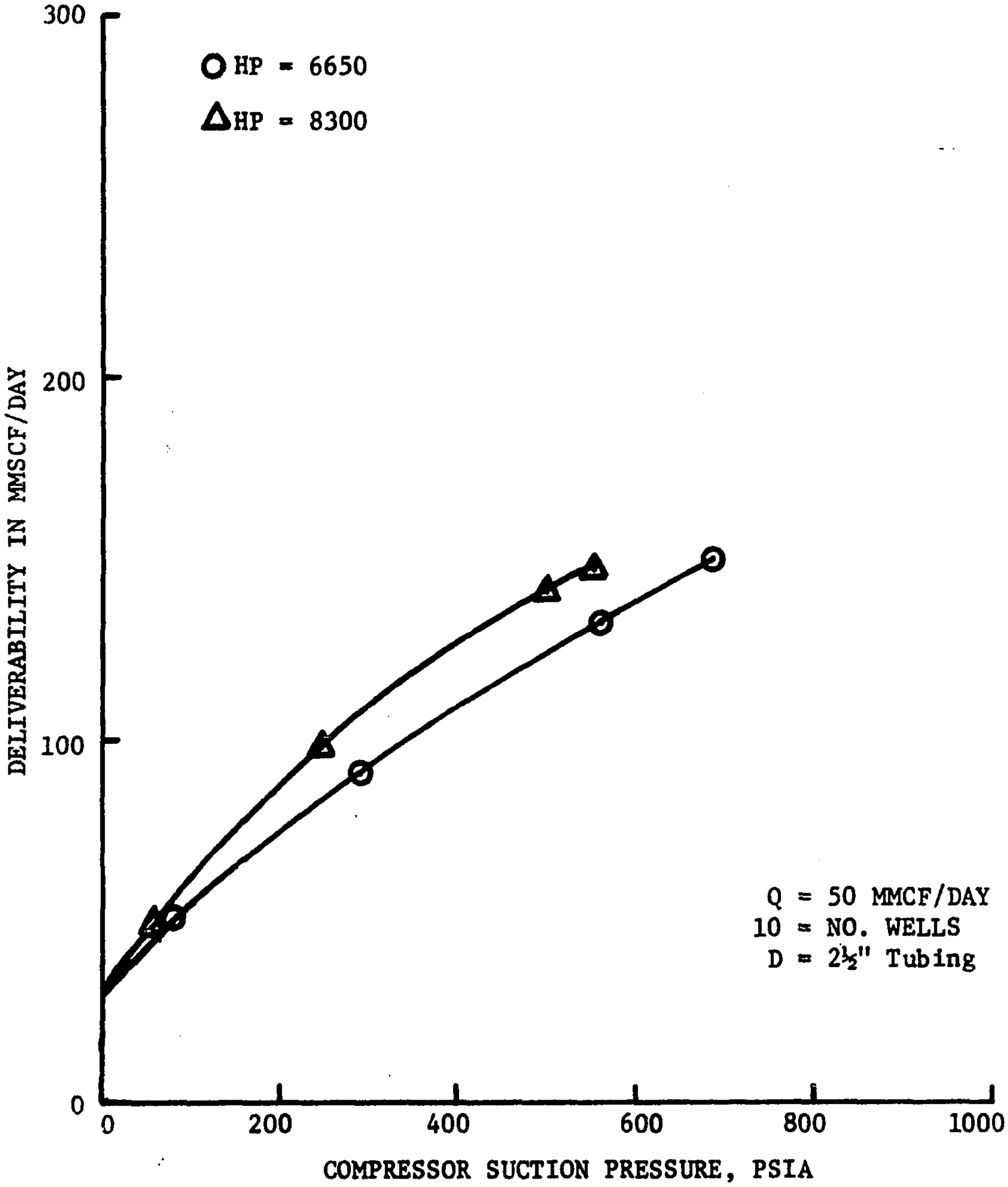


FIGURE 19. Total field deliverability vs. compressor station suction pressure for a dry gas production system.

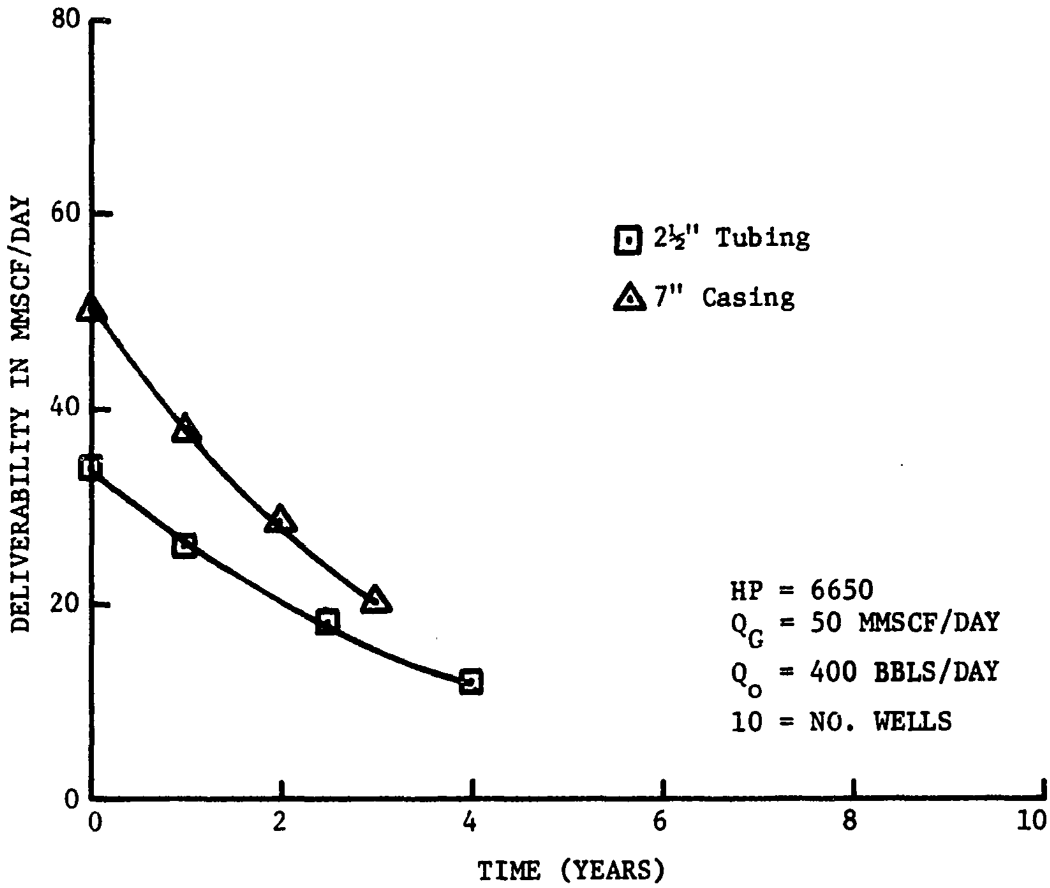


FIGURE 20. Total field deliverability vs. time

for a gas-condensate production system.

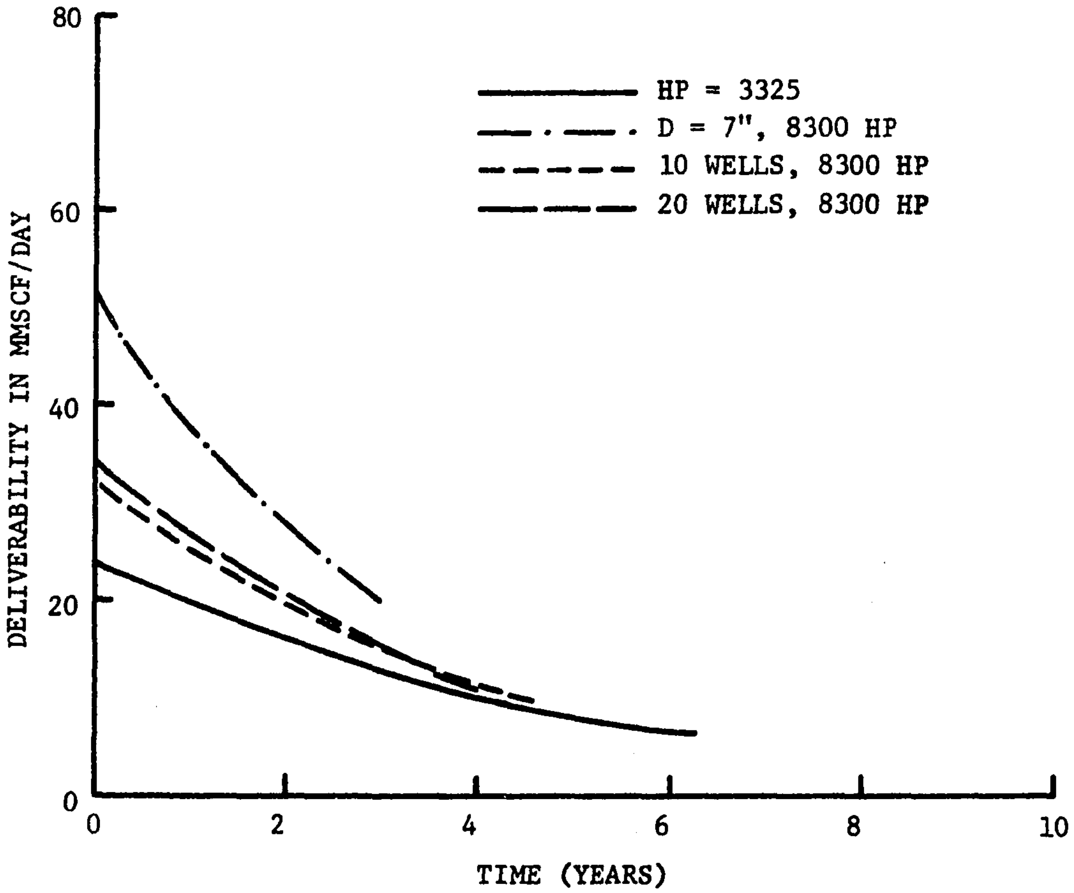


FIGURE 21. Total field deliverability vs. time for a gas-condensate production system.

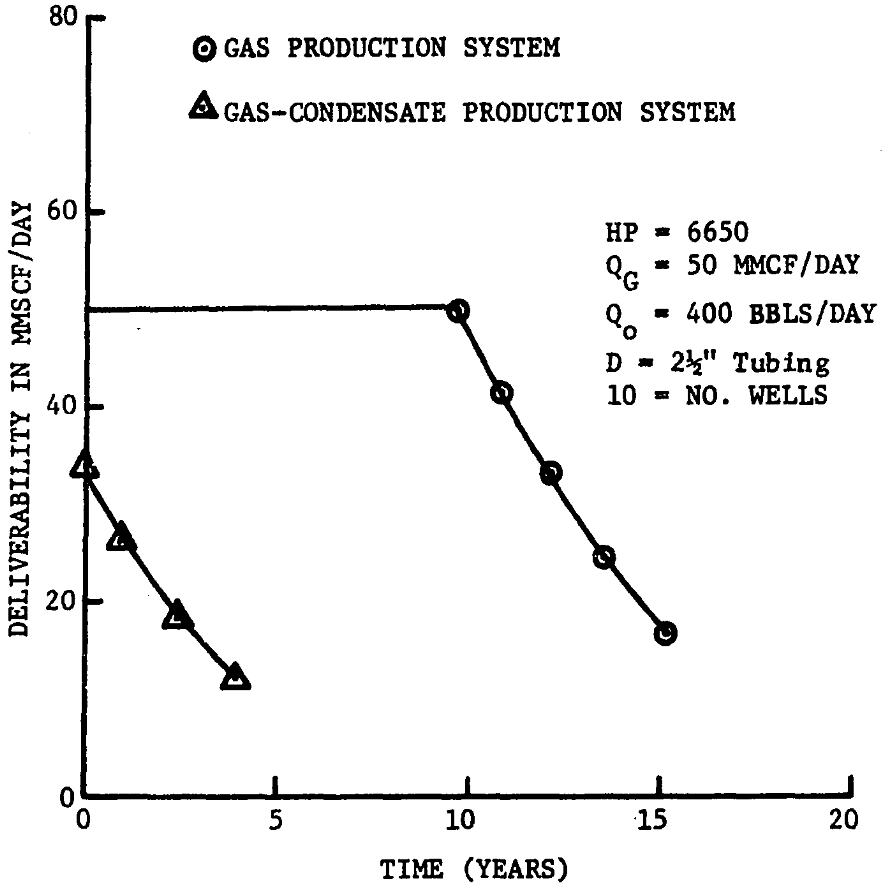


FIGURE 22. Comparison of the total field deliverability of a dry gas and a gas-condensate system vs. time.

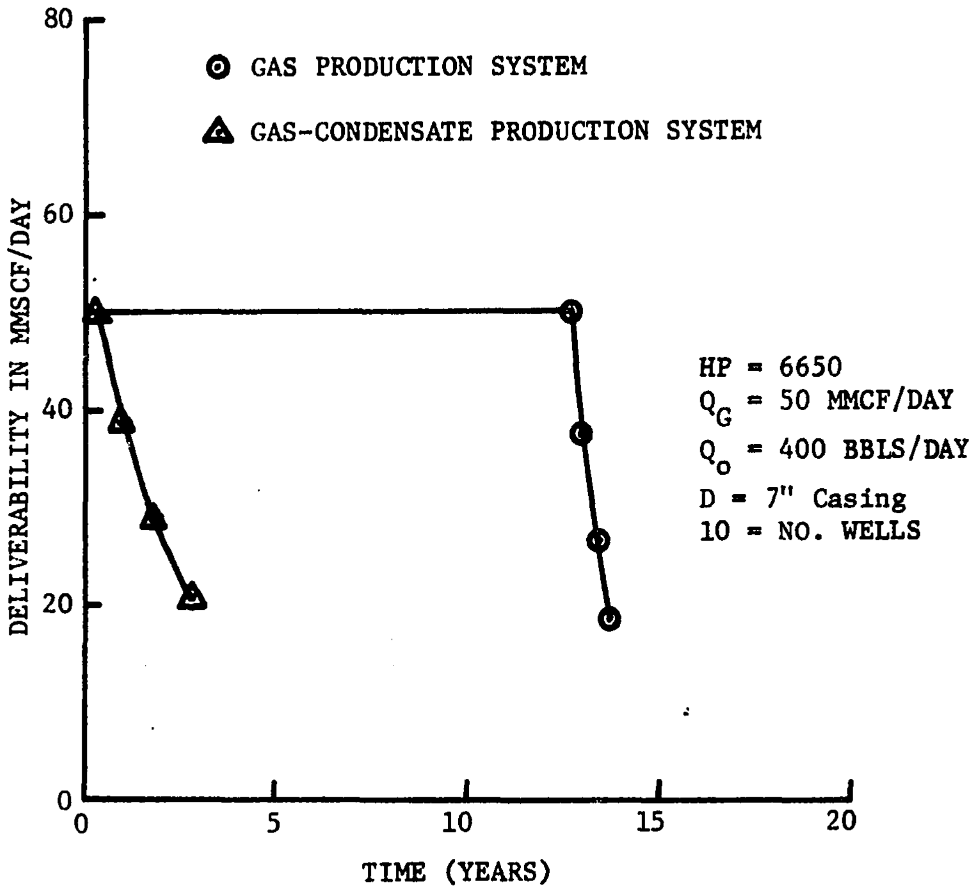


FIGURE 23. Comparison of the total field deliverability of a dry gas and a gas-condensate system vs. time.

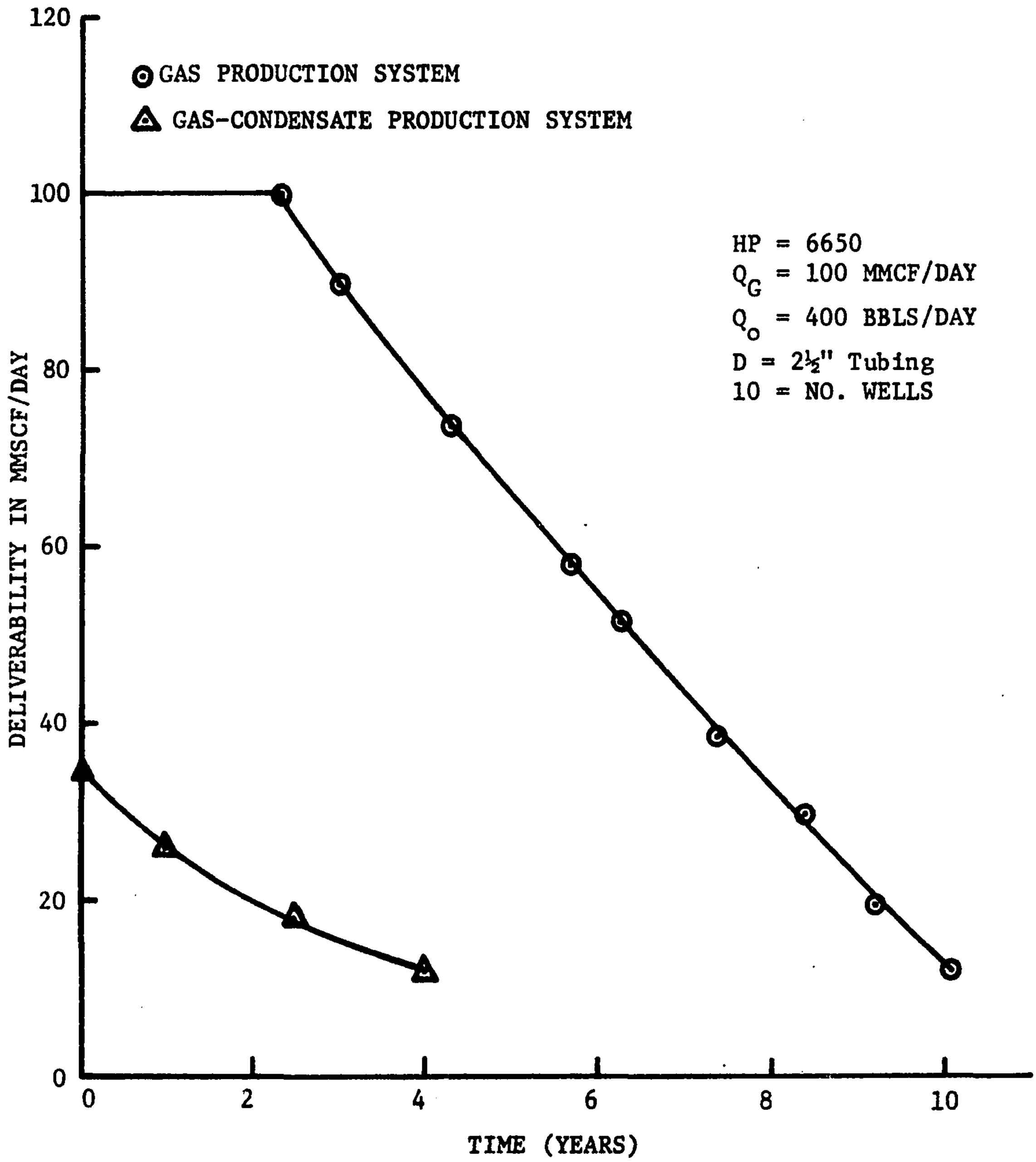


FIGURE 24. **Comparison of the total field deliverability of a dry gas and a gas-condensate system vs. time.**

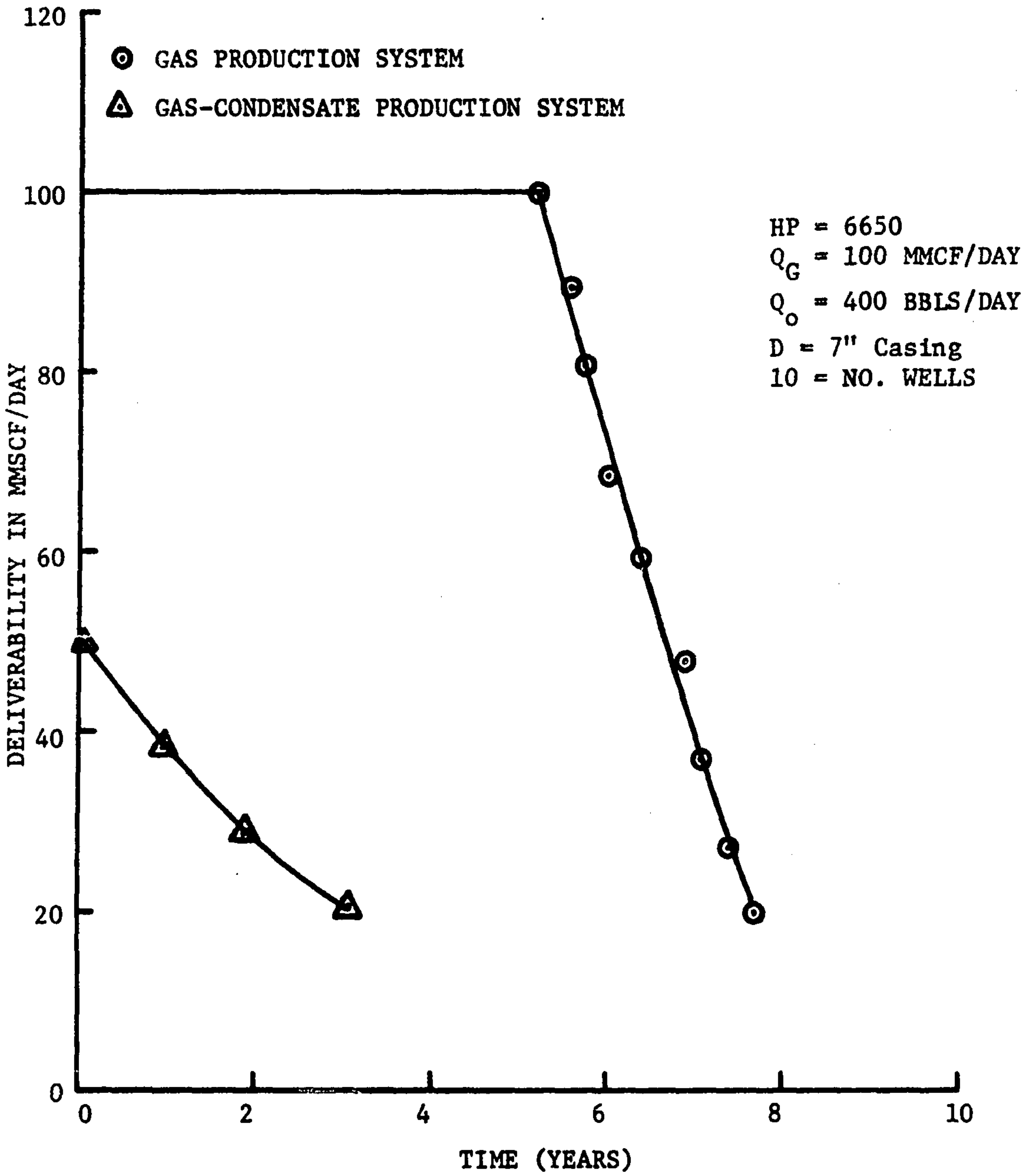


FIGURE 25. Comparison of the total field deliverability of a dry gas and a gas-condensate system vs. time.

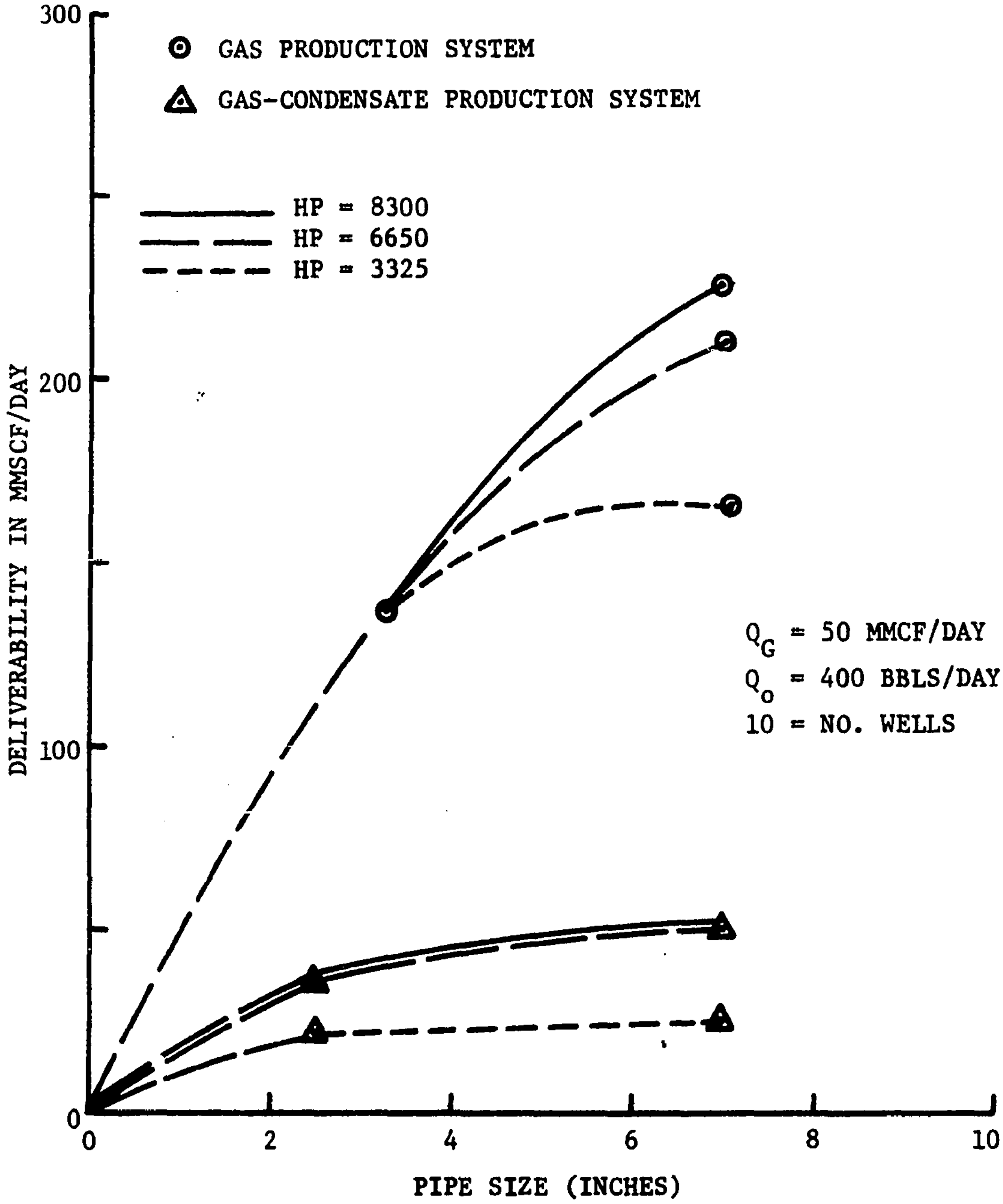


FIGURE 26. Comparison of total field deliverability of a dry gas and gas condensate system vs. the size of tubing strings.

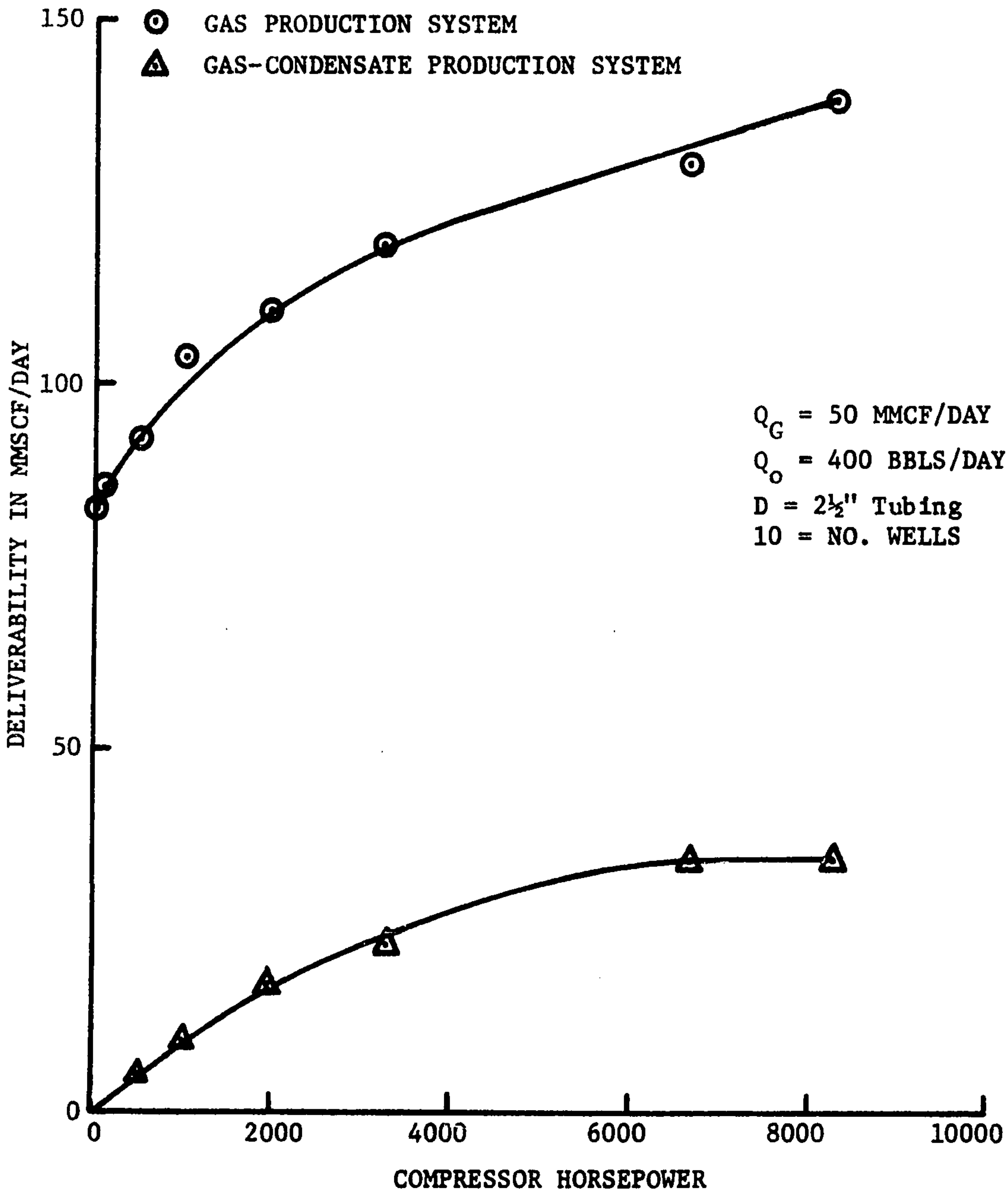


FIGURE 27. Comparison of the total field deliverability of a gas and a gas-condensate system vs. the compressor station capacity.

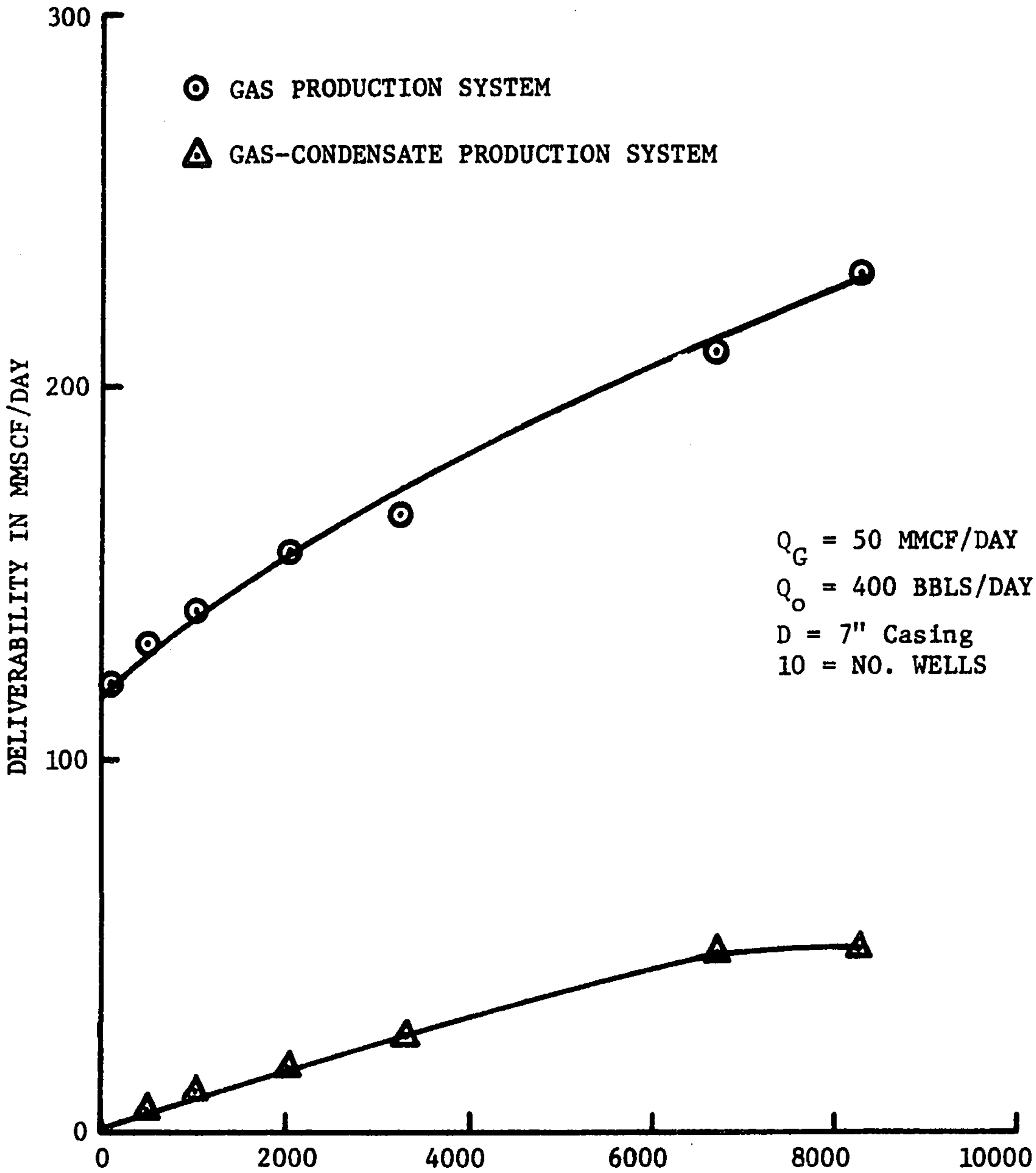


FIGURE 28. Comparison of the total field deliverability of a gas and a gas-condensate system vs. the compressor station capacity.

APPENDIX D

CALCULATION OF CONDENSATE RATE

The prediction of the condensate rate was based on Figure 2. Figure 2, which shows the percent liquid at the reservoir condition, is the result of laboratory analysis on the bottom-hole or wellhead flowing sample. If we assume that the GOR at any value of gas rate and reservoir pressure is some ratio of the initial GOR, we can calculate the condensate rate for any time step as follows:

$$(GOR)_J = GOR' \times \frac{C'}{C}$$

where:

GOR' = initial gas-condensate ratio

C' = the % liquid at initial reservoir pressure

C = the % liquid at (reservoir pressure)$_J$

Therefore,

$$\frac{(Q_g)_J}{(Q_o)_J} = \frac{Q'_g}{Q'_o} \times \frac{C'}{C}$$

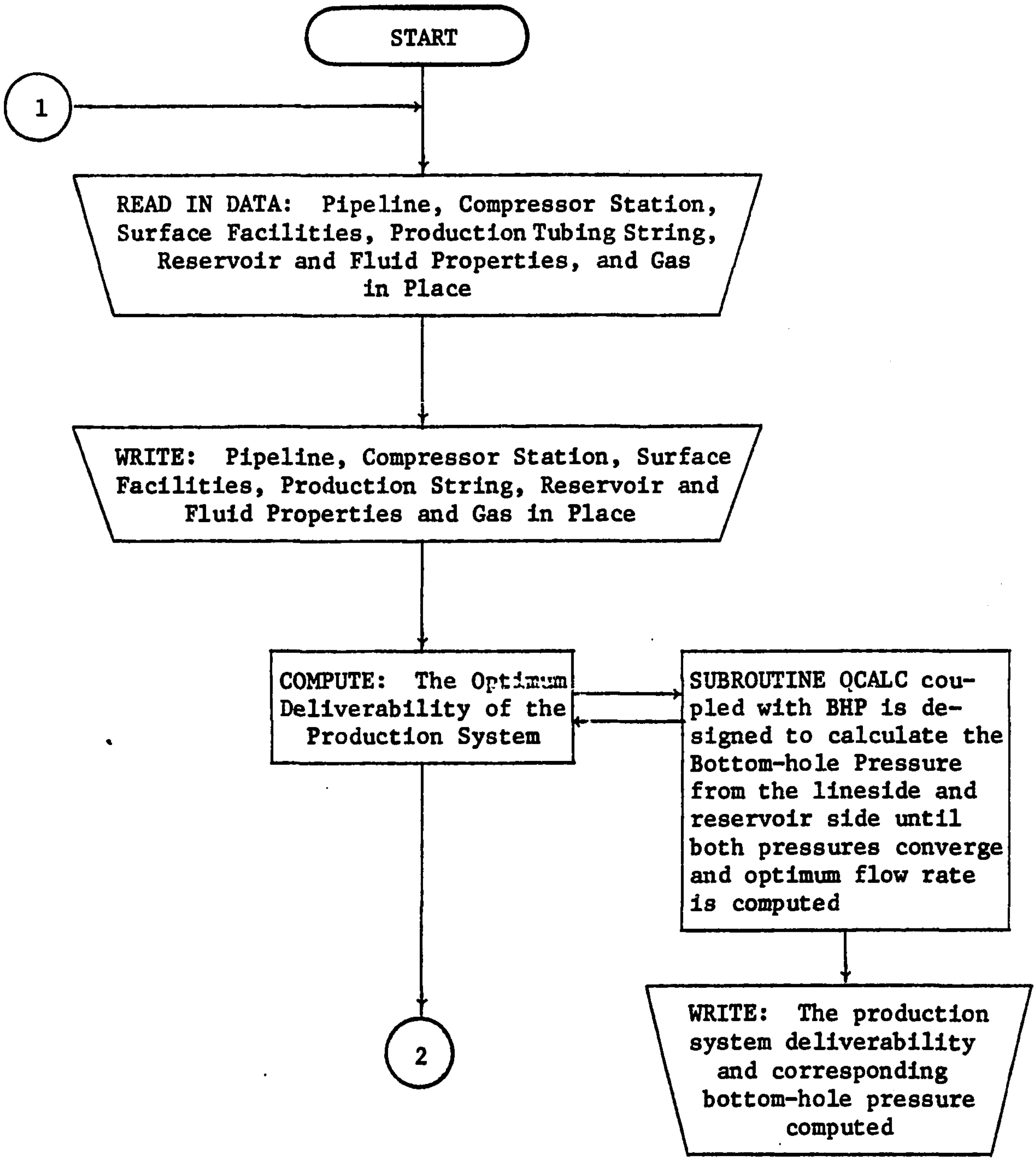
or

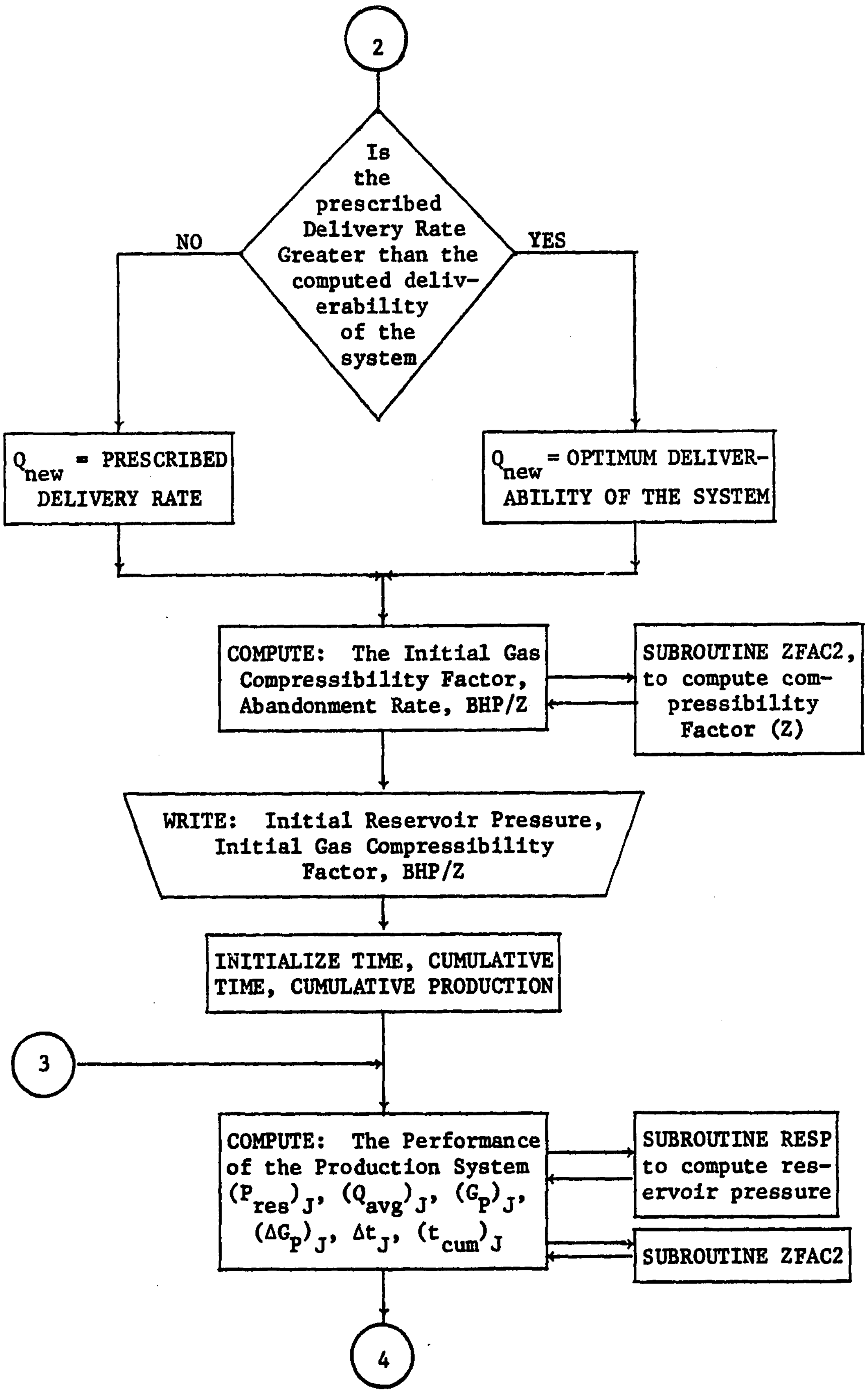
$$Q_o = \frac{Q'_o}{Q'_g} \times \frac{C}{C'} \times Q_g$$

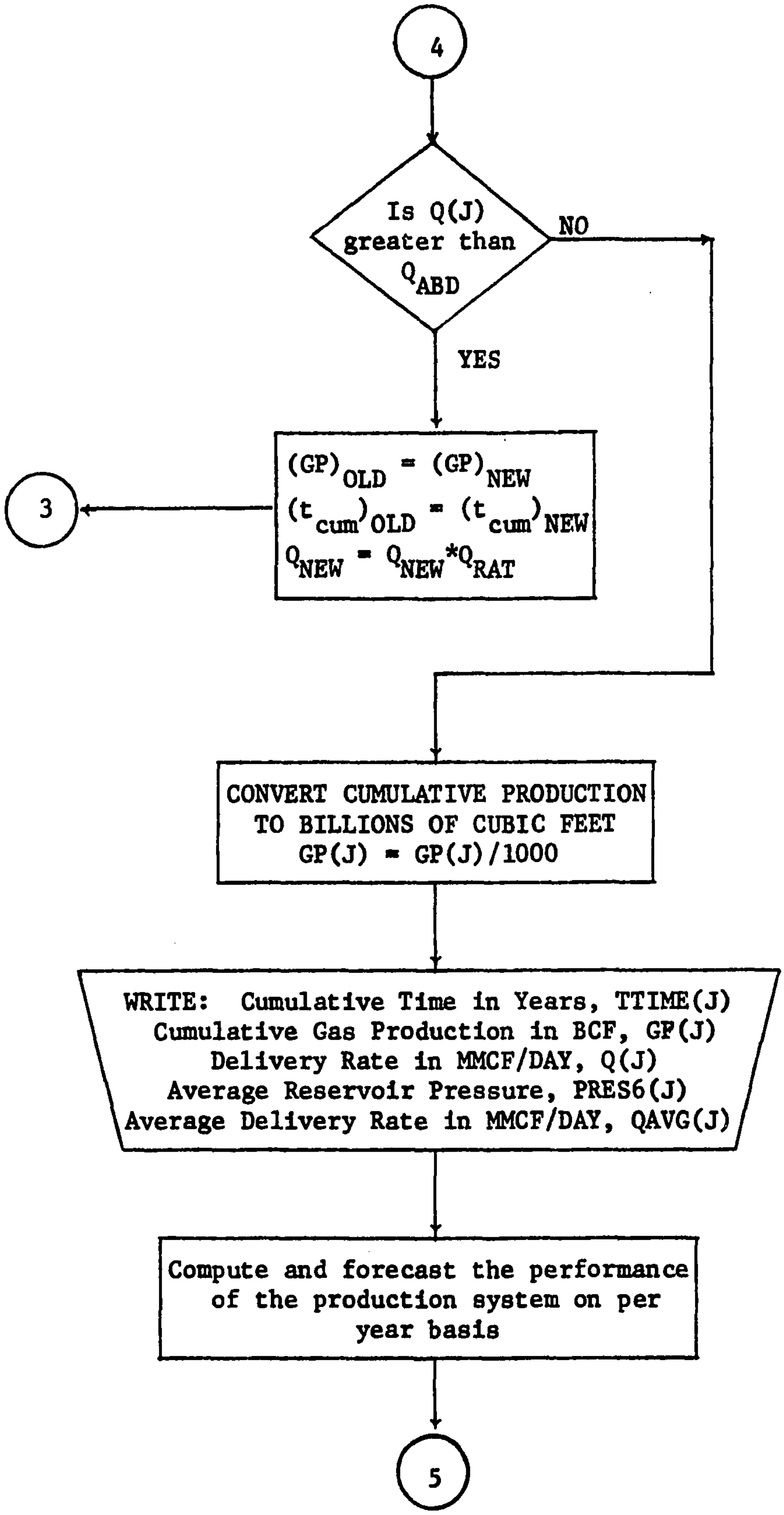
where C and C' are obtained from Figure 2, and GOR' = Q_g'/Q_o' is prescribed in the computation.

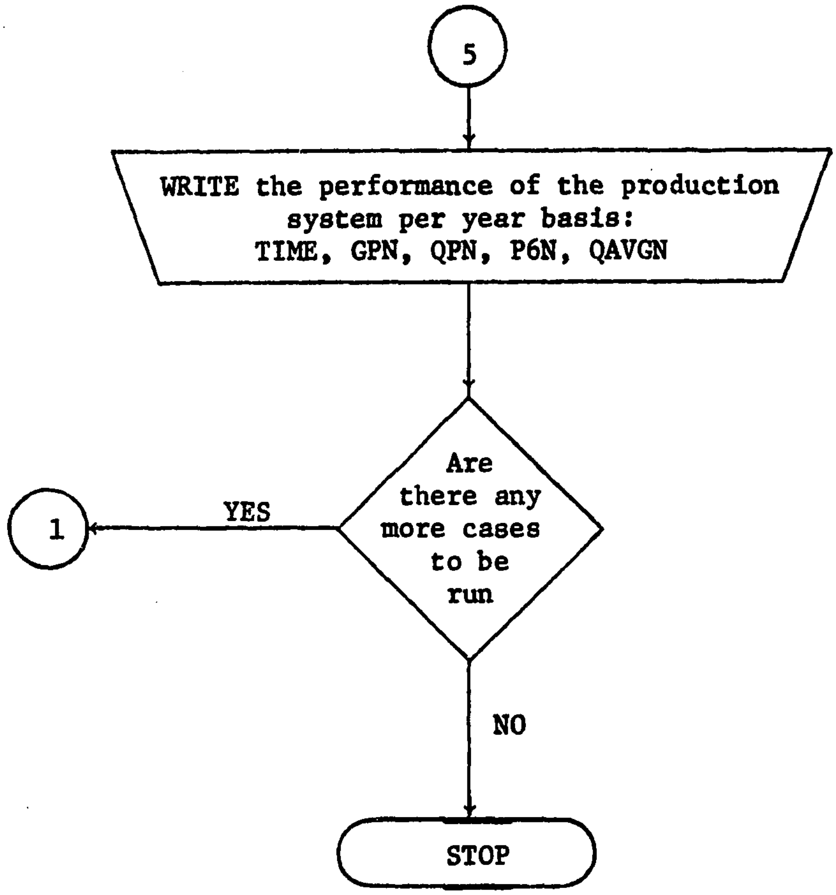
APPENDIX E

FLOW CHART OF THE COMPUTER PROGRAM FOR THE DRY GAS MODEL

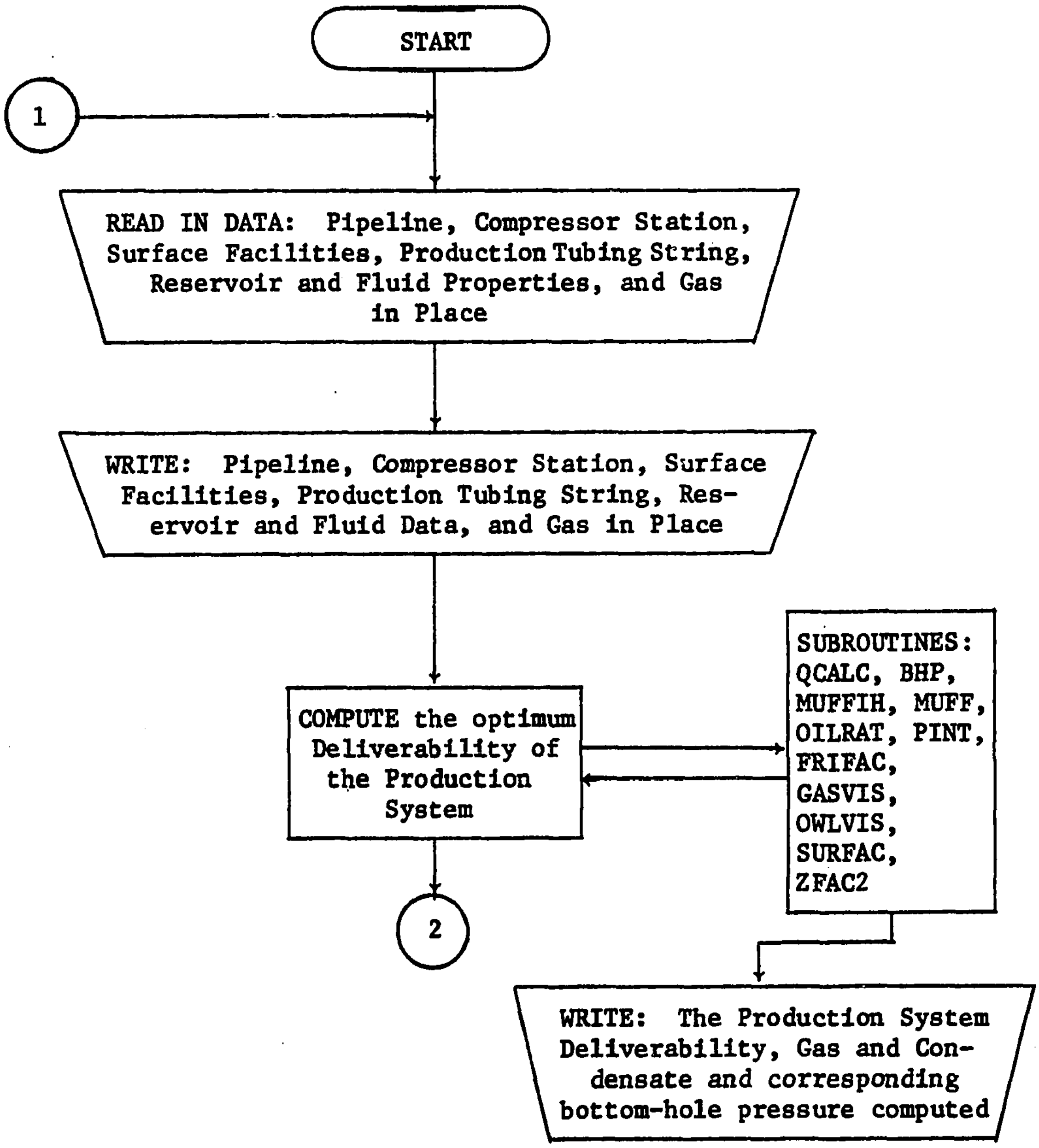


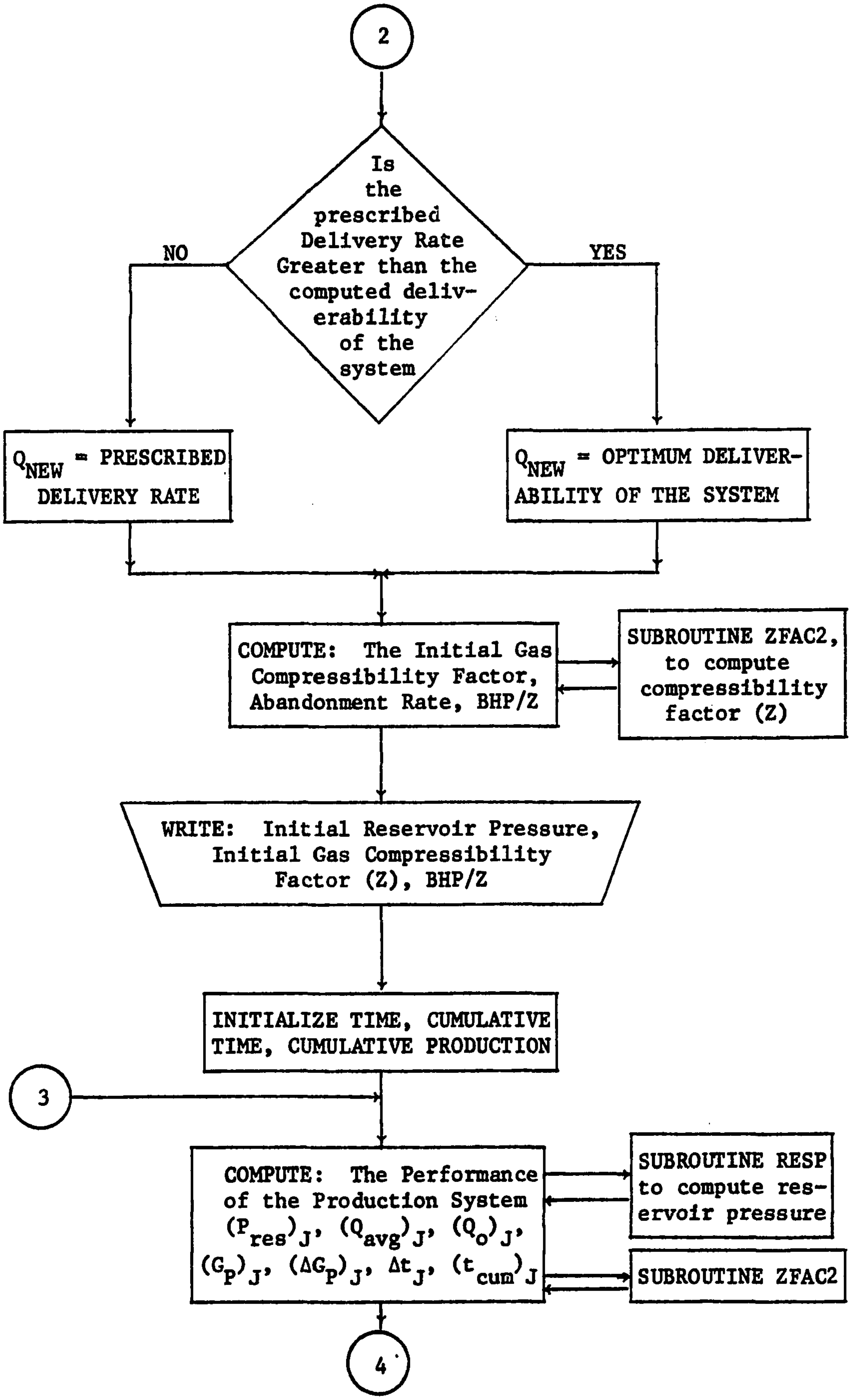

2
Is the prescribed Delivery Rate Greater than the computed deliverability of the system
NO
YES
Q new = PRESCRIBED DELIVERY RATE
Q new = OPTIMUM DELIVERABILITY OF THE SYSTEM
COMPUTE: The Initial Gas Compressibility Factor, Abandonment Rate, BHP/Z
SUBROUTINE ZFAC2, to compute compressibility Factor (Z)
WRITE: Initial Reservoir Pressure, Initial Gas Compressibility Factor, BHP/Z
INITIALIZE TIME, CUMULATIVE TIME, CUMULATIVE PRODUCTION
3
COMPUTE: The Performance of the Production System (P res)J, (Q avg)J, (G P)J, (ΔG P)J, Δt J, (t cum)J
SUBROUTINE RESP to compute reservoir pressure
SUBROUTINE ZFAC2
4

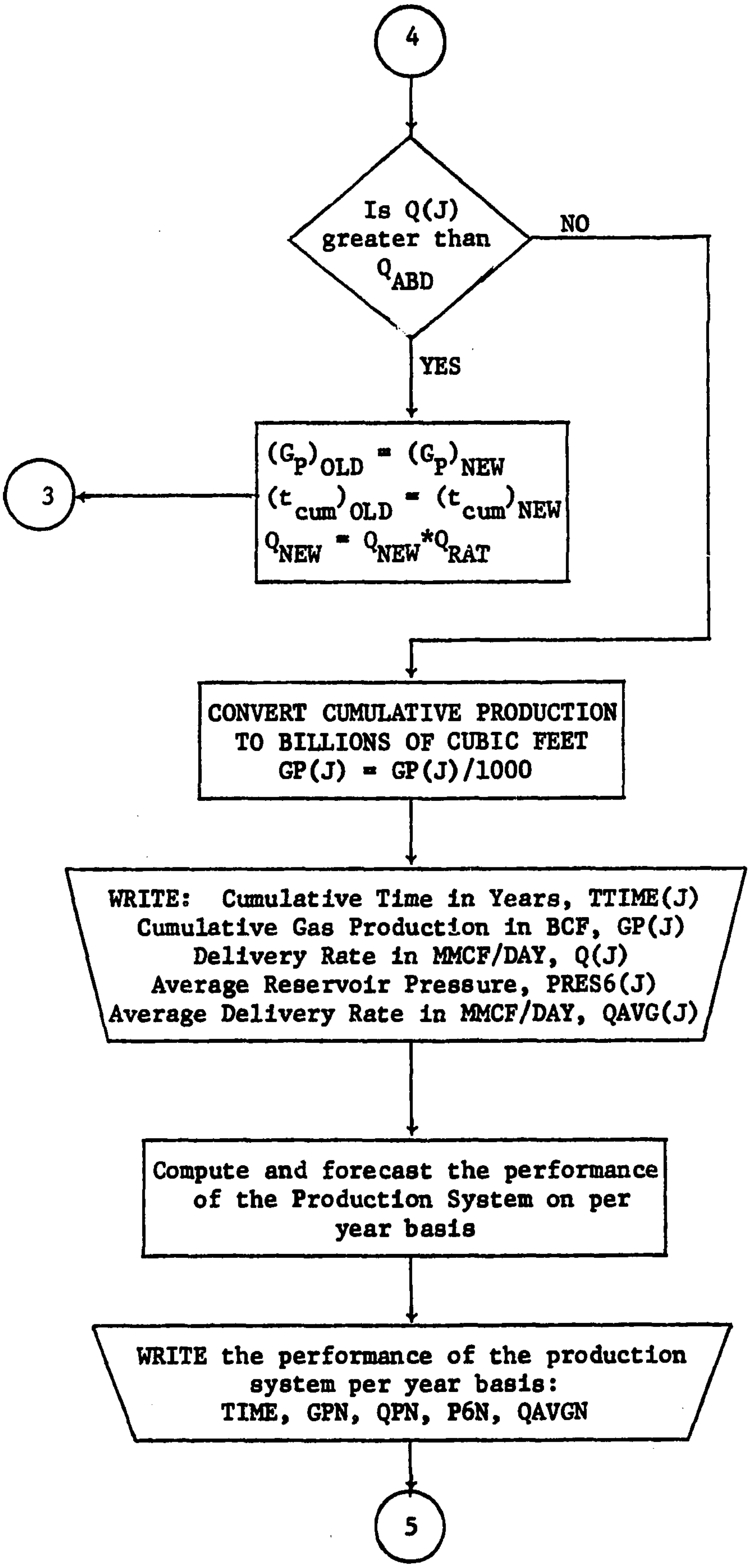

4
Is Q(J) greater than Q_{ABD}
NO
YES
$(GP)_{OLD} = (GP)_{NEW}$
$(t_{cum})_{OLD} = (t_{cum})_{NEW}$
$Q_{NEW} = Q_{NEW}*Q_{RAT}$
3
CONVERT CUMULATIVE PRODUCTION TO BILLIONS OF CUBIC FEET
GP(J) = GP(J)/1000
WRITE: Cumulative Time in Years, TTIME(J)
Cumulative Gas Production in BCF, GP(J)
Delivery Rate in MMCF/DAY, Q(J)
Average Reservoir Pressure, PRES6(J)
Average Delivery Rate in MMCF/DAY, QAVG(J)
Compute and forecast the performance of the production system on per year basis
5

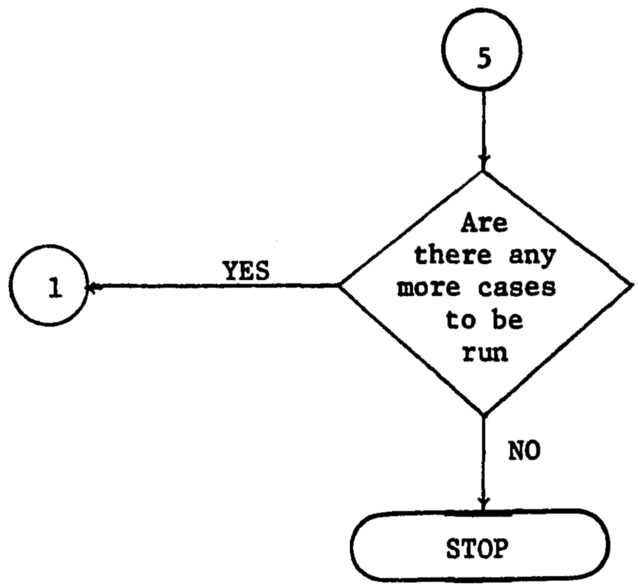

5
WRITE the performance of the production system per year basis: TIME, GPN, QPN, P6N, QAVGN
Are there any more cases to be run
YES
1
NO
STOP

FLOW CHART OF THE COMPUTER PROGRAM FOR THE GAS-CONDENSATE SYSTEM




2
Is the prescribed Delivery Rate Greater than the computed deliverability of the system
NO
YES
QNEW = PRESCRIBED DELIVERY RATE
QNEW = OPTIMUM DELIVERABILITY OF THE SYSTEM
COMPUTE: The Initial Gas Compressibility Factor, Abandonment Rate, BHP/Z
SUBROUTINE ZFAC2, to compute compressibility factor (Z)
WRITE: Initial Reservoir Pressure, Initial Gas Compressibility Factor (Z), BHP/Z
INITIALIZE TIME, CUMULATIVE TIME, CUMULATIVE PRODUCTION
3
COMPUTE: The Performance of the Production System (Pres)J, (Qavg)J, (Qo)J, (GP)J, (ΔGP)J, ΔtJ, (tcum)J
SUBROUTINE RESP to compute reservoir pressure
SUBROUTINE ZFAC2
4


4
Is Q(J) greater than Q_{ABD}
NO
YES
$(G_P)_{OLD} = (G_P)_{NEW}$
$(t_{cum})_{OLD} = (t_{cum})_{NEW}$
$Q_{NEW} = Q_{NEW}*Q_{RAT}$
3
CONVERT CUMULATIVE PRODUCTION TO BILLIONS OF CUBIC FEET
GP(J) = GP(J)/1000
WRITE: Cumulative Time in Years, TTIME(J)
Cumulative Gas Production in BCF, GP(J)
Delivery Rate in MMCF/DAY, Q(J)
Average Reservoir Pressure, PRES6(J)
Average Delivery Rate in MMCF/DAY, QAVG(J)
Compute and forecast the performance of the Production System on per year basis
WRITE the performance of the production system per year basis:
TIME, GPN, QPN, P6N, QAVGN
5


5
Are there any more cases to be run
YES
1
NO
STOP

APPENDIX F

FORTRAN IV G LEVEL 21 MAIN DATE = 75151 11/26/45

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C*******************************************************************************
C*******************************************************************************
C*******************************************************************************
C***************************** UNIVERSITY OF OKLAHOMA ***************************
C*****************************           1975          ***************************
C***************************       PH.D. RESEARCH      ***************************
C*******************************************************************************
C*******************************************************************************
C*******************************************************************************
C***********************************************************************FLOW   10
C***********************************************************************FLOW   20
C      INTEGRATED PERFORMANCE OF FLOW BEHAVIOR IN  DRY GAS RESERVOIR     FLOW   30
C      COMBINES FLOW BEHAVIOR OF RESERVOIR,FLOW STRING,PROCESSING EQUIPMEFLOW   40
C      GATHERING SYSTEM,COMPRESSION FACILITIES,TRUNKLINE.                FLOW   50
C      IT CALCULATES:                                                    FLOW   60
C         FLOW THROUGH THE RESERVOIR                                     FLOW   70
C         FLOW THROUGH THE PRODUC ING STRING                             FLOW   80
C         FLOW THROUGH THE SURFACE FACILITIES INCLUDING THE GATHERING    FLOW   90
C       SYSTEM,METERING EQUIPMENT AND GAS TREATMENT  EQUIPMENT           FLOW  100
C         FLOW THROUGH THE COMPRESSOR SATATION                           FLOW  110
C         FLOW THROUGH PIPELINE TO THE SALES POINT                       FLOW  120
C***********************************************************************FLOW  130
C***********************************************************************FLOW  140
C      MAXIMUM DELIVERABILITY OF A GAS PRODUCTION SYSTEM TO SALES CONNECTFLOW  150
C      OR PIPELINE IS EVALUATED                                          FLOW  160
C***********************************************************************FLOW  170
C***********************************************************************FLOW  180
C***********************************************************************FLOW  190
C***********************************************************************FLOW  200
C      P1 IS THE DELIVERY PRESSURE IN PSIA                               FLOW  210
C      T1 IS THE PIPELINE TEMP. IN DEG. RANKIN                           FLOW  220
C      D1 IS THE PIPELINE DIAM. IN INCHES                                FLOW  230
C      X1 IS THE PIPELINE LENGTH IN MILES                                FLOW  240
C      E1 IS THE PIPELINE EFFICIENCY FACTOR UNITLESS                     FLOW  250
C      P0 IS THE BASE PRESSURE IN PSIA                                   FLOW  260
C      T0 IS THE BASE TEMP. IN DEG. RANKIN                               FLOW  270
C      HP IS THE HORSE POWER IN HP                                       FLOW  280
C      RK IS THE COMPRESSION RATIO UNITLESS                              FLOW  290
C      T3 IS THE SUCTION TEMP. IN DEG. RANKIN                            FLOW  300
C      E2 IS THE COMPRESSOR EFFICIENCY FACTOR  UNITLESS                  FLOW  310
C      Z3 IS THE Z-FACTOR AT COMPRESSOR SUCTION UNITLESS                 FLOW  320
C      C3 IS THE CONSTANT IN GATHERING LINE SYSTEM SCF/PSIA              FLOW  330
C      T4 IS THE AVERAGE TUBING TEMP. IN DEG. RANKIN                     FLOW  340
C      Z4 IS THE  Z-FACTOR IN THE TUBING UNITLESS                        FLOW  350
C      D4 IS THE TUBING DIAM. IN INCHES                                  FLOW  360
C      X4 IS THE TUBING LENGTH IN FT.                                    FLOW  370
C      G  IS THE GAS GRAVITY UNITLESS                                    FLOW  380
C      VIS4 IS THE GAS VISCOSITY IN CP.                                  FLOW  390
C      WELLS IS THE NO. OF THE WELLS UNITLESS                            FLOW  400
C      P6 IS THE RESERVOIR PRESSURE IN PSIA                              FLOW  410
C      T6 IS THE RESERVOIR TEMP. IN DEG. RANKIN                          FLOW  420
C      C5 IS THE SLOPE OF OPEN FLOW CURVE IN MMCF/DAV/PSIA**2N           FLOW  430
```

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FORTRAN IV G LEVEL  21                MAIN                DATE = 75151          11/26/45

             C      RN IS THE CONSTANT IN RESERVOIR EQ, UNITLESS                          FLOW 440
             C      QN IS THE GAS PRODUCTION RATE IN MMCF                                 FLOW 450
             C      GI IS THE GAS IN PLACE IN MMCF                                        FLOW 460
             C*************************************************************************FLOW 470
             C*************************************************************************FLOW 480
0001              DIMENSION PRES6(100),Z6(100),Q(100),DTIME(100),TTIME(100),GP(100) FLOW 490
                 1,QAVG(100),A(6,6),PY(6),S6(6)                                      FLOW 500
0002              REAL*8 A                                                           FLOW 520
0003           98 READ(5,100) P1,T1,D1,X1,E1,P0,T0                                   FLOW 550
0004              IF(P1 .LT. 0.) GO TO 99                                            FLOW 560
0005              READ(5,100) HP,RK,T3,E2,Z3                                         FLOW 570
0006              READ(5,100) C3                                                     FLOW 580
0007              READ(5,100) T4,Z4,D4,X4,G,VIS4,WELLS                               FLOW 590
0008              READ(5,100) P6,RN,C5,T6                                            FLOW 600
0009          100 FORMAT(8F10.0)                                                     FLOW 610
0010              READ(5,2)GI                                                        FLOW 620
0011            2 FORMAT(F14.4)                                                      FLOW 630
0012              READ(5,100) QN,QRAT                                                FLOW 640
0013              WRITE (6,222)
0014          222 FORMAT (1H1,45X,'=================',/,46X,'THE INPUT DATA IS',/,4
                 16X,'=================',/)
0015              WRITE(6,310) P1,T1,D1,X1                                           FLOW 690
0016          310 FORMAT(//,5X,' P1 = ',F6.0,' PSIA ',7X,' T1 = ',F6.0,' DEG.R ',6X,FLOW 700
                 1' D1 = ',F5.0,' INCHES ',6X,' X1 = ',F6.0,' MILES ')               FLOW 710
0017              WRITE(6,315) E1,P0,T0                                              FLOW 720
0018          315 FORMAT(//,5X,' E1 = ',F6.2,' UNITLESS ',3X,' P0 = ',F5.0,' PSIA ',FLOW 730
                 18X,' T0 = ',F6.0,' DEG.R ')                                        FLOW 740
0019              WRITE(6,320) HP,RK,T3                                              FLOW 750
0020          320 FORMAT(//,5X,' HP = ',F7.0,' HP ',8X,' RK = ',F5.2,' UNITLESS ',  FLOW 760
                 14X,' T3 = ',F8.2,' DEG.R ')                                        FLOW 770
0021              WRITE(6,325) E2,Z3                                                 FLOW 780
0022          325 FORMAT(//,5X,' E2 = ',F6.2,' UNITLESS ',3X,' Z3 = ',F6.2,' UNITLESFLOW 790
                 1S ')                                                               FLOW 800
0023              WRITE(6,330) C3                                                    FLOW 810
0024          330 FORMAT(//,5X,' C3 =',F10.3,'SCF/DAY/PSI**2')
0025              WRITE(6,335) T4,Z4,D4,X4                                           FLOW 830
0026          335 FORMAT(//,5X,' T4 = ',F6.0,' DEG.R ',6X,' Z4 = ',F6.2,' UNITLESS 'FLOW 840
                 1,3X,' D4 = ',F6.2,' INCHES ',4X,' X4 = ',F7.0,' FEET ')            FLOW 850
0027              WRITE(6,340) G,VIS4,WELLS                                          FLOW 860
0028          340 FORMAT(//,5X,' G = ',F7.2,' UNITLESS ',3X,' VIS4 = ',F6.4,' CP ', FLOW 870
                 17X,' WELLS = ',F4.0,' UNITLESS ')                                  FLOW 880
0029              WRITE(6,345) P6,RN,C5,T6
0030          345 FORMAT(//,5X,' P6 = ',F7.0,' PSIA ',2X,' RN = ',F4.2,' UNITLESS ' FLOW 900
                 1,2X,' C5 = ',F10.6,' %MMCF/DAY</%PSIA<**%2N< ',' T6=',F6.0,' DEG')FLOW 910
0031              WRITE(6,350) QN                                                    FLOW 920
0032          350 FORMAT(//,5X,' QN = ',E20.8,'MMSCF/DAY ')                          FLOW 930
0033              WRITE(6,360) GI                                                    FLOW 940
0034         360  FORMAT(//,5X,' INITIAL GAS INPLACE GI = ',E15.7,/)                 FLOW 950
0035              PC=688.M=19.85*G=15.86*G*G                                         FLOW 960
0036              TC=170.0+313.6*G                                                   FLOW 970
0037              WRITE (6,200) QRAT,PC,TC                                           FLOW 980
0038          200 FORMAT(5X,'QRATE=',F10.5,5X,'PC=',F10.4,5X,'TC=',F10.4)            FLOW 990
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FORTRAN IV G LEVEL  21                MAIN                DATE = 75151         11/26/45

0039              CALL       ZFACO(A)                                              FLOW1000
0040              CALL       ZFAC1(ZI,P6,T6,PC,TC,PY,86,A)                         FLOW1010
0041              QSAVE=QN                                                         FLOW1020
0042              CALL        QCALC(P1,T1,D1,X1,E1,P0,T0,HP,RK,T3,E2,Z3,C3,T4,Z4,D4,FLOW1030
                 1X4,G,VIS4,WELLS,P6,RN,C5,QN,P5LS,P5RS,P5,Q1)                     FLOW1040
0043              QX=QN                                                            FLOW1050
0044              IF (QSAVE .GT. QN) GO TO 77                                      FLOW1060
0045              QO=QSAVE                                                         FLOW1070
0046              IF (QSAVE .GT. QX) GO TO 77                                      FLOW1080
0047              QN=QSAVE                                                         FLOW1090
0048              GO TO 88                                                         FLOW1100
0049           77 QO=QX                                                            FLOW1110
0050              QN=QX*QRAT                                                       FLOW1120
0051          88  QABD=0.1*QX
0052              PI=P6                                                            FLOW1140
0053              CALL       ZFAC2(ZI,PI,T6,PC,TC,PY,86)                           FLOW1150
0054              POZI=PI/ZI                                                       FLOW1160
0055              WRITE(6,370)PI,ZI,POZI                                           FLOW1170
0056          370 FORMAT(5X,' RESERVOIR PRESS =',F9.2,5X,'Z=',F10.6,5X,' P/Z=',F12.2FLOW1180
                 1,/)                                                              FLOW1190
0057              GPO=0.                                                           FLOW1200
0058              TO=0.                                                            FLOW1210
0059              GP(1)=GPO                                                        FLOW1220
0060              TTIME(1)=TO                                                      FLOW1230
0061              Q(1)=QO                                                          FLOW1240
0062              PRES6(1)=P6                                                      FLOW1250
0063              DO 16 J=2,100                                                    FLOW1260
0064              WRITE(6,380) GPO,QN                                              FLOW1270
0065          380 FORMAT(5X,'CUM GAS PROD =',F14.2,5X,'GAS RATE=',F12.2,/)         FLOW1280
0066              CALL        RESP(P1,T1,D1,X1,E1,P0,T0,HP,RK,T3,E2,Z3,C3,T4,Z4,D4, FLOW1290
                 1X4,G,VIS4,WELLS,P6,RN,C5,QN,P5LS,P5RS,P5,Q1)                     FLOW1300
0067              PRES6(J)=P6                                                      FLOW1310
0068              CALL       ZFAC2(ZZ,P6,T6,PC,TC,PY,86)                           FLOW1320
0069              Z6(J)=ZZ                                                         FLOW1330
0070              POZ=PRES6(J)/Z6(J)                                               FLOW1340
0071              F=1.-POZ/POZI                                                    FLOW1350
0072              GP(J)=F*GI                                                       FLOW1360
0073              WRITE(6,390)PRES6(J),Z6(J),POZ,F                                 FLOW1370
0074          390 FORMAT(5X,'RES PRESS=',F9.2,5X,'Z=',F10.4,5X,' P/Z=',F10.2,5X,   FLOW1380
                 1' F = ',E16.8,/)                                                 FLOW1390
0075              Q(J)=QN                                                          FLOW1400
0076              QAVG(J)=SQRT(QN*QO)                                              FLOW1410
0077              DTIME(J)=(GP(J)-GPO)/(QAVG(J)*365.)                              FLOW1420
0078              TTIME(J)=DTIME(J)+TO                                             FLOW1430
0079              WRITE(6,400)Q(J),DTIME(J),TTIME(J)                               FLOW1440
0080          400 FORMAT(5X,' GAS RATE =',F12.2,5X,'INCREMENTAL TIME =',F          FLOW1450
                 110.2,5X,' CUM TIME =',F10.2,/)                                   FLOW1460
0081              NSTEPB=J                                                         FLOW1470
0082              WRITE(6,201) NSTEPB,J                                            FLOW1480
0083              IF(Q(J) .LT. QABD) GO TO 17                                      FLOW1490
0084              GPO=GP(J)                                                        FLOW1500
0085              QO=QN                                                            FLOW1510
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FORTRAN IV G LEVEL  21                MAIN              DATE = 75151          11/26/45

0086          TO=TTIME(J)                                                       FLO*1520
0087          QN=QN*QRAT                                                        FLO*1530
0088       16 CONTINUE                                                          FLO*1540
0089       17 DO 19 J=1,NSTEPS                                                  FLO*1550
0090          GP(J)=GP(J)/1000.                                                 FLO*1560
0091       19 CONTINUE                                                          FLO*1570
0092          WRITE(6,40)                                                       FLO*1580
0093          WRITE(6,42)  TTIME(1),GP(1),Q(1),PRES6(1)                         FLO*1590
0094          WRITE(6,41) (TTIME(J),GP(J),Q(J),PRES6(J),QAVG(J),J=2,NSTEPS)     FLO*1600
0095          ILIM=TTIME(NSTEPS)                                                FLO*1610
0096          TLIM=ILIM                                                         FLO*1620
0097          DTPRIN=1.                                                         FLO*1630
0098          TIME=0.                                                           FLO*1640
0099          P60=PRES6(1)                                                      FLO*1650
0100          QPO=Q(1)                                                          FLO*1660
0101          GPO=0.                                                            FLO*1670
0102          WRITE(6,43)                                                       FLO*1680
0103          WRITE(6,42) TIME,GPO,QPO,P60                                      FLO*1690
0104          ISTART=2                                                          FLO*1700
0105      117 TIME=TIME+DTPRIN                                                  FLO*1710
0106          NSTART=ISTART                                                     FLO*1720
0107          DO 116 I=NSTART,NSTEPS                                            FLO*1730
0108          IF(TIME .GT. TTIME(I)) GO TO 116                                  FLO*1740
0109          GPN=(GP(I)-GP(I-1))/(TTIME(I)-TTIME(I-1))*(TIME-TTIME(I-1))       FLO*1750
             1+GP(I-1)                                                          FLO*1760
0110          QAVGN=(GPN-GPO)/(DTPRIN*0.365)                                    FLO*1770
0111          F=(GPN*1000.)/GI                                                  FLO*1780
0112          POZ=(1.0-F)*POZI                                                  FLO*1790
0113          CALL      SOLZ(POZ,ZZ,P6N,T6,PC,TC,PY,S6,A)                       FLO*1800
0114          QPN=QAVGN*QAVGN/QPO                                               FLO*1810
0115          WRITE(6,41) TIME,GPN,QPN,P6N,QAVGN                                FLO*1820
0116          GPO=GPN                                                           FLO*1830
0117          QPO=QPN                                                           FLO*1840
0118          ISTART=I                                                          FLO*1850
0119          IF(TIME .GE. TLIM) GO TO 97                                       FLO*1860
0120          GO TO 117                                                         FLO*1870
0121      116 CONTINUE                                                          FLO*1880
0122       97 CONTINUE                                                          FLO*1890
0123          TSAVE=TIME                                                        FLO*1900
0124          I=NSTEPS                                                          FLO*1910
0125          TIME=TTIME(I-1)+(TTIME(I)-TTIME(I-1))/ALOG10(Q(I)/Q(I-1))*ALOG10  FLO*1920
             1(QABD/Q(I-1))                                                     FLO*1930
0126          GPN=(GP(I)-GP(I-1))/(TTIME(I)-TTIME(I-1))*(TIME-TTIME(I-1))       FLO*1940
             1+GP(I-1)                                                          FLO*1950
0127          QAVGN=(GPN-GPO)/((TIME-TSAVE)*0.365)                              FLO*1960
0128          F=(GPN*1000)/GI                                                   FLO*1970
0129          POZ=(1.0-F)*POZI                                                  FLO*1980
0130          CALL      SOLZ(POZ,ZZ,P6N,T6,PC,TC,PY,S6,A)                       FLO*1990
0131          QPN=QABD                                                          FLO*2000
0132          WRITE(6,41) TIME,GPN,QPN,P6N,QAVGN                                FLO*2010
0133          GO TO 98                                                          FLO*2020
0134       40 FORMAT(1H1,11X,16HCUMULATIVE  TIME,5X,14HCUMULATIVE GAS,6X,14HDELIFLO*2030
             1VERY  RATE,4X,18HAVERAGE  RESERVOIR,2X,21HAVERAGE DELIVERY RATE/  FLO*2040
             216X,4HIN YEARS,7X,18HPRODUCTION  IN BCF ,5X,12HIN  MMCF/DAY,5X,18HFLO*2050
             3PRESSURE  IN PSIA,,6X,12HIN  MMCF/DAY///)                         FLO*2060
0135       41 FORMAT(7X,5F20.4)                                                 FLO*2070
0136       42 FORMAT(7X,4F20.4)                                                 FLO*2080
0137       43 FORMAT(////12X,16HCUMULATIVE  TIME,5X,14HCUMULATIVE GAS,6X,14HDELIFLO*2090
             1VERY  RATE,4X,18HAVERAGE  RESERVOIR,2X,21HAVERAGE DELIVERY RATE/  FLO*2100
             216X,4HIN YEARS,7X,18HPRODUCTION  IN BCF ,5X,12HIN  MMCF/DAY,5X,18HFLO*2110
             3PRESSURE  IN PSIA,,6X,12HIN  MMCF/DAY///)                         FLO*2120
0138      201 FORMAT(2I10)                                                      FLO*2130
0139       99 STOP                                                              FLO*2140
0140          END                                                               FLO*2150
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FORTRAN IV G LEVEL  21                 RESP               DATE = 75151          11/26/45

0001            SUBROUTINE RESP(P1,T1,D1,X1,E1,P0,T0,HP,RK,T3,E2,Z3,C3,T4,Z4,D4,   FLO=2160
               1X4,G,VIS4,WELLS,P6,RN,C5,DN,P5LS,P5RS,P5,Q1)                       FLO=2170
0002            COMMON/OKLA1/QGG,L                                                  FLO=2180
0003            Q=QN*1.E6                                                           FLO=2190
0004            C1=435.*7*E1*(T0/P0)**1.07881                                       FLO=2200
0005            VICON4=0.000672*VIS4                                                FLO=2210
0006            IF(X1.LE.0..OR.D1.LE.0.) GO TO 10                                   FLO=2220
0007            Y1=(X1*T1)**(-0.5394)*G**(-0.4606)*D1**2.6182                       FLO=2230
0008            GO TO 20                                                            FLO=2240
0009         10 Y1=0.                                                               FLO=2250
0010         20 CONTINUE                                                            FLO=2260
0011            IF(Y1.LE.0.) GO TO 30                                               FLO=2270
0012            IF(C1.LE.0.) GO TO 30                                               FLO=2280
0013            Y2=Q/(C1*Y1)                                                        FLO=2290
0014            GO TO 40                                                            FLO=2300
0015         30 Y2=0.                                                               FLO=2310
0016         40 CONTINUE                                                            FLO=2320
0017            P2=SQRT(P1*P1+Y2**1.854)                                            FLO=2330
0018            WRITE(6,50)P1,P2                                                    FLO=2340
0019         50 FORMAT(//,5X,'DELIVERY PRESS P1=',F10.2,5X,'DISCHARGE PRES P2='     FLO=2350
               1,F10.2,/)                                                          FLO=2360
0020            RKRAT=RK/(RK-1.)                                                    FLO=2370
0021            IF(RKRAT.LE.0) GO TO 60                                             FLO=2380
0022            Y3=HP/(0.08531E-6*RKRAT*Q*T3)+1.                                    FLO=2390
0023            IF(Y3.LE.0.) GO TO 60                                               FLO=2400
0024            P3=P2/Y3**(RKRAT/Z3)                                                FLO=2410
0025            GO TO 70                                                            FLO=2420
0026         60 P3=P2+3.                                                            FLO=2430
0027         70 CONTINUE                                                            FLO=2440
0028            WRITE(6,80)P3                                                       FLO=2450
0029         80 FORMAT(5X,'SUCTION PRES P3=',F10.2,/)                               FLO=2460
0030            IF(C3.LE.0.) GO TO 90                                               FLO=2470
0031            P4=SQRT(P3*P3+(Q/C3)**2)                                            FLO=2480
0032            GO TO 100                                                           FLO=2490
0033         90 P4=P3+3.                                                            FLO=2500
0034        100 CONTINUE                                                            FLO=2510
0035            WRITE(6,110)P4                                                      FLO=2520
0036        110 FORMAT(5X,' WELL HEAD PRES P4=',F10.2,/)                            FLO=2530
0037            S=0.0375*G*X4/(T4*Z4)                                               FLO=2540
0038            Y4=S/(EXP(S)-1.)                                                    FLO=2550
0039            Q1=Q/WELLS                                                          FLO=2560
0040            QGG=Q1/1.E6                                                         FLO=2570
0041            SGG=G                                                               FLO=2580
0042            F=0.0309*(Q1*G/(VICON4*1.E6))**(-0.065)                             FLO=2590
0043            WRITE(6,120)Q1                                                      FLO=2600
0044        120 FORMAT(5X,'GAS RATE Q1= ',E15.7,/)                                  FLO=2610
0045            F=F*(D4/12.)**(-0.058)                                              FLO=2620
0046            Y5=D4**5/(G*Z4*T4*F*X4)                                             FLO=2630
0047            Y6=(Q1/2.F5)**2/(Y4*Y5)                                             FLO=2640
0048            P5LS=SQRT(P4*P4*EXP(S)+Y6)                                          FLO=2650

0049            P6=SQRT(P5LS*P5LS+(Q1/(C5*1.E6))**(1./RN))                          FLO=2670
0050            WRITE(6,130)P5LS,P6                                                 FLO=2680
0051        130 FORMAT(5X,'FLOWING BHP P5LS=',F10.2,5X,'RES PRES P6=',F10.2,/)      FLO=2690
0052            RETURN                                                              FLO=2700
0053            END                                                                 FLO=2710
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FORTRAN IV G LEVEL  21                 QCALC               DATE = 75151          11/26/45

0001            SUBROUTINE  QCALC(P1,T1,D1,X1,E1,P0,T0,HP,RK,T3,E2,Z3,C3,T4,Z4,D4,FLOW2720
               1X4,G,VIS4,WELLS,P6,RN,C5,QN,P5LS,P5RS,P5,Q1)                       FLOW2730
0002            COMMON/OKLA1/QGG,L                                                  FLOW2740
0003            L=0                                                                 FLOW2750
0004            ITNO=0                                                              FLOW2760
0005            QO=0.                                                               FLOW2770
0006            DPO=P6                                                              FLOW2780
0007         50 ITNO=ITNO+1                                                         FLOW2790
0008            CALL         BHP(P1,T1,D1,X1,E1,P0,T0,HP,RK,T3,E2,Z3,C3,T4,Z4,D4,   FLOW2800
               1X4,G,VIS4,WELLS,P6,RN,C5,QN,P5LS,P5RS,P5,Q1)                       FLOW2810
0009            SAM=(P6*P6-(Q1/(C5*1.E6))**(1./RN))                                 FLOW2820
0010            IF(SAM.LE.0.) GO TO 500                                             FLOW2830
0011            P5RS=SQRT(P6*P6-(Q1/(C5*1.E6))**(1./RN))                            FLOW2840
0012            GO TO 400                                                           FLOW2850
0013      500   SAM=ABS(SAM)                                                        FLOW2860
0014            P5RS=SQRT(SAM)                                                      FLOW2870
0015        400 CONTINUE                                                            FLOW2880
0016            WRITE(6,201) ITNO                                                   FLOW2890
0017            WRITE(6,202) QN,P5LS,P5RS                                           FLOW2900
0018            IF (ITNO .GT. 10.) GO TO 75                                         FLOW2910
0019            DPN=P5RS-P5LS                                                       FLOW2920
0020            IF (ABS(DPN)-1.0) 99,80,80                                          FLOW2930
0021         80 QSTAR=QO+DPO*(QN-QO)/(DPO-DPN)                                      FLOW2940
0022            QO=QN                                                               FLOW2950
0023            QN=ABS(QSTAR)                                                       FLOW2960
0024            DPO=DPN                                                             FLOW2970
0025            GO TO 50                                                            FLOW2980
0026         75 WRITE (6,204)                                                       FLOW2990
0027        201 FORMAT(5X,24HTHE SOLUTION AFTER TRIAL,I5,16H    IS AS FOLLOWS//)    FLOW3000
0028        202 FORMAT(5X,20HTHE GAS FLOW RATE IS,F10.3,12H    MMSCF/DAY//5X,40HTHEFLOW3010
               1 BHP CALCULATED FROM THE LINE SIDE IS,F10.3,8H   PSIA.//5X,40HTHE FLOW3020
               2BHP CALCULATED FROM THE RES. SIDE IS,F10.3,8H   PSIA.////)         FLOW3030
0029        204 FORMAT (5X,29HTEN ITERATIONS HAVE BEEN MADE)                        FLOW3040
0030         99 RETURN                                                              FLOW3050
0031            END                                                                 FLOW3060
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FORTRAN IV G LEVEL  21                    BHP                DATE = 75151          11/26/45

0001          SUBROUTINE  BHP(P1,T1,D1,X1,E1,P0,T0,HP,RK,T3,E2,Z3,C3,T4,Z4,D4,   FLOW3070
             1X4,G,VIS4,WELLS,P6,RN,C5,QN,P5LS,P5RS,P5,Q1)                         FLOW3080
0002          COMMON/ORLA1/QGG,L                                                   FLOW3090
0003          Q=QN*1.E6                                                            FLOW3100
0004          C1=435.87*E1*(T0/P0)**1.07881                                        FLOW3110
0005          VICON4=0.000672*VIS4                                                 FLOW3120
0006          IF(X1.LE.0.0.OR.D1.LE.0.0) GO TO 180                                 FLOW3130
0007          Y1=(X1*T1)**(-0.5394)*G**(-0.4606)*D1**2.6182                        FLOW3140
0008          GO TO 190                                                            FLOW3150
0009      180 Y1=0.                                                                FLOW3160
0010      190 CONTINUE                                                             FLOW3170
0011          IF(Y1.LE.0.) GO TO 140                                               FLOW3180
0012          IF(C1.LE.0.) GO TO 140                                               FLOW3190
0013          Y2=Q/(C1*Y1)                                                         FLOW3200
0014          GO TO 150                                                            FLOW3210
0015      140 Y2=0.                                                                FLOW3220
0016      150 CONTINUE                                                             FLOW3230
0017          P2=SQRT(P1*P1+Y2**1.854)                                             FLOW3240
0018          WRITE (6,202)                                                        FLOW 650
0019      202 FORMAT(1H1)                                                          FLOW 660
0020          WRITE(6,310)P1,P2                                                    FLOW3250
0021      310 FORMAT(//,4X,'DELIVERY PRESS  P1 =',F10.2,4X,'DISCHARGE PRESS  P2 FLOW3260
             1 =',F10.2,/)                                                         FLOW3270
0022          RKRAT=RK/(RK-1.)                                                     FLOW3280
0023          IF(RKRAT.LE.0.) GO TO 110                                            FLOW3290
0024          Y3=HP/(0.08531E-6*RKRAT*Q*T3)+1.                                     FLOW3300
0025          IF(Y3.LE.0.) GO TO 110                                               FLOW3310
0026          P3=P2/Y3**(RKRAT/Z3)                                                 FLOW3320
0027          GO TO 130                                                            FLOW3330
0028      110 P3=P2+3                                                              FLOW3340
0029      130 CONTINUE                                                             FLOW3350
0030          WRITE(6,320)P3                                                       FLOW3360
0031      320 FORMAT(///,5X,'SUCTION PRESS  P3=',F10.2,/)                          FLOW3370
0032          IF(C3.LE.0.) GO TO 160                                               FLOW3380
0033          P4=SQRT(P3*P3+(Q/C3)**2)                                             FLOW3390
0034          GO TO 170                                                            FLOW3400
0035      160 P4=P3+3                                                              FLOW3410
0036      170 CONTINUE                                                             FLOW3420
0037          WRITE(6,330) P4                                                      FLOW3430
0038      330 FORMAT(//,5X,' THE WELL HEAD PRESS  P4=',F10.2,/)                    FLOW3440
0039          S=0.0375*G*X4/(T4*Z4)                                                FLOW3450
0040          Y4=S/(EXP(S)-1.)                                                     FLOW3460
0041          Q1=Q/WELLS                                                           FLOW3470
0042          F=0.0309*(Q1*G/(VICON4*1.E6))**(-0.065)                              FLOW3480
0043          WRITE(6,340)Q1                                                       FLOW3490
0044      340 FORMAT(//,5X,' GAS RATE Q1=',E15.6,/)                                FLOW3500
0045          F=F*(D4/12.)**(-0.058)                                               FLOW3510
0046          Y5=D4**5/(G*Z4*T4*F*X4)                                              FLOW3520
0047          Y6=(Q1/2.E5)**2/(Y4*Y5)                                              FLOW3530
0048          P5LS=SQRT(P4*P4*EXP(S)+Y6)                                           FLOW3540
        C     SGG=G                                                                FLOW3550
        C     QGG=Q1/1.E6                                                          FLOW3560
        C     IF(L.LT.1) READ(5,100)                                               FLOW3570
        C 100 FORMAT(I4)                                                           FLOW3580
        C     IF(M.EQ.1) CALL     (P6,P4,T6,T0,X4,D4,SGG,P5LS)                     FLOW3590
        C     L=L+1                                                                FLOW3600
0049          RETURN                                                               FLOW3610
0050          END                                                                  FLOW3620
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FORTRAN IV G LEVEL  21                SOLZ              DATE = 75151          11/26/45

          SUBROUTINE SOLZ(POZ,Z,P,T,PC,TC,PY,S,A)                        FLO-3630
          REAL*8 A                                                       FLO-3640
          DIMENSION A(6,6),PY(6),S(6)                                    FLO-3650
          PO=POZ                                                         FLO-3660
          I=1                                                            FLO-3670
          CALL      ZFAC2(ZO,PO,TO,PC,TC,PY,S)                           FLO-3680
          POOZO=PO/ZO                                                    FLO-3690
          DELPO=POOZO-POZ                                                FLO-3700
          PN=0.85*PO                                                     FLO-3710
       17 CALL      ZFAC2(ZN,PN,TN,PC,TC,PY,S)                           FLO-3720
          PNOZN=PN/ZN                                                    FLO-3730
          DELPN=PNOZN-POZ                                                FLO-3740
          IF(ABS(DELPN).LT. 1.) GO TO 88                                 FLO-3750
          PSTAR=PO-DELPO*(PN-PO)/(DELPN-DELPO)                           FLO-3760
          PO=PN                                                          FLO-3770
          PN=PSTAR                                                       FLO-3780
          DELPO=DELPN                                                    FLO-3790
          I=I+1                                                          FLO-3800
          IF(I .GT. 10) GO TO 90                                         FLO-3810
          GO TO 17                                                       FLO-3820
       90 WRITE(6,91)                                                    FLO-3830
       88 Z=ZN                                                           FLO-3840
          P=PN                                                           FLO-3850
       91 FORMAT(5X,29HTEN ITERATIONS HAVE BEEN MADE)                    FLO-3860
          RETURN                                                         FLO-3870
          END                                                            FLO-3880
```

FORTRAN IV G LEVEL 21 ZFACO DATE = 75151 11/26/45

```
      SUBROUTINE ZFACU(A)                                   FLOW3890
      DIMENSION A(6,6)                                      FLOW3900
      REAL*8 A                                              FLOW3910
      A(1,1)=2.1433504                                      FLOW3920
      A(2,1)=0.83176184D-1                                  FLOW3930
      A(3,1)=-0.21467042D-1                                 FLOW3940
      A(4,1)=-0.87140318D-3                                 FLOW3950
      A(5,1)=0.42846283D-2                                  FLOW3960
      A(6,1)=-0.16595343D-2                                 FLOW3970
      A(1,2)=0.33123524                                     FLOW3980
      A(2,2)=-0.13403614                                    FLOW3990
      A(3,2)=0.66880961D-1                                  FLOW4000
      A(4,2)=-0.27174261D-1                                 FLOW4010
      A(5,2)=0.88512291D-2                                  FLOW4020
      A(6,2)=-0.21520929D-2                                 FLOW4030
      A(1,3)=0.10572871                                     FLOW4040
      A(2,3)=-0.50393654D-1                                 FLOW4050
      A(3,3)=0.50924748D-2                                  FLOW4060
      A(4,3)=0.10551336D-1                                  FLOW4070
      A(5,3)=-0.73181955D-2                                 FLOW4080
      A(6,3)=0.24959963D-2                                  FLOW4090
      A(1,4)=-0.52184040D-1                                 FLOW4100
      A(2,4)=0.44312146D-1                                  FLOW4110
      A(3,4)=-0.19329465D-1                                 FLOW4120
      A(4,4)=0.58972516D-2                                  FLOW4130
      A(5,4)=0.15366676D-2                                  FLOW4140
      A(6,4)=-0.28326809D-2                                 FLOW4150
      A(1,5)=0.19703980D-1                                  FLOW4160
      A(2,5)=-0.26383354D-1                                 FLOW4170
      A(3,5)=0.19262143D-1                                  FLOW4180
      A(4,5)=-0.11535539D-1                                 FLOW4190
      A(5,5)=0.42910089D-2                                  FLOW4200
      A(6,5)=-0.81302526D-3                                 FLOW4210
      A(1,6)=-0.53095900D-2                                 FLOW4220
      A(2,6)=0.89178330D-2                                  FLOW4230
      A(3,6)=-0.10894821D-1                                 FLOW4240
      A(4,6)=0.9559389D-2                                   FLOW4250
      A(5,6)=-0.60114017D-2                                 FLOW4260
      A(6,6)=0.31175170D-2                                  FLOW4270
      RETURN                                                FLOW4280
      END                                                   FLOW4290
```

```
FORTRAN IV G LEVEL  21                    ZFAC1              DATE = 75151          11/26/45

           SUBROUTINE ZFAC1 (Z,P,T,PC,TC,PY,S,A)                                    FLO=4300
           DIMENSION A(6,6),PY(6),S(6)                                              FLO=4310
           REAL*8A                                                                  FLO=4320
           Y=(2,*(T/TC)=4,)/1,9                                                     FLO=4330
           YSQ=Y*Y                                                                  FLO=4340
           YCUBE=YSQ*Y                                                              FLO=4350
           YTO4=YSQ*YSQ                                                             FLO=4360
           PY(1)=0,7071068                                                          FLO=4370
           PY(2)=1,224745*Y                                                         FLO=4380
           PY(3)=0,7905695*(3,*YSQ=1,)                                              FLO=4390
           PY(4)=0,9354145*(5,*YCUBE=3,*Y)                                          FLO=4400
           PY(5)=0,265165*(35,*YTO4=30,*YSQ+3,)                                     FLO=4410
           PY(6)=0,293151*(63,*YTO4*Y=70,*YCUBE+15,*Y)                              FLO=4420
           DO 20 I=1,6                                                              FLO=4430
           S(I)=0,                                                                  FLO=4440
           DO 10 J=1,6                                                              FLO=4450
           S(I)=S(I)+A(J,I)*PY(J)                                                   FLO=4460
        10 CONTINUE                                                                 FLO=4470
        20 CONTINUE                                                                 FLO=4480
           RETURN                                                                   FLO=4490
           END                                                                      FLO=4500
```

```
FORTRAN IV G LEVEL  21                    ZFAC2              DATE = 75151          11/26/45

           SUBROUTINE ZFAC2 (Z,P,T,PC,TC,PY,S)                                      FLO=4510
           DIMENSION         PY(6),S(6)                                             FLO=4520
           Y=(2,*(P/PC)=15,)/14,8                                                   FLO=4530
           YSQ=Y*Y                                                                  FLO=4540
           YCUBE=YSQ*Y                                                              FLO=4550
           YTO4=YSQ*YSQ                                                             FLO=4560
           PY(1)=0,7071068                                                          FLO=4570
           PY(2)=1,224745*Y                                                         FLO=4580
           PY(3)=0,7905695*(3,*YSQ=1,)                                              FLO=4590
           PY(4)=0,9354145*(5,*YCUBE=3,*Y)                                          FLO=4600
           PY(5)=0,265165*(35,*YTO4=30,*YSQ+3,)                                     FLO=4610
           PY(6)=0,293151*(63,*YTO4*Y=70,*YCUBE+15,*Y)                              FLO=4620
           Z=0,                                                                     FLO=4630
           DO 10 I=1,6                                                              FLO=4640
           Z=Z+S(I)*PY(I)                                                           FLO=4650
        10 CONTINUE                                                                 FLO=4660
           RETURN                                                                   FLO=4670
           END                                                                      FLO=4680
```

```
FORTRAN IV G LEVEL  21                PINT                 DATE = 75151          11/26/45

           SUBROUTINE PINT(XA,YA,X,Y,M)                                          FLO=4690
           DIMENSION X(20),Y(20)                                                 FLO=4700
           IF(XA.EQ.X(1))GO TO 3                                                 FLO=4710
           DO 1 K=2,M                                                            FLO=4720
           I=K                                                                   FLO=4730
           IF(XA.GT.X(K))GO TO 2                                                 FLO=4740
           IF(XA.EQ.X(K))GO TO 4                                                 FLO=4750
     1     CONTINUE                                                              FLO=4760
     2     YA=((XA-X(I-1))/(X(I)-X(I-1)))*(Y(I)-Y(I-1))+Y(I-1)                   FLO=4770
           GO TO 5                                                               FLO=4780
     3     YA=Y(1)                                                               FLO=4790
           GO TO 5                                                               FLO=4800
     4     YA=Y(I)                                                               FLO=4810
     5     RETURN                                                                FLO=4820
           END                                                                   FLO=4830
```

```
C***********************************************************************FLOW
C***********************************************************************FLOW
C***********************************************************************FLOW
C***************************** UNIVERSITY OF OKLAHOMA *******************FLOW
C*****************************          1975          *******************FLOW
C****************************      PH.D. RESEARCH     *******************FLOW
C***********************************************************************FLOW
C***********************************************************************FLOW
C***********************************************************************FLOW
C***********************************************************************FLOW
C***********************************************************************FLOW
C***********************************************************************FLOW
C     INTEGRATED PERFORMANCE OF FLOW BEHAVIOR IN GAS COND. RESERVOIR    FLOW
C     COMBINES FLOW BEHAVIOR OF RESERVOIR,FLOW STRING,PROCESSING EQUIPMEFLOW
C     GATHERING SYSTEM,COMPRESSION FACILITIES,TRUNKLINE.                FLOW
C     IT CALCULATES:                                                    FLOW
C        FLOW THROUGH THE RESERVOIR                                     FLOW
C        FLOW THROUGH THE PRODUCING STRING                              FLOW
C        FLOW THROUGH THE SURFACE FACILITIES INCLUDING THE GATHERING    FLOW
C      SYSTEM,METERING EQUIPMENT AND GAS TREATMENT  EQUIPMENT           FLOW
C        FLOW THROUGH THE COMPRESSOR SATATION                           FLOW
C        FLOW THROUGH PIPELINE TO THE SALES POINT                       FLOW
C***********************************************************************FLOW
C***********************************************************************FLOW
C     MAXIMUM DELIVERABILITY OF A GAS PRODUCTUIN SYSTEM TO SALES CONNECTFLOW
C     OR PIPELINE IS EVALUATED                                          FLOW
C***********************************************************************FLOW
C***********************************************************************FLOW
C***********************************************************************FLOW
C***********************************************************************FLOW
C     P1 IS THE DELIVERY PRESSURE IN PSIA                               FLOW
C     T1 IS THE PIPELINE TEMP. IN DEG. RANKIN                           FLOW
C     D1 IS THE PIPELINE DIAM. IN INCHES                                FLOW
C     X1 IS THE PIPELINE LENGTH IN MILES                                FLOW
C     E1 IS THE PIPELINE EFFICIENCY FACTOR UNITLESS                     FLOW
C     P0 IS THE BASE PRESSURE IN PSIA                                   FLOW
C     T0 IS THE BASE TEMP. IN DEG. RANKIN                               FLOW
C     HP IS THE HORSE POWER IN HP                                       FLOW
C     RX IS THE COMPRESSION RATIO UNITLESS                              FLOW
C     T3 IS THE SUCTION TEMP. IN DEG. RANKIN                            FLOW
C     E2 IS THE COMPRESSOR EFFICIENCY FACTOR  UNITLESS                  FLOW
C     Z3 IS THE Z-FACTOR AT COMPRESSOR SUCTION UNITLESS                 FLOW
C     C3 IS THE CONSTANT IN GATHERING LINE SYSTEM SCF/PSIA              FLOW
C     T4 IS THE AVERAGE TUBING TEMP. IN DEG. RANKIN                     FLOW
C     Z4 IS THE  Z-FACTOR IN THE TUBING UNITLESS                        FLOW
C     D4 IS THE TUBING DIAM. IN INCHES                                  FLOW
C     X4 IS THE TUBING LENGTH IN FT.                                    FLOW
C     G  IS THE GAS GRAVITY UNITLESS                                    FLOW
```

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FORTRAN IV G LEVEL  21                MAIN                DATE = 75216          14/24/53

            C       VIS4 IS THE GAS VISCOSITY IN CP.
            C       WELLS IS THE NO. OF THE WELLS UNITLESS
            C       P6 IS THE RESERVOIR PRESSURE IN PSIA
            C       T6 IS THE RESERVOIR TEMP. IN DEG. RANKIN
            C       C5 IS THE SLOPE OF OPEN FLOW CURVE IN MMCF/DAY/PSIA**2N
            C       RN IS THE CONSTANT IN RESERVOIR EQ. UNITLESS
            C       QN IS THE GAS PRODUCTION RATE IN MMCF
            C       GI IS THE GAS IN PLACE IN MMCF
            C***********************************************************************
            C***********************************************************************
 0001               DIMENSION PRES6(100),Z6(100),Q(100),DTIME(100),TTIME(100),GP(100)
                   1,QAVG(100),A(6,6),PY(6),S6(6)
 0002               COMMON/OKLA3/S6
 0003               COMMON/OKLA4/PC,TC
 0004               COMMON/OKLA9/RS,BO,VISLIQ,RHOOIL,QOO,G
 0005               COMMON/NORM1/SURFOL,DEGAPI
 0006               COMMON/NORM2/V100,V210,FRCGI,QW
 0007               COMMON/NORM4/TRES,TSURF
 0008               COMMON/NORM5/DI
 0009               COMMON/NORM6/IDEBUG
 0010               REAL*8 A
 0011               IDEBUG=10
 0012            98 READ(5,100) P1,T1,D1,X1,E1,P0,T0
 0013               IF(P1 .LT. 0.) GO TO 99
 0014               READ(5,100) HP,RK,T3,E2,Z3
 0015               READ(5,100) C3
 0016               READ(5,100) T4,Z4,D4,X4,G,VIS4,WELLS
 0017               READ(5,100) P6,RN,C5,T6
 0018           100 FORMAT(8F10.0)
 0019               READ(5,2)GI
 0020             2 FORMAT(F14.4)
 0021               READ(5,100) QN,QRAT
 0022               READ(5,600) RS,BO,VISLIQ,RHOOIL,QOO
 0023                READ(5,600)DEGAPI,V100,V210,SURFOL,FRCGI,QW
 0024               READ(5,600)TRES,TSURF
 0025          600  FORMAT(8F10.3)
 0026               WRITE (6,221)
 0027          221  FORMAT(//,45X,'------------------------------',/,45X,'F.FARSHAD 19
                   175 PH.D. RESEARCH',/,45X,'------------------------------',/)
 0028               WRITE (6,222)
 0029           222 FORMAT (///,45X,'----------------',/,46X,'THE INPUT DATA IS',/,4
                   16X,'----------------',/)
 0030               WRITE(6,310) P1,T1,D1,X1
 0031           310 FORMAT(//,5X,' P1 = ',F6.0,' PSIA ',7X,' T1 = ',F6.0,' DEG.R ',6X,
                   1' D1 = ',F5.0,' INCHES ',6X,' X1 = ',F6.0,' MILES ')
 0032               WRITE(6,315) E1,P0,T0
 0033           315 FORMAT(//,5X,' E1 = ',F6.2,' UNITLESS ',3X,' P0 = ',F8.0,' PSIA ',
                   18X,' T0 = ',F6.0,' DEG.R ')
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FORTRAN IV G LEVEL  21                 MAIN              DATE = 75216          14/24/53

0034             WRITE(6,320) HP,   S                                          FLOW 970
0035         320 FORMAT(//,5X,' H      ',F7.0,' HP ',8X,' RK = ',F8.2,' UNITLESS ',  FLOW 980
               14X,' T3 = ',F8.2,   EG,R ')                                    FLOW 990
0036             WRITE(6,325) E2,Z.                                            FLOW1000
0037         325 FORMAT(//,5X,' E2 =  ,F6.2,' UNITLESS ',3X,' Z3 = ',F6.2,' UNITLESFLOW1010
               1S ')                                                           FLOW1020
0038             WRITE(6,330) C3                                               FLOW1030
0039         330 FORMAT(//,5X,' C3 = ',F10.1,' BCF/PSI ')                      FLOW1040
0040             WRITE(6,335) T4,Z4,D4,X4                                      FLOW1050
0041         335 FORMAT(//,5X,' T4 = ',F6.0,' DEG,R ',6X,' Z4 = ',F6.2,' UNITLESS 'FLOW1060
               1,3X,' D4 = ',F6.2,' INCHES ',4X,' X4 = ',F7.0,' FEET ')        FLOW1070
0042             WRITE(6,340) G,VIS4,WELLS                                     FLOW1080
0043         340 FORMAT(//,5X,' G = ',F7.2,' UNITLESS ',3X,' VIS4 = ',F6.4,' CP ', FLOW1090
               17X,' WELLS = ',F4.0,' UNITLESS ')                              FLOW1100
0044             WRITE(6,345) P6,RN,C5,T6                                      FLOW1110
0045         345 FORMAT(//,5X,' P6 = ',F7.0,' PSIA ',2X,' RN = ',F4.2,' UNITLESS ' FLOW1120
               1,2X,' C5 = ',F10.6,'  MMCF/DAY/PSIA**2N      ',' T6 ',F6.0,' DEG')FLOW1130
0046             WRITE(6,350) QN                                               FLOW1140
0047         350 FORMAT(//,5X,' QN = ',E20.8,'MMSCF/DAY ')                     FLOW1150
0048             WRITE(6,360) GI                                               FLOW1160
0049        360  FORMAT(//,5X,' INITIAL GAS INPLACE GI = ',E15.7,/)            FLOW1170
0050             IF(IDEBUG.EQ.1)WRITE(6,610)RS,BO,VISLIQ,RHOOIL,QOO            FLOW1180
0051        610  FORMAT(//,5X,' RS=',F14.3,5X,' BO=',F14.6,5X,'LIQVIS= ',F14.6,5X, FLOW1190
               1'ROOIL =',F14.6,5X,'OILRAT=',F14.6,/)                          FLOW1200
0052             IF(IDEBUG.EQ.1)WRITE(6,600)DEGAPI,V100,V210,SURFOL,FRCGI,QW   FLOW1210
0053             D1=D4/12.                                                     FLOW1220
0054             PC=688.8-19.85*G-15.86*G*G                                    FLOW1230
0055             TC=170.0+313.6*G                                              FLOW1240
0056             WRITE (6,200) QRAT,PC,TC                                      FLOW1250
0057         200 FORMAT(5X,'QRATE=',F10.5,5X,'PC=',F10.4,5X,'TC=',F10.4)       FLOW1260
0058             CALL        ZFACO(A)                                          FLOW1270
0059             CALL        ZFAC1(ZI,P6,T6,PC,TC,PY,S6,A)                     FLOW1280
0060             QSAVE=QN                                                      FLOW1290
0061             CALL        QCALC(P1,T1,D1,X1,E1,P0,T0,HP,RK,T3,E2,Z3,C3,T4,Z4,D4,FLOW1300
               1X4,G,VIS4,WELLS,P6,RN,C5,QN,P5LS,P5RS,P5,Q1)                   FLOW1310
0062             QX=QN                                                         FLOW1320
0063             IF (QSAVE .GT. QN) GO TO 77                                   FLOW1330
0064             QO=QSAVE                                                      FLOW1340
0065             IF (QSAVE .GT. QX) GO TO 77                                   FLOW1350
0066             QN=QSAVE                                                      FLOW1360
0067             GO TO 88                                                      FLOW1370
0068          77 QO=QX                                                         FLOW1380
0069             QN=QX*QRAT                                                    FLOW1390
0070        88   QABD=0.1 *QX                                                  FLOW1400
0071             PI=P6                                                         FLOW1410
0072             CALL       ZFAC2(ZI,PI,T6,PC,TC,PY,S6)                        FLOW1420
0073             POZI=PI/ZI                                                    FLOW1430
0074             WRITE(6,1000)                                                 FLOW1440
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FORTRAN IV G LEVEL  21                    MAIN                 DATE = 75216          14/24/53

0075         1000 FORMAT(1H1)                                                          FLOW1450
0076              WRITE(6,370)PI,ZI,PUZI                                               FLOW1460
0077          370 FORMAT(5X,' RESERVOIR PRESS =',F9.2,5X,'Z=',F10.6,5X,' P/Z=',F12.2FLOW1470
                 1,/)                                                                  FLOW1480
0078              GPU=0.                                                               FLOW1490
0079              TO=0.                                                                FLOW1500
0080              GP(1)=GPU                                                            FLOW1510
0081              TTIME(1)=TO                                                          FLOW1520
0082              Q(1)=QU                                                              FLOW1530
0083              PRES6(1)=P6                                                          FLOW1540
0084              DO 16 J=2,100                                                        FLOW1550
0085              WRITE(6,380) GPO,QN                                                  FLOW1560
0086          380 FORMAT(5X,'CUM GAS PROD =',F14.2,5X,'GAS RATE=',F12.2,/)             FLOW1570
0087              CALL        RESP(P1,T1,D1,X1,E1,PO,TO,HP,RK,13,E2,Z3,C3,T4,Z4,D4,    FLOW1580
                 1X4,G,VIS4,WELLS,P6,RN,C5,QN,P5LS,P5RS,P5,Q1)                         FLOW1590
0088              PRES6(J)=P6                                                          FLOW1600
0089              CALL        ZFAC2(ZZ,P6,T6,PC,TC,PY,86)                              FLOW1610
0090              Z6(J)=ZZ                                                             FLOW1620
0091              POZ=PRES6(J)/Z6(J)                                                   FLOW1630
0092              F=1.-POZ/POZI                                                        FLOW1640
0093              GP(J)=F*GI                                                           FLOW1650
0094              WRITE(6,390)PRES6(J),Z6(J),POZ,F                                     FLOW1660
0095          390 FORMAT(5X,'RES PRESS=',F9.2,5X,'Z=',F10.4,5X,' P/Z=',F10.2,5X,       FLOW1670
                 1' F = ',E16.8,/)                                                     FLOW1680
0096              Q(J)=QN                                                              FLOW1690
0097              QAVG(J)=SQRT(QN*QU)                                                  FLOW1700
0098              DTIME(J)=(GP(J)-GPU)/(QAVG(J)*365.)                                  FLOW1710
0099              TTIME(J)=DTIME(J)+TO                                                 FLOW1720
0100              WRITE(6,400)Q(J),DTIME(J),TTIME(J)                                   FLOW1730
0101          400 FORMAT(5X,' GAS RATE =',F12.2,5X,'INCREMENTAL TIME =',F              FLOW1740
                 110.2,5X,' CUM TIME =',F10.2,/)                                       FLOW1750
0102              NSTEPS=J                                                             FLOW1760
0103              WRITE(6,201) NSTEPS,J                                                FLOW1770
0104              IF(Q(J) .LT. QABD) GO TO 17                                          FLOW1780
0105              GPU=GP(J)                                                            FLOW1790
0106              QU=QN                                                                FLOW1800
0107              TO=TTIME(J)                                                          FLOW1810
0108              QN=QN*QRAT                                                           FLOW1820
0109           16 CONTINUE                                                             FLOW1830
0110           17 DO 19 J=1,NSTEPS                                                     FLOW1840
0111              GP(J)=GP(J)/1000.                                                    FLOW1850
0112           19 CONTINUE                                                             FLOW1860
0113              WRITE(6,40)                                                          FLOW1870
0114              WRITE(6,42)  TTIME(1),GP(1),Q(1),PRES6(1)                            FLOW1880
0115              WRITE(6,41) (TTIME(J),GP(J),Q(J),PRES6(J),QAVG(J),J=2,NSTEPS)        FLOW1890
0116              ILIM=TTIME(NSTEPS)                                                   FLOW1900
0117              TLIM=ILIM                                                            FLOW1910
0118              DTPRIN=1.                                                            FLOW1920
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FORTRAN IV G LEVEL  21                MAIN              DATE = 75216        14/24/53

0119            TIME=0.                                                           FLOW1930
0120            P6O=PRE36(1)                                                      FLOW1940
0121            QPU=Q(1)                                                          FLOW1950
0122            GPU=0.                                                            FLOW1960
0123            WRITE(6,43)                                                       FLOW1970
0124            WRITE(6,42) TIME,GPO,QPU,P6O                                      FLOW1980
0125            ISTART=2                                                          FLOW1990
0126        117 TIME=TIME+DTPRIN                                                  FLOW2000
0127            NSTART=ISTART                                                     FLOW2010
0128            DO 116 I=NSTART,NSTEPS                                            FLOW2020
0129            IF(TIME .GT. TTIME(I)) GO TO 116                                  FLOW2030
0130            GPN=(GP(I)-GP(I-1))/(TTIME(I)-TTIME(I-1))*(TIME-TTIME(I-1))       FLOW2040
               1+GP(I-1)                                                          FLOW2050
0131            QAVGN=(GPN-GPO)/(DTPRIN*0.365)                                    FLOW2060
0132            F=(GPN*1000.)/GI                                                  FLOW2070
0133            POZ=(1.0-F)*POZI                                                  FLOW2080
0134            CALL       SOLZ(POZ,ZZ,P6N,T6,PC,TC,PY,S6,A)                      FLOW2090
0135            QPN=QAVGN*QAVGN/QPU                                               FLOW2100
0136            WRITE(6,41) TIME,GPN,QPN,P6N,QAVGN                                FLOW2110
0137            GPO=GPN                                                           FLOW2120
0138            QPU=QPN                                                           FLOW2130
0139            ISTART=I                                                          FLOW2140
0140            IF(TIME .GE. TLIM) GO TO 97                                       FLOW2150
0141            GO TO 117                                                         FLOW2160
0142        116 CONTINUE                                                          FLOW2170
0143         97 CONTINUE                                                          FLOW2180
0144            TSAVE=TIME                                                        FLOW2190
0145            I=NSTEPS                                                          FLOW2200
0146            TIME=TTIME(I-1)+(TTIME(I)-TTIME(I-1))/ALOG10(Q(I)/Q(I-1))*ALOG10  FLOW2210
               1(QABD/Q(I-1))                                                     FLOW2220
0147            GPN=(GP(I)-GP(I-1))/(TTIME(I)-TTIME(I-1))*(TIME-TTIME(I-1))       FLOW2230
               1+GP(I-1)                                                          FLOW2240
0148            QAVGN=(GPN-GPO)/((TIME-TSAVE)*0.365)                              FLOW2250
0149            F=(GPN*1000)/GI                                                   FLOW2260
0150            POZ=(1.0-F)*POZI                                                  FLOW2270
0151            CALL       SOLZ(POZ,ZZ,P6N,T6,PC,TC,PY,S6,A)                      FLOW2280
0152            QPN=QABD                                                          FLOW2290
0153            WRITE(6,41) TIME,GPN,QPN,P6N,QAVGN                                FLOW2300
0154            GO TO 98                                                          FLOW2310
0155         40 FORMAT(1H1,11X,16HCUMULATIVE  TIME,5X,14HCUMULATIVE GAS,6X,14HDELIFLOW2320
               1VERY  RATE,4X,18HAVERAGE  RESERVOIR,2X,21HAVERAGE DELIVERY RATE/  FLOW2330
               216X,8HIN YEARS,7X,18HPRODUCTION  IN BCF ,5X,12HIN  MMCF/DAY,5X,18HFLOW2340
               3PRESSURE  IN PSIA,,6X,12HIN  MMCF/DAY///)                         FLOW2350
0156         41 FORMAT(7X,5F20.4)                                                 FLOW2360
0157         42 FORMAT(7X,4F20.4)                                                 FLOW2370
0158         43 FORMAT(////12X,16HCUMULATIVE  TIME,5X,14HCUMULATIVE GAS,6X,14HDELIFLOW2380
               1VERY  RATE,4X,18HAVERAGE  RESERVOIR,2X,21HAVERAGE DELIVERY RATE/  FLOW2390
               216X,8HIN YEARS,7X,18HPRODUCTION  IN BCF ,5X,12HIN  MMCF/DAY,5X,18HFLOW2400
               3PRESSURE  IN PSIA,,6X,12HIN  MMCF/DAY///)                         FLOW2410
0159        201 FORMAT(2I10)                                                      FLOW2420
0160         99 STOP                                                              FLOW2430
0161            END                                                               FLOW2440
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FORTRAN IV G LEVEL  21                 QCALC              DATE = 75216         14/24/53

0001              SUBROUTINE  QCALC(P1,T1,D1,X1,E1,P0,T0,HP,RK,T3,E2,Z3,C3,T4,Z4,D4,FLOW2450
                 1X4,G,VIS4,WELLS,P6,RN,C5,QN,P5LS,P5RS,P5,Q1)                    FLOW2460
0002              COMMON/OKLA1/L,QGG                                              FLOW2470
0003              COMMON/OKLA8/K                                                  FLOW2480
0004              K=0                                                             FLOW2490
0005              L=0                                                             FLOW2500
0006              ITNO=0                                                          FLOW2510
0007              QO=0.                                                           FLOW2520
0008              DPO=P6                                                          FLOW2530
0009           50 ITNO=ITNO+1                                                     FLOW2540
0010              CALL        BHP(P1,T1,D1,X1,E1,P0,T0,HP,RK,T3,E2,Z3,C3,T4,Z4,D4, FLOW2550
                 1X4,G,VIS4,WELLS,P6,RN,C5,QN,P5LS,P5RS,P5,Q1)                    FLOW2560
0011              SAM=(P6*P6-(Q1/(C5*1.E6))**(1./RN))                             FLOW2570
0012              IF(SAM.LE.0.) GO TO 500                                         FLOW2580
0013              P5RS=SQRT(P6*P6-(Q1/(C5*1.E6))**(1./RN))                        FLOW2590
0014              GO TO 400                                                       FLOW2600
0015         500  SAM=ABS(SAM)                                                    FLOW2610
0016              P5RS=SQRT(SAM)                                                  FLOW2620
0017          400 CONTINUE                                                        FLOW2630
0018              WRITE(6,201) ITNO                                               FLOW2640
0019              WRITE(6,202) QN,P5LS,P5RS                                       FLOW2650
0020              IF (ITNO .GT. 40.) GO TO 75                                     FLOW2660
0021              DPN=P5RS-P5LS                                                   FLOW2670
0022              IF (ABS(DPN)-1.0) 99,80,80                                      FLOW2680
0023           80 QSTAR=QO+DPO*(QN-QO)/(DPO-DPN)                                  FLOW2690
0024              QO=QN                                                           FLOW2700
0025              QN=ABS(QSTAR)                                                   FLOW2710
0026              DPO=DPN                                                         FLOW2720
0027              GO TO 50                                                        FLOW2730
0028           75 WRITE (6,204)                                                   FLOW2740
0029          201 FORMAT(5X,24HTHE SOLUTION AFTER TRIAL,I5,16H   IS AS FOLLOWS//)  FLOW2750
0030          202 FORMAT(5X,20HTHE GAS FLOW RATE IS,F10.3,12H   MMSCF/DAY//5X,40HTHEFLOW2760
                1 BHP CALCULATED FROM THE LINE SIDE IS,F14.3,8H   PSIA.//5X,40HTHE FLOW2770
                2BHP CALCULATED FROM THE RES. SIDE IS,F14.3,8H   PSIA.////)       FLOW2780
0031          204 FORMAT (5X,29HTEN ITERATIONS HAVE BEEN MADE)                    FLOW2790
0032           99 RETURN                                                          FLOW2800
0033              END                                                             FLOW2810
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FORTRAN IV G LEVEL  21                 BHP                    DATE = 75216          14/24/53

0001              SUBROUTINE  BHP(P1,T1,D1,X1,E1,P0,T0,HP,RK,T3,E2,Z3,C3,T4,Z4,D4,   FLOW2820
                 1X4,G,VIS4,WELLS,P6,RN,C5,QN,P5LS,P5RS,P5,Q1)                        FLOW2830
0002              COMMON/OKLA1/L,QGG                                                  FLOW2840
0003              COMMON/OKLA8/K                                                      FLOW2850
0004              Q=QN*1.E6                                                           FLOW2860
0005              C1=435.87*E1*(T0/P0)**1.07881                                       FLOW2870
0006              VICON4=0.000672*VIS4                                                FLOW2880
0007              IF(X1.LE.0.0.OR.D1.LE.0.0) GO TO 180                                FLOW2890
0008              Y1=(X1*T1)**(-0.5394)*G**(-0.4606)*D1**2.6182                       FLOW2900
0009              GO TO 190                                                           FLOW2910
0010          180 Y1=0.                                                               FLOW2920
0011          190  CONTINUE                                                           FLOW2930
0012              IF(Y1.LE.0.) GO TO 140                                              FLOW2940
0013              IF(C1.LE.0.) GO TO 140                                              FLOW2950
0014              Y2=Q/(C1*Y1)                                                        FLOW2960
0015              GO TO 150                                                           FLOW2970
0016          140  Y2=0.                                                              FLOW2980
0017          150 CONTINUE                                                            FLOW2990
0018              P2=SQRT(P1*P1+Y2**1.854)                                            FLOW3000
0019              WRITE (6,202)                                                       FLOW3010
0020          202 FORMAT(1H1)                                                         FLOW3020
0021              WRITE(6,310)P1,P2                                                   FLOW3030
0022          310 FORMAT(//,4X,'DELIVERY PRESS  P1 =',F10.2,4X,'DISCHARGE PRESS   P2 FLOW3040
                 1 =',F10.2,/)                                                        FLOW3050
0023              RKRAT=RK/(RK-1.)                                                    FLOW3060
0024              IF(RKRAT.LE.0.) GO TO 110                                           FLOW3070
0025              Y3=HP/(0.08531E-6*RKRAT*Q*T3)+1.                                    FLOW3080
0026              IF(Y3.LE.0.) GO TO 110                                              FLOW3090
0027              P3=P2/Y3**(RKRAT/Z3)                                                FLOW3100
0028              GO TO 130                                                           FLOW3110
0029          110  P3=P2+3                                                            FLOW3120
0030          130  CONTINUE                                                           FLOW3130
0031              WRITE(6,320)P3                                                      FLOW3140
0032          320  FORMAT(///,5X,'SUCTION PRESS  P3=',F10.2,/)                        FLOW3150
0033              IF(C3.LE.0.) GO TO 160                                              FLOW3160
0034              P4=SQRT(P3*P3+(Q/C3)**2)                                            FLOW3170
0035              CALL        MUFFIM(P3,T1,D1,X1,E1,P0,T0,Q,VICON4,P4)                FLOW3180
0036              GO TO 170                                                           FLOW3190
0037          160  P4=P3+3                                                            FLOW3200
0038          170  CONTINUE                                                           FLOW3210
0039              WRITE(6,330) P4                                                     FLOW3220
0040          330  FORMAT(//,5X,' THE WELL HEAD PRESS  P4=',F10.2,/)                  FLOW3230
0041              S=0.0375*G*X4/(T4*Z4)                                               FLOW3240
0042              Y4=S/(EXP(S)-1.)                                                    FLOW3250
0043              Q1=Q/WELLS                                                          FLOW3260
0044              F=0.0309*(Q1*G/(VICON4*1.E6))**(-0.065)                             FLOW3270
0045              WRITE(6,340)Q1                                                      FLOW3280
0046          340  FORMAT(//,5X,' GAS RATE Q1=',E15.6,/)                              FLOW3290
0047              F=F*(D4/12.)**(-0.058)                                              FLOW3300
0048              Y5=D4**5/(G*Z4*T4*F*X4)                                             FLOW3310
0049              Y6=(Q1/2.E5)**2/(Y4*Y5)                                             FLOW3320
0050              P5LS=SQRT(P4*P4*EXP(S)+Y6)                                          FLOW3330
0051              SGG=G                                                               FLOW3340
0052              QGG=Q1/1.E6                                                         FLOW3350
0053              CALL        MUFF(P6,P4,T6,T0,X4,SGG,QGG,P5LS)                       FLOW3360
0054              WRITE(6,6000)P5LS                                                   FLOW3370
0055         6000 FORMAT(//,5X,'P5LS=',F14.3,//)                                      FLOW3380
0056              L=L+1                                                               FLOW3390
0057              RETURN                                                              FLOW3400
0058              END                                                                 FLOW3410
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FORTRAN IV G LEVEL  21                    RESP                DATE = 75216          14/24/55

0001              SUBROUTINE RESP(P1,T1,D1,X1,E1,P0,T0,HP,RK,T3,E2,Z3,C3,T4,Z4,D4,   FLOW3420
                 1X4,G,VIS4,WELLS,P6,RN,C5,QN,PSL8,PSRS,PS,Q1)                       FLOW3430
0002              COMMON/OKLA1/L,QGG                                                 FLOW3440
0003              Q=QN*1.E6                                                          FLOW3450
0004              C1=435.87*E1*(T0/P0)**1.07881                                      FLOW3460
0005              VICON4=0.000672*VIS4                                               FLOW3470
0006              IF(X1.LE.0..OR.D1.LE.0.) GO TO 10                                  FLOW3480
0007              Y1=(X1*T1)**(-0.5394)*G**(-0.4606)*D1**2.6182                      FLOW3490
0008              GO TO 20                                                           FLOW3500
0009           10 Y1=0.                                                              FLOW3510
0010           20 CONTINUE                                                           FLOW3520
0011              IF(Y1.LE.0.) GO TO 30                                              FLOW3530
0012              IF(C1.LE.0.) GO TO 30                                              FLOW3540
0013              Y2=Q/(C1*Y1)                                                       FLOW3550
0014              GO TO 40                                                           FLOW3560
0015           30 Y2=0.                                                              FLOW3570
0016           40 CONTINUE                                                           FLOW3580
0017              P2=SQRT(P1*P1+Y2**1.854)                                           FLOW3590
0018              WRITE(6,50)P1,P2                                                   FLOW3600
0019           50 FORMAT(//,5X,'DELIVERY PRESS P1=',F10.2,5X,'DISCHARGE PRES P2='    FLOW3610
                 1,F10.2,/)                                                          FLOW3620
0020              RKRAT=RK/(RK-1.)                                                   FLOW3630
0021              IF(RKRAT.LE.0) GO TO 60                                            FLOW3640
0022              Y3=HP/(0.08531E-6*RKRAT*Q*T3)+1.                                   FLOW3650
0023              IF(Y3.LE.0.) GO TO 60                                              FLOW3660
0024              P3=P2/Y3**(RKRAT/Z3)                                               FLOW3670
0025              GO TO 70                                                           FLOW3680
0026           60 P3=P2+3.                                                           FLOW3690
0027           70 CONTINUE                                                           FLOW3700
0028              WRITE(6,80)P3                                                      FLOW3710
0029           80 FORMAT(5X,'SUCTION PRES P3=',F10.2,/)                              FLOW3720
0030              IF(C3.LE.0.) GO TO 90                                              FLOW3730
0031              P4=SQRT(P3*P3+(Q/C3)**2)                                           FLOW3740
0032              CALL       MUFFIH(P3,T1,D1,X1,E1,P0,T0,Q,VICON4,P4)                FLOW3750
0033              GO TO 100                                                          FLOW3760
0034           90 P4=P3+3.                                                           FLOW3770
0035          100 CONTINUE                                                           FLOW3780
0036              WRITE(6,110)P4                                                     FLOW3790
0037          110 FORMAT(5X,' WELL HEAD PRES P4=',F10.2,/)                           FLOW3800
0038              S=0.0375*G*X4/(T4*Z4)                                              FLOW3810
0039              Y4=S/(EXP(S)-1.)                                                   FLOW3820
0040              Q1=Q/WELLS                                                         FLOW3830
0041              WRITE(6,120)Q1                                                     FLOW3840
0042          120 FORMAT(5X,'GAS RATE Q1= ',E15.7,/)                                 FLOW3850
0043              F=0.03096(Q1*G/(VICON4*1.E6))**(-0.065)                            FLOW3860
0044              F=F*(D4/12.)**(-0.058)                                             FLOW3870
0045              Y5=D4**5/(G*Z4*T4*F*X4)                                            FLOW3880
0046              Y6=(Q1/2.E5)**2/(Y4*Y5)                                            FLOW3890
0047              PSLS=SQRT(P4*P4*EXP(S)+Y6)                                         FLOW3900
0048              SGG=G                                                              FLOW3910
0049              QGG=Q1/1.E6                                                        FLOW3920
0050              CALL       MUFF(P6,P4,T6,T0,X4,SGG,QGG,PSLS)                       FLOW3930
0051              WRITE(6,6000)PSLS                                                  FLOW3940
0052         6000 FORMAT(//,5X,'PSLS=',F14.3,//)                                     FLOW3950
0053              P6=SQRT(PSLS*PSLS+(Q1/(C5*1.E6))**(1./RN))                         FLOW3960
0054              WRITE(6,130)PSL8,P6                                                FLOW3970
0055          130 FORMAT(5X,'FLOWING BHP PSL8=',F10.2,5X,'RES PRES P6=',F10.2,/)     FLOW3980
0056              L=L+1                                                              FLOW3990
0057              RETURN                                                             FLOW4000
0058              END                                                                FLOW4010
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FORTRAN IV G LEVEL  21                 MUFFIM              DATE = 75216          14/24/53

          SUBROUTINE MUFFIM(P3,T1,D1,X1,E1,P0,T0,QN,V184,P4)            FLOW4020
          DIMENSION X(20),Y(20)                                          FLOW4030
          DIMENSION S6(6)                                                FLOW4040
          COMMON/OKLA3/S6                                                FLOW4050
          COMMON/OKLA4/PC,TC                                             FLOW4060
          COMMON/OKLA8/K                                                 FLOW4070
          COMMON/OKLA9/RS,BO,VISLIQ,RHOOIL,QOO,G                         FLOW4080
          COMMON/NORM1/SURFOL,DEGAPI                                     FLOW4090
          CALL  ZFAC2(Z,P3,T1,PC,TC,PY,S6)                               FLOW4100
          IF(K.GT.0) GO TO 700                                           FLOW4110
          READ(5,601)M                                                   FLOW4120
      601 FORMAT(I3)                                                     FLOW4130
          DO 602 I=1,M                                                   FLOW4140
          READ(5,20) X(I),Y(I)                                           FLOW4150
       20 FORMAT(2F14.5)                                                 FLOW4160
      602 CONTINUE                                                       FLOW4170
          DO 30 I=1,M                                                    FLOW4180
          X(I)=ALOG(X(I))                                                FLOW4190
          Y(I)=ALOG(Y(I))                                                FLOW4200
       30 CONTINUE                                                       FLOW4210
      700 CONTINUE                                                       FLOW4220
          BG=0.0283*Z*T1/P3                                              FLOW4230
          RHOGAS=2.70*P3*G/(Z*T1)                                        FLOW4240
          X4=X1                                                          FLOW4250
          API=DEGAPI                                                     FLOW4260
          E=0.0006                                                       FLOW4270
          PHI=3.1414                                                     FLOW4280
          VISGAS=V184                                                    FLOW4290
          DIA =D1/12.                                                    FLOW4300
          GAMAG=G                                                        FLOW4310
          SURTO=SURFOL                                                   FLOW4320
          QGA=QN/1.E6                                                    FLOW4330
          RP=QGA/QOO                                                     FLOW4340
          RP=RP*1.E6                                                     FLOW4350
          QO=QOO*BO*5.164/86400.                                         FLOW4360
          QGA=QOO*(RP-RS)*BG/86400.                                      FLOW4370
          GAMAO=141.5/(131.5+API)                                        FLOW4380
          AREA=PHI*DIA **2./4.                                           FLOW4390
          VSL=QO/AREA                                                    FLOW4400
          VG=QGA/AREA                                                    FLOW4410
          VM=VSL+VG                                                      FLOW4420
          ALAML=VSL/VM                                                   FLOW4430
          VISCN=VISLIQ*ALAML+VISGAS*(1-ALAML:                            FLOW4440
          RHON=RHOOIL*ALAML+RHOGAS*(1-ALAML)                             FLOW4450
          WO=QO*RHOOIL                                                   FLOW4460
          WG=RHOGAS*QGA                                                  FLOW4470
          WM=WO+WG                                                       FLOW4480
          XA=0.057*SQRT(WG*WM)/(VISGAS*DIA **2.25)                       FLOW4490
          XA=ALOG(XA)                                                    FLOW4500
          CALL PINT(XA,YA,X,Y,M)                                         FLOW4510
          URD=EXP(YA)                                                    FLOW4520
          FF=URD/(WO/WM)**0.1                                            FLOW4530
          DPDX=FF**M**2/(64.35*DIA *AREA**2*RHON)                        FLOW4540
          DPDX=DPDX/144.                                                 FLOW4550
          P2=DPDX*X4                                                     FLOW4560
          P4=P2+P3                                                       FLOW4570
          K=K+1                                                          FLOW4580
          RETURN                                                         FLOW4590
          END                                                            FLOW4600
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FORTRAN IV G LEVEL  21                 MUFF                DATE = 75215          14/24/53

0001            SUBROUTINE MUFF(P6,PS,TK,TY,TOTALD,GGAS,QG,PSLS)                     FLOW4610
0002            DIMENSION AD(120),PD(120),DA(120),DH(120),TBAR(120)                  FLOW4620
               1,TH(120),PR(120),A(6,6),PY(6),B6(6)                                  FLOW4630
0003            COMMON/OKLA1/L,XXXX                                                  FLOW4640
0004            COMMON/OKLA3/S6                                                      FLOW4650
0005            COMMON/NORM1/SURFOL,DEGAPI                                           FLOW4660
0006            COMMON/NORM2/V100,V210,FRCGI,QW                                      FLOW4670
0007            COMMON/NORM4/TRES,TSURF                                              FLOW4680
0008            COMMON/NORM5/DI                                                      FLOW4690
0009            COMMON/NORM6/IDEBUG                                                  FLOW4700
0010            REAL*8 A                                                             FLOW4710
0011            IF(L.GT.0) GO TO 2221                                                FLOW4720
0012            READ(5,31)PFNL,FFNL,PPK,FPK,PINT,FINT,FPR,PPR,QOP,QGP                FLOW4730
0013            IF(IDEBUG.GT.1) GO TO 2221                                           FLOW4740
0014             WRITE(6,35)PFNL,FFNL,PPK,FPK,PINT,FINT,FPR,PPR,QOP,QGP              FLOW4750
0015       31   FORMAT(10F8.3)                                                       FLOW4760
0016       35   FORMAT(10F12.3)                                                      FLOW4770
0017            WRITE(6,500)TRES,TSURF     ,TOTALD,DI,GGAS                           FLOW4780
0018            WRITE(6,500)QG,SURFOL,DEGAPI                                         FLOW4790
0019            WRITE(6,500)V100,V210,FRCGI,QW                                       FLOW4800
0020      500   FORMAT(6F14.4)                                                       FLOW4810
0021            WRITE(6,2500)PS                                                      FLOW4820
0022     2500   FORMAT(5X,'SURFACE PRESSURE=',F14.3,//)                              FLOW4830
0023     2221   CONTINUE                                                             FLOW4840
0024            CALL OILRAT(P6,PFNL,FFNL,PPK,FPK,PINT,FINT,FPR,PPR,QOP,QGP,QL)       FLOW4850
0025            QO=QL                                                                FLOW4860
0026            WRITE(6,29)QO                                                        FLOW4870
0027       29    FORMAT(5X,'QO=',F10.3,5X,'BBLS/DAY',//)                             FLOW4880
0028            L1=0                                                                 FLOW4890
0029            L=1                                                                  FLOW4900
0030            TB=TRES                                                              FLOW4910
0031            TS=TSURF                                                             FLOW4920
0032            QG=QG*1.E06                                                          FLOW4930
0033            GOIL=141.5/(DEGAPI+131.5)                                            FLOW4940
0034            GOR=QG/QO                                                            FLOW4950
0035            QG=QG/86000.                                                         FLOW4960
0036            GOR=GOR*10.E6                                                        FLOW4970
0037            BRUM=DI                                                              FLOW4980
0038            BRUM=BRUM*12.                                                        FLOW4990
0039            EOD=.0006/BRUM                                                       FLOW5000
0040            AREAUT=(3.141592/4)*DI**2.                                           FLOW5010
0041            TBAR(1)=TS                                                           FLOW5020
0042            GRAD=(TB-TS)/TOTALD                                                  FLOW5030
0043            X=10.0**(.0125*DEGAPI)                                               FLOW5040
0044            Y=10.0**(.00091*TBAR(1))                                             FLOW5050
0045            XX=X/Y                                                               FLOW5060
0046            COEFF=1.0                                                            FLOW5070
0047            RSULB=COEFF*GGAS*((PS/18.)*XX)**(1./.83)                             FLOW5080
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FORTRAN IV G LEVEL 21 MUFF DATE = 75216 14/24/53

```
      PH=30000.                                                         FLOW5090
      GWTR=1.0                                                          FLOW5100
      SURW=72.                                                          FLOW5110
      WOR=1.                                                            FLOW5120
      CALL ZFAC0(A)                                                     FLOW5130
      CALL OHLVIS(TBAR(1),RSOLB,V100,V210,OVIS)                         FLOW5140
      DA(1)=0.0                                                         FLOW5150
      DH(1)=0.0                                                         FLOW5160
      DP=TOTALD*.005                                                    FLOW5170
      PD(1)=PS                                                          FLOW5180
      DD=30.                                                            FLOW5190
      AD(1)=PS                                                          FLOW5200
      K1=0                                                              FLOW5210
      K=0                                                               FLOW5220
      DEL=DD/2.                                                         FLOW5230
      DO 3 J=2,60                                                       FLOW5240
      PDU=PD(J-1)+DP/2.                                                 FLOW5250
      DH(J)=DD                                                          FLOW5260
  100 CONTINUE                                                          FLOW5270
      PD(J)=AD(J-1)+DP/2.                                               FLOW5280
      TBAR(J)=DEL*GRAD+TS                                               FLOW5290
      TC=170.+313.6*GGAS                                                FLOW5300
      PC=688.8-19.85*GGAS-15.86*GGAS*GGAS                               FLOW5310
      TABAR=TBAR(J)+460.                                                FLOW5320
      CALL ZFAC1(Z1,PD(J),TABAR    ,PC,TC,PY,S6,A)                      FLOW5330
      CALL ZFAC2(Z,PD(J),TABAR    ,PC,TC,PY,S6)                         FLOW5340
      X1=10.**(.0125*DEGAPI)                                            FLOW5350
      Y1=10.**(.00091*TBAR(J))                                          FLOW5360
      X2=X1/Y1                                                          FLOW5370
      RSOL=COEFF*GGAS*((PDU/18.)*X1)**(1./.83)                          FLOW5380
      IF(GOR-RSOL)6,6,7                                                 FLOW5390
    6 GOR=RSOL                                                          FLOW5400
    7 CONTINUE                                                          FLOW5410
      FACTOR=1.25*TBAR(J)+RSOL*(GGAS/GOIL)**.5                          FLOW5420
      IF(FACTOR.LE.0.)GO TO 110                                         FLOW5430
      BO=.000147*FACTOR**1.175+0.972                                    FLOW5440
      GO TO 111                                                         FLOW5450
  110 BO=.972                                                           FLOW5460
  111 CONTINUE                                                          FLOW5470
      CALL OHLVIS(TBAR(J),RSOL ,V100,V210,OVIS)                         FLOW5480
      QL=6.49E-5*QO*BO                                                  FLOW5490
      QG=3.27E-7*QO*(GOR-RSOL)*(TBAR(J)+460.)/PD(J)                     FLOW5500
      QTOT=QL+QG                                                        FLOW5510
      WL=QO*(4.05E-3*GOIL+8.85E-7*GGAS*RSOL)                            FLOW5520
      WG=8.85E-7*QO*GGAS*(GOR-RSOL)                                     FLOW5530
      WTOT=WL+WG                                                        FLOW5540
      ROOIL=WL/QL                                                       FLOW5550
      IF(QG)8,8,9                                                       FLOW5560
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 FORTRAN IV G LEVEL  21                  MUFF                DATE = 75216          14/24/53

0096          8     RDG=0.                                                           FLOW5570
0097                GO TO 10                                                         FLOW5580
0098          9     ROG=WG/QG                                                        FLOW5590
0099         10     CONTINUE                                                         FLOW5600
0100                VTOT=QTOT/AREAOT                                                 FLOW5610
0101                XLIMB=1.071-(0.2218*(VTOT**2.)/DI)                               FLOW5620
0102                IF(XLIMB-0.13)11,11,12                                           FLOW5630
0103         11     XLIMB=0.13                                                       FLOW5640
0104                GO TO 12                                                         FLOW5650
0105         12     CONTINUE                                                         FLOW5660
0106                CALL SURFAC(SURFOL,PD(J),SURTEN)                                 FLOW5670
0107                VG=QG*(ROOIL/32.174*SURTEN)**0.25/AREAOT                         FLOW5680
            C       CHECK FOR DETERMINATION OF FLOW REGIME                           FLOW5690
            C       THE FLOW REGIME MAY BE DETERMINED BY TESTING WHETHER THE         FLOW5700
            C       VARIABLES QG/QT OR VG OR BOTH FALL WITHIN THE LIMITS PRESCRIBED BEFLOW5710
            C************************************************************************FLOW5720
            C                                                                        FLOW5730
            C           LIMITS                    FLOW REGIME                        FLOW5740
            C                                                                        FLOW5750
            C         QG/QT < (L)B               BUBBLE                              FLOW5760
            C         QG/QT>(L)B,VG<(L)S         SLUG                                FLOW5770
            C         (L)M>VG>(L)S               TRANSITION                          FLOW5780
            C         VG>(L)M                    MIST                                FLOW5790
0108                IF(VG)13,13,14                                                   FLOW5800
0109         13     XLIMS=50.                                                        FLOW5810
0110                XLIMM=75.                                                        FLOW5820
0111                GO TO 15                                                         FLOW5830
0112         14     XLIMS=50.+36.*VG*QL/QG                                           FLOW5840
0113                XLIMM=75.+84.*(VG*QL/QG)**0.75                                   FLOW5850
0114         15     IF(VG)16,16,17                                                   FLOW5860
0115         17     QBUND=QG/QTOT                                                    FLOW5870
0116                GO TO 18                                                         FLOW5880
0117         16     QBUND=0.                                                         FLOW5890
0118         18     CONTINUE                                                         FLOW5900
0119                IF(XLIMB-QBUND)19,19,20                                          FLOW5910
0120         19      IF(XLIMS-VG)21,21,22                                            FLOW5920
0121         21     IF(XLIMM-VG)23,23,24                                             FLOW5930
            C       FLOW REGIME IS BUBBLE  (L)B>QG/QT                                FLOW5940
0122         20     REGIME=1.                                                        FLOW5950
0123                EG=(1.+QTOT/(0.8*AREAOT)-((1.+QTOT/(.8*AREAOT))**2-4.*QG/(.8*    FLOW5960
                   1AREAOT)))/2.                                                     FLOW5970
0124                ROBAR=(1.-EG)*ROOIL+EG*ROG                                       FLOW5980
0125                VLIQ=QL/(AREAOT*(1.-EG))                                         FLOW5990
0126                REYNOL=1488.*VLIQ*DI*ROOIL/OVIS                                  FLOW6000
0127                CALL FRIFAC(REYNOL,EOD,FRCGI,FF)                                 FLOW6010
0128                FRICLG=FF*ROOIL*VLIQ**2./(64.4*DI)                               FLOW6020
0129                GO TO 50                                                         FLOW6030
0130         22     REGIME=2.                                                        FLOW6040
```

```
                C     FLOW REGIME IS SLUG (L)B<QG/OT & (L)S>VG                                  FLOW6050
0131            85    VBAT1=1.75                                                                FLOW6060
0132                  REYNOL=1488.*VTOT*DI*RODIL/UVIS                                           FLOW6070
0133                  KK1=0.0                                                                   FLOW6080
0134            59    KK1=KK1+1.                                                                FLOW6090
0135                  IF(KK1-3.)51,51,52                                                        FLOW6100
0136            51    REYNOB=1488.*VBAT1*RODIL*DI/UVIS                                          FLOW6110
0137                  IF(REYNOB-3000.)53,53,54                                                  FLOW6120
0138            54    IF(REYNOB-8000.)55,55,56                                                  FLOW6130
0139            53    VBAT=(0.546+8.74E-6*REYNOL)*(32.2*DI)**.5                                 FLOW6140
0140                  DELT=VBAT-VBAT1                                                           FLOW6150
0141                  IF(ABS(DELT)-0.1)57,57,58                                                 FLOW6160
0142            57    GO TO 52                                                                  FLOW6170
0143            58    VBAT1=VBAT                                                                FLOW6180
0144                  GO TO 59                                                                  FLOW6190
0145            55    ALPH=(0.251+8.74E-6*REYNOL)*(32.2*DI)**.5                                 FLOW6200
0146                  VBAT=ALPH/2.+(ALPH**2.+15.59*UVIS/(RODIL*DI**.5))**.5                     FLOW6210
0147                  DELT=VBAT-VBAT1                                                           FLOW6220
0148                  IF(ABS(DELT)-0.1)60,60,61                                                 FLOW6230
0149            60    GO TO 52                                                                  FLOW6240
0150            61    VBAT1=VBAT                                                                FLOW6250
0151                  GO TO 59                                                                  FLOW6260
0152            56    VBAT=(0.35+8.74E-6*REYNOL)*(32.2*DI)**.5                                  FLOW6270
0153                  DELT=VBAT-VBAT1                                                           FLOW6280
0154                  IF(ABS(DELT)-.1)62,62,63                                                  FLOW6290
0155            62    GO TO 52                                                                  FLOW6300
0156            63    VBAT1=VBAT                                                                FLOW6310
0157                  GO TO 59                                                                  FLOW6320
0158            52    IF(VTOT-10.)70,70,71                                                      FLOW6330
0159            70    CONS1=UVIS+1.                                                             FLOW6340
0160                  DELTA=0.0127*ALOG10(CONS1)/(DI **1.415)                                   FLOW6350
                     1-.284+.167*ALOG10(VTOT)+0.113*ALOG10(DI)                                  FLOW6360
0161                  GO TO 72                                                                  FLOW6370
0162            71    CONS2=UVIS+1.                                                             FLOW6380
0163                  DELTA=0.0274*ALOG10(CONS2)/(DI**1.371)+.161+0.569*ALOG10(DI)              FLOW6390
                     1-ALOG10(VTOT)*((.01*ALOG(CONS2)/(DI**1.571))+.397+.63*ALOG10(DI))         FLOW6400
0164                  GO TO 73                                                                  FLOW6410
0165            72    GAMA=-0.065*VTOT                                                          FLOW6420
0166                  IF(DELTA-GAMA)74,74,75                                                    FLOW6430
0167            74    DELTA=GAMA                                                                FLOW6440
0168                  GO TO 78                                                                  FLOW6450
0169            75    GO TO 78                                                                  FLOW6460
0170            73    ROBAR=(WTOT+RODIL*VBAT*AREAOT)/(QTOT+VBAT*AREAOT)+DELTA*RODIL             FLOW6470
0171                  GAMA=+(VBAT)/(VBAT+VTOT)*(1.-ROBAR/RODIL)                                 FLOW6480
0172                  IF(DELTA-GAMA)79,79,78                                                    FLOW6490
0173            79    DELTA=GAMA                                                                FLOW6500
0174            78    CONTINUE                                                                  FLOW6510
0175                  ROBAR=(WTOT+RODIL*VBAT*AREAOT)/(QTOT+VBAT*AREAOT)+DELTA*RODIL             FLOW6520
```

```
0176           CALL FRIFAC(REYNOL,EOD,FRCGI,FF)                                  FLOW6530
0177           FRICLG=FF*ROOIL*(VTOT**2.)/(64.4*DI)*((QL  +VBAT*AREAOT)/         FLOW6540
              1(QTOT+VBAT*AREAOT)-DELTA)                                         FLOW6550
0178           GO TO 50                                                          FLOW6560
0179      23   REGIME=3.                                                         FLOW6570
          C    REGIME IS MIST FLOW  VG>(L)M                                      FLOW6580
0180           EG=1./(1.+QL  /QG)                                                FLOW6590
0181           CALL GASVIS(PC,TC,TABAR   ,AD(L),GGAS,GVIS)                       FLOW6600
0182           GASVEL=QG/AREAOT                                                  FLOW6610
0183           REYNOL=1488.*ROG*DI*GASVEL/GVIS                                   FLOW6620
0184           YN=4.52E-07*(GASVEL*GVIS/Z)**2.*ROG/ROOIL                         FLOW6630
0185           IF(EOD-0.001)80,80,81                                             FLOW6640
0186      80   EOD=174.8*SURTEN*(YN**.302)/(ROG*GASVEL**2.*DI)                   FLOW6650
0187           GO TO 84                                                          FLOW6660
0188      81   IF(EOD-0.5)82,82,83                                               FLOW6670
0189      83   EOD=174.8*SURTEN*(YN**.302)/(ROG*GASVEL**2.*DI)                   FLOW6680
0190           GO TO 84                                                          FLOW6690
0191      82   EOD=34.*SURTEN/(ROG*GASVEL**2.*DI)                                FLOW6700
0192      84   CONTINUE                                                          FLOW6710
0193           CALL FRIFAC(REYNOL,EOD,FRCGI,FF)                                  FLOW6720
0194           FRICLG=FF*ROG*GASVEL**2./(2.*32.174*DI)                           FLOW6730
0195           ROBAR=(1.-EG)*ROOIL+EG*ROG                                        FLOW6740
0196           GO TO 50                                                          FLOW6750
0197      24   REGIME=4.                                                         FLOW6760
          C    REGIME IS TRANSITION FLOW                                         FLOW6770
0198           GO TO 85                                                          FLOW6780
0199      50   IF(REGIME-1.)86,86,87                                             FLOW6790
0200      87   IF(REGIME-2.)86,86,88                                             FLOW6800
0201      88   IF(REGIME-3.)86,86,89                                             FLOW6810
0202      89   CONTINUE                                                          FLOW6820
0203           EG=1./(1.+QL  /QG)                                                FLOW6830
0204           CALL GASVIS(PC,TC,TABAR   ,AD(L),GGAS,GVIS)                       FLOW6840
0205           ROSLUG=ROBAR                                                      FLOW6850
0206           FLSLUG=FRICLG                                                     FLOW6860
0207           QG=XLIMM*AREAOT*(ROOIL/(SURTEN*32.174))**(-1./4.)                 FLOW6870
0208           GASVEL=QG/AREAOT                                                  FLOW6880
0209           REYNOL=1488.*ROG*DI*GASVEL/GVIS                                   FLOW6890
0210           YN=4.52E-07*(GASVEL*GVIS/Z)**2.*ROG/ROOIL                         FLOW6900
0211           IF(EOD-0.001)90,90,91                                             FLOW6910
0212      90   EOD=174.8*SURTEN*(YN**.302)/(ROG*GASVEL**2.*DI)                   FLOW6920
0213           GO TO 94                                                          FLOW6930
0214      91   IF(EOD-0.5)92,93,93                                               FLOW6940
0215      93   EOD=174.8*SURTEN*(YN**.302)/(ROG*GASVEL**2.*DI)                   FLOW6950
0216           GO TO 94                                                          FLOW6960
0217      92   EOD=34.*SURTEN/(ROG*GASVEL**2.*DI)                                FLOW6970
0218      94   CONTINUE                                                          FLOW6980
0219           CALL  FRIFAC(REYNOL,EOD,FRCGI,FF)                                 FLOW6990
0220           FLMIST=FF*ROG*(GASVEL**2.)/(2.*32.174*DI)                         FLOW7000
```

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FORTRAN IV G LEVEL  21                  MUFF                DATE = 75216          14/24/53

0221             ROMIST=(1.-EG)*ROOIL+EG*ROG                                            FLOW7010
0222             ROBAR=  (XLIMM-VG)/(XLIMM-XLIMS)*ROSLUG                                FLOW7020
                1+(VG-XLIMS)/(XLIMM-XLIMS)*ROMIST                                       FLOW7030
0223             FRICLG=(XLIMM-VG)/(XLIMM-XLIMS)*FLSLUG                                 FLOW7040
                1+(VG-XLIMS)/(XLIMM-XLIMS)*FLMIST                                       FLOW7050
0224       86    CONTINUE                                                               FLOW7060
0225             CALCDP=144.*(DP    *(1.-WTUT*QG/(4637.*AREAUT**2.*PD(J))))/(ROBAR+ FLOW7070
                1FRICLG)                                                                FLOW7080
0226             DELDEP=DH(J)-CALCDP                                                    FLOW7090
0227             DAM=ABS(DELDEP)                                                        FLOW7100
0228             IF(DAM-1.)95,95,96                                                     FLOW7110
0229       96    DH(J)=DH(J)-DELDEP/2.                                                  FLOW7120
0230             DEL=DH(J)/2.+DA(J-1)                                                   FLOW7130
0231             L1=L1+1                                                                FLOW7140
0232             IF(L1-100)100,100,95                                                   FLOW7150
0233       95    DA(J)=CALCDP+DA(J-1)                                                   FLOW7160
0234             L1=0                                                                   FLOW7170
0235             DEL=DD/2.+DA(J)                                                        FLOW7180
0236             AD(J)=DP+AD(J-1)                                                       FLOW7190
0237             IF(IDEBUG.EQ.1)WRITE(6,2503)AD(J-1)                                    FLOW7200
0238       2503 FORMAT(5X,'CUMMULATIVE PRESSURE =',F15.3)                               FLOW7210
0239             L=J                                                                    FLOW7220
0240             IF(TOTALD)97,97,98                                                     FLOW7230
0241       97    IF(PM-AD(J))99,99,101                                                  FLOW7240
0242       98    IF(TOTALD-DA(J))99,99,101                                              FLOW7250
0243       101   CONTINUE                                                               FLOW7260
0244       3     CONTINUE                                                               FLOW7270
0245       99    LL=L-1                                                                 FLOW7280
0246             AD(L)=AD(LL)                                                           FLOW7290
0247             IF(IDEBUG.EQ.1)WRITE(6,2502)AD(L)                                      FLOW7300
0248       2502 FORMAT(//,5X,' BOTTOMHOLE PRESSURE=',F15.3//)                           FLOW7310
0249             PSLS=AD(L)                                                             FLOW7320
0250             RETURN                                                                 FLOW7330
0251             END                                                                    FLOW7340
```

FORTRAN IV G LEVEL 21 ZFACO DATE = 75216 14/24/53

```
      SUBROUTINE ZFACO(A)                                FLOW7350
      DIMENSION A(6,6)                                   FLOW7360
      REAL*8 A                                           FLOW7370
      A(1,1)=2.1433504                                   FLOW7380
      A(2,1)=0.83176184D-1                               FLOW7390
      A(3,1)=-0.21467042D-1                              FLOW7400
      A(4,1)=-0.87140318D-3                              FLOW7410
      A(5,1)=0.42846283D-2                               FLOW7420
      A(6,1)=-0.16595343D-2                              FLOW7430
      A(1,2)=0.33123524                                  FLOW7440
      A(2,2)=-0.13403614                                 FLOW7450
      A(3,2)=0.66880961D-1                               FLOW7460
      A(4,2)=-0.27174261D-1                              FLOW7470
      A(5,2)=0.88512291D-2                               FLOW7480
      A(6,2)=-0.21520929D-2                              FLOW7490
      A(1,3)=0.10572871                                  FLOW7500
      A(2,3)=-0.50393654D-1                              FLOW7510
      A(3,3)=0.50924798D-2                               FLOW7520
      A(4,3)=0.10551336D-1                               FLOW7530
      A(5,3)=-0.73181933D-2                              FLOW7540
      A(6,3)=0.26959963D-2                               FLOW7550
      A(1,4)=-0.52184040D-1                              FLOW7560
      A(2,4)=0.44312146D-1                               FLOW7570
      A(3,4)=-0.19329465D-1                              FLOW7580
      A(4,4)=0.58972516D-2                               FLOW7590
      A(5,4)=0.15366676D-2                               FLOW7600
      A(6,4)=-0.28326809D-2                              FLOW7610
      A(1,5)=0.14703980D-1                               FLOW7620
      A(2,5)=-0.26383354D-1                              FLOW7630
      A(3,5)=0.19262143D-1                               FLOW7640
      A(4,5)=-0.11535339D-1                              FLOW7650
      A(5,5)=0.42910089D-2                               FLOW7660
      A(6,5)=-0.81302526D-3                              FLOW7670
      A(1,6)=-0.53095900D-2                              FLOW7680
      A(2,6)=0.89178330D-2                               FLOW7690
      A(3,6)=-0.10894821D-1                              FLOW7700
      A(4,6)=0.95593890D-2                               FLOW7710
      A(5,6)=-0.60114017D-2                              FLOW7720
      A(6,6)=0.31175170D-2                               FLOW7730
      RETURN                                             FLOW7740
      END                                                FLOW7750
```

```
FORTRAN IV G LEVEL  21                ZFAC1            DATE = 75216          14/24/53

           SUBROUTINE ZFAC1 (Z,P,T,PC,TC,PY,S,A)                             FLOW7760
           DIMENSION A(6,6),PY(6),S(6)                                        FLOW7770
           REAL*8A                                                            FLOW7780
           Y=(2.*(T/TC)-4.)/1.9                                               FLOW7790
           YSQ=Y*Y                                                            FLOW7800
           YCUBE=YSQ*Y                                                        FLOW7810
           YTO4=YSQ*YSQ                                                       FLOW7820
           PY(1)=0.7071068                                                    FLOW7830
           PY(2)=1.224745*Y                                                   FLOW7840
           PY(3)=0.7905695*(3.*YSQ-1.)                                        FLOW7850
           PY(4)=0.9354145*(5.*YCUBE-3.*Y)                                    FLOW7860
           PY(5)=0.265165*(35.*YTO4-30.*YSQ+3.)                               FLOW7870
           PY(6)=0.293151*(63.*YTO4*Y-70.*YCUBE+15.*Y)                        FLOW7880
           DO 20 I=1,6                                                        FLOW7890
           S(I)=0.                                                            FLOW7900
           DO 10 J=1,6                                                        FLOW7910
           S(I)=S(I)+A(J,I)*PY(J)                                             FLOW7920
        10 CONTINUE                                                           FLOW7930
        20 CONTINUE                                                           FLOW7940
           RETURN                                                             FLOW7950
           END                                                                FLOW7960
```

```
FORTRAN IV G LEVEL  21                ZFAC2            DATE = 75216          14/24/53

           SUBROUTINE ZFAC2 (Z,P,T,PC,TC,PY,S)                               FLOW7970
           DIMENSION      PY(6),S(6)                                          FLOW7980
           Y=(2.*(P/PC)-15.)/14.8                                             FLOW7990
           YSQ=Y*Y                                                            FLOW8000
           YCUBE=YSQ*Y                                                        FLOW8010
           YTO4=YSQ*YSQ                                                       FLOW8020
           PY(1)=0.7071068                                                    FLOW8030
           PY(2)=1.224745*Y                                                   FLOW8040
           PY(3)=0.7905695*(3.*YSQ-1.)                                        FLOW8050
           PY(4)=0.9354145*(5.*YCUBE-3.*Y)                                    FLOW8060
           PY(5)=0.265165*(35.*YTO4-30.*YSQ+3.)                               FLOW8070
           PY(6)=0.293151*(63.*YTO4*Y-70.*YCUBE+15.*Y)                        FLOW8080
           Z=0.                                                               FLOW8090
           DO 10 I=1,6                                                        FLOW8100
           Z=Z+S(I)*PY(I)                                                     FLOW8110
        10 CONTINUE                                                           FLOW8120
           RETURN                                                             FLOW8130
           END                                                                FLOW8140
```

FORTRAN IV G LEVEL 21   OWLVIS   DATE = 75216   14/24/53

```
          SUBROUTINE OWLVIS(TEMPER,RSOL,V1,V2,VISCOS)                 FLOW8150
          VISCOL=V1*((TEMPER/100.)**(1.345*ALOG(V2/V1)))              FLOW8160
          IF(RSOL-50.)1,2,2                                           FLOW8170
    1       X=.898                                                    FLOW8180
          Y=.931                                                      FLOW8190
          GO TO 100                                                   FLOW8200
    2     IF(RSOL-100.)3,4,4                                          FLOW8210
    3     X=.820                                                      FLOW8220
          Y=.884                                                      FLOW8230
          GO TO 100                                                   FLOW8240
    4     IF(RSOL-200.)5,6,6                                          FLOW8250
    5     X=.7                                                        FLOW8260
          Y=.810                                                      FLOW8270
          GO TO 100                                                   FLOW8280
    6     IF(RSOL-400.)7,8,8                                          FLOW8290
    7     X=.545                                                      FLOW8300
          Y=.720                                                      FLOW8310
          GO TO 100                                                   FLOW8320
    8     IF(RSOL-600.)9,10,10                                        FLOW8330
    9     X=.499                                                      FLOW8340
          Y=.650                                                      FLOW8350
          GO TO 100                                                   FLOW8360
   10     IF(RSOL-800.)11,12,12                                       FLOW8370
   11     X=.375                                                      FLOW8380
          Y=.615                                                      FLOW8390
          GO TO 100                                                   FLOW8400
   12     IF(RSOL-1000.)13,14,14                                      FLOW8410
   13     X=.312                                                      FLOW8420
          Y=.575                                                      FLOW8430
          GO TO 100                                                   FLOW8440
   14     IF(RSOL-1200.)15,16,16                                      FLOW8450
   15     X=.273                                                      FLOW8460
          Y=.548                                                      FLOW8470
          GO TO 100                                                   FLOW8480
   16     IF(RSOL-1400.)17,18,18                                      FLOW8490
   17     X=.250                                                      FLOW8500
          Y=.522                                                      FLOW8510
          GO TO 100                                                   FLOW8520
   18     X=.230                                                      FLOW8530
          Y=.498                                                      FLOW8540
  100     VISLIQ=X*VISCOL**Y                                          FLOW8550
          IF(VISLIQ-VISCOL)60,60,70                                   FLOW8560
   60     VISLIQ=VISCOL                                               FLOW8570
   70     VISCOS=VISLIQ                                               FLOW8580
          RETURN                                                      FLOW8590
          END                                                         FLOW8600
```

FORTRAN IV G LEVEL 21 SOLZ DATE = 75216 14/24/53

```
      SUBROUTINE SOLZ(POZ,Z,P,T,PC,TC,PY,S,A)                           FLOW8610
      REAL*8 A                                                          FLOW8620
      DIMENSION A(6,6),PY(6),S(6)                                       FLOW8630
      PO=POZ                                                            FLOW8640
      I=1                                                               FLOW8650
      CALL       ZFAC2(ZO,PO,TO,PC,TC,PY,S)                             FLOW8660
      PDDZD=PO/ZO                                                       FLOW8670
      DELPO=POOZO-POZ                                                   FLOW8680
      PN=0.85*PO                                                        FLOW8690
   17 CALL       ZFAC2(ZN,PN,TN,PC,TC,PY,S)                             FLOW8700
      PNUZN=PN/ZN                                                       FLOW8710
      DELPN=PNOZN-POZ                                                   FLOW8720
      IF(ABS(DELPN).LT. 1.) GO TO 88                                    FLOW8730
      PSTAR=PO-DELPO*(PN-PO)/(DELPN-DELPO)                              FLOW8740
      PO=PN                                                             FLOW8750
      PN=PSTAR                                                          FLOW8760
      DELPO=DELPN                                                       FLOW8770
      I=I+1                                                             FLOW8780
      IF(I .GT. 10) GO TO 90                                            FLOW8790
      GO TO 17                                                          FLOW8800
   90 WRITE(6,91)                                                       FLOW8810
   88 Z=ZN                                                              FLOW8820
      P=PN                                                              FLOW8830
   91 FORMAT(5X,29HTEN ITERATIONS HAVE BEEN MADE)                       FLOW8840
      RETURN                                                            FLOW8850
      END                                                               FLOW8860
```

FORTRAN IV G LEVEL 21 GASVIS DATE = 75216 14/24/53

```
      SUBROUTINE GASVIS(PC,TC,TB,P,G,VISG)                              FLOW8870
      DIMENSION PY(6),S6(6)                                             FLOW8880
      COMMON/OKLA3/S6                                                   FLOW8890
      CALL ZFAC2(Z,P,TB,PC,TC,PY,S6)                                    FLOW8900
      IF(P-1.)49,49,50                                                  FLOW8910
   49 VISG=0.047                                                        FLOW8920
      GO TO 60                                                          FLOW8930
   50 W=G*29.                                                           FLOW8940
      AK=(9.5+0.02*W)*(TB**1.5)/(209.+19.*W+TB)                         FLOW8950
      X=3.5+(986./TB)+.01*W                                             FLOW8960
       Y=2.4-.2*X                                                       FLOW8970
      RHOG=P*W*144./(Z*TB*1545.*62.4)                                   FLOW8980
      VISG=AK*EXP(X*RHOG**Y)/10000.                                     FLOW8990
   60 RETURN                                                            FLOW9000
      END                                                               FLOW9010
```

```
FORTRAN IV G LEVEL  21                PINT              DATE = 75216        14/24/53

              SUBROUTINE PINT(XA,YA,X,Y,M)                                    FLO-9020
              DIMENSION X(20),Y(20)                                           FLO-9030
              IF(XA.LE.X(1)) GO TO 3                                          FLO-9040
              DO 1 K=2,M                                                      FLO-9050
              I=K                                                             FLO-9060
              IF(I.EQ.M)GO TO 4                                               FLO-9070
              IF(XA.GT.X(K).AND.XA.LT.X(K+1)) GO TO 2                         FLO-9080
              IF(XA.EQ.X(K))GO TO 4                                           FLO-9090
        1     CONTINUE                                                        FLO-9100
        2     YA=((XA-X(I-1))/(X(I)-X(I-1)))*(Y(I)-Y(I-1))+Y(I-1)             FLO-9110
              GO TO 5                                                         FLO-9120
        3     YA=Y(1)                                                         FLO-9130
              GO TO 5                                                         FLO-9140
        4     YA=Y(I)                                                         FLO-9150
        5     RETURN                                                          FLO-9160
              END                                                             FLO-9170
```

```
FORTRAN IV G LEVEL  21                SURFAC            DATE = 75216        14/24/53

              SUBROUTINE SURFAC(SURF1,PRES,SUFTEN)                            FLO-9180
              IF(PRES-550.)1,1,2                                              FLO-9190
        1     SURF=100.-0.0625*PRES                                           FLO-9200
              GO TO 3                                                         FLO-9210
        2     IF(PRES-1025.)4,4,5                                             FLO-9220
        4     SURF=85.-0.0371*PRES                                            FLO-9230
              GO TO 3                                                         FLO-9240
        5     IF(PRES-1680.)6,6,7                                             FLO-9250
        6     SURF=72.4-0.025*PRES                                            FLO-9260
              GO TO 3                                                         FLO-9270
        7     IF(PRES-2500.)8,8,9                                             FLO-9280
        8     SURF=56.2-0.016*PRES                                            FLO-9290
              GO TO 3                                                         FLO-9300
        9     IF(PRES-3910.)10,11,11                                          FLO-9310
       10     SURF=40.-.01*PRES                                               FLO-9320
              GO TO 3                                                         FLO-9330
       11      SURF=1.                                                        FLO-9340
        3     SUFTEN=SURF1*SURF/100.                                          FLO-9350
              RETURN                                                          FLO-9360
              END                                                             FLO-9370
```

```
FORTRAN IV G LEVEL  21                    OILRAT               DATE = 75216         14/24/53

0001            SUBROUTINE OILRAT(P6,PFNL,FFNL,PPK,FPK,PINT,FINT,FPR,PPR,QOP,QGP   FLOW9380
               1,QL)                                                                FLOW9390
0002            COMMON/OKLA1/L,QGG                                                  FLOW9400
0003            IF(P6.LT.PFNL)FRC=FFNL                                              FLOW9410
0004            IF(P6.GT.PFNL.AND.P6.LT.PPK)FRC=FFNL+(FPK-FFNL)*(P6-PFNL)/(PPK      FLOW9420
               1-PFNL)                                                              FLOW9430
0005            IF(P6.GT.PPK.AND.P6.LT.PINT)FRC=FPK+(FINT-FPK)*(P6-PPK)/(PINT-PPK)FLOW9440
0006            IF(P6.GT.PINT)FRC=FINT                                              FLOW9450
0007            QL=FRC*QOP*QGG/(FPR*QGP)                                            FLOW9460
0008            RETURN                                                              FLOW9470
0009            END                                                                 FLOW9480
```

```
FORTRAN IV G LEVEL  21                    FRIFAC               DATE = 75216         14/24/53

0001            SUBROUTINE FRIFAC(RY,BUD,FRIC1,FACTOR)                              FLOW9490
0002            FRIC=64./RY                                                         FLOW9500
          C     FRIC=0.0056+.5*RY**(-0.32)                                          FLOW9510
0003      200   FACTOR=(1./(1.74-2.*ALOG(2.*BUD+18.68/(RY*FRIC1**.5))))             FLOW9520
0004            DELTA=FRIC1-FACTOR                                                  FLOW9530
0005            DELTA=ABS(DELTA)                                                    FLOW9540
0006            IF(DELTA-0.0005)60,60,61                                            FLOW9550
0007       61   FRIC1=(FACTOR+FRIC1)/2.                                             FLOW9560
0008            GO TO 200                                                           FLOW9570
0009       60   IF(FACTOR-FRIC)62,63,63                                             FLOW9580
0010       62   FACTOR=FRIC                                                         FLOW9590
0011       63   RETURN                                                              FLOW9600
0012            END                                                                 FLOW9610
```