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PRODUCTION ESTIMATION

Inflow Performance Relationships for Solution-Gas Drive Wells

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Abstract

In calculating oilwell production, it has commonly been assumed that producing rates are proportional to drawdowns. Using this assumption, a well's behavior can be described by its productivity index (PI). This PI relationship was developed from Darcy's law for the steady-state radial flow of a single, incompressible fluid. Although Muskat pointed out that the relationship is not valid when both oil and gas flow in a reservoir, its use has continued for lack of better approximations. Gilbert proposed methods of well analysis utilizing a curve of producing rates plotted against bottom-hole well pressures; he termed this complete graph the inflow performance relationship (IPR) of a well.

The calculations necessary to compute IPR's from two-phase flow theory were extremely tedious before advent of the computer. Using machine computations, IPR curves were calculated for wells producing from several fictitious solution-gas drive reservoirs that covered a wide range of oil PVT properties and reservoir relative permeability characteristics. Wells with hydraulic fractures were also included. From these curves, a reference IPR curve was developed that is simple to apply and, it is believed, can be used for most solution-gas drive reservoirs to provide more accurate calculations for oilwell productivity than can be secured with PI methods. Field verification is needed.

Introduction

In calculating the productivity of oil wells, it is commonly assumed that inflow into a well is directly proportional to the pressure differential between the reservoir and the wellbore — that production is directly proportional to drawdown. The constant of proportionality is the PI, derived from Darcy's law for the steady-state radial flow of a single, incompressible fluid. For cases in which this relationship holds, a plot of the producing rates vs the corresponding bottom-hole pressures results in a straight line (Fig. 1). The PI of the well is the inverse of the slope of the straight line.

However, Muskat[1] pointed out that when two-phase liquid and gas flow exists in a reservoir, this relationship should not be expected to hold; he presented theoretical calculations to show that graphs of producing rates vs bottom-hole pressures for two-phase flow resulted in curved rather than straight lines. When curvature exists, a well cannot be said to have a single PI because the value of the slope varies continuously with the variation in drawdown. For this reason, Gilbert[2] proposed methods of well analysis that could utilize the whole curve of producing rates plotted against intake pressures. He termed this complete graph the inflow performance relationship (IPR) of a well.

Although the straight-line approximation is known to have limitations when applied to two-phase flow in the reservoir, it still is used primarily because no simple substitutes have been available. The calculations necessary to compute IPR's from two-phase flow theory have been extremely tedious. However, recently the approximations of Weller[3] for a solution-gas drive reservoir were programmed for computers. The solution involved the following simplifying assumptions: (1) the reservoir is circular and completely bounded with a completely penetrating well at its center; (2) the porous medium is uniform and isotropic with a constant water saturation at all points; (3) gravity effects can be neglected; (4) compressibility of rock and water can be neglected; (5) the composition and equilibrium are constant for oil and gas; (6) the same pressure exists in both the oil and gas phases; and (7) the semisteady-state assumption that the tank-oil desaturation rate is the same at all points at a given instant. Weller's solution did not require the constant-GOR assumption.

The resulting computer program proved convenient to use and gave results closely approaching those furnished by the more complicated method of West, Garvin and Sheldon.[4] The program also includes the unique feature

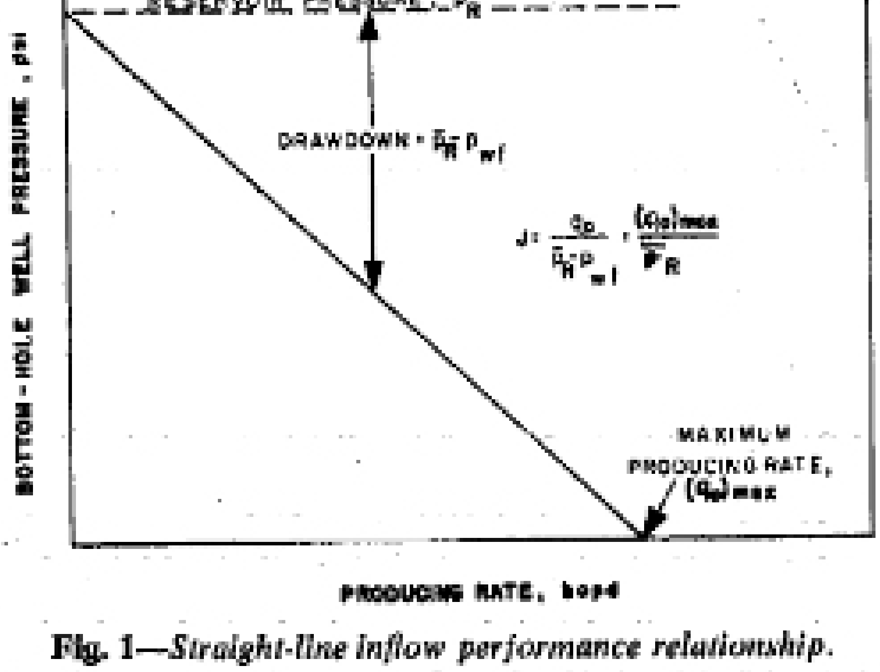

Fig. 1—*Straight-line inflow performance relationship.*

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[1]References given at end of paper.

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of making complete IPR predictions for a reservoir. Such predictions for a typical solution-gas drive reservoir are shown as a family of IPR curv s on Fig. 2. Note that they confirm the existence of curv.ture.

It appeared that if several solution-gas drive reservoirs were examined with the aid of this program, empirical relationships might be established that would apply to solution-gas drive reservoirs in general. This paper summarizes the results of such a study that dealt with several simulated reservoirs covering a wide range of conditions. These conditions included differing crude oil characteristics and differing reservoir relative permeability characteristics, as well as the effects of well spacing, fracturing and skin restrictions.

The investigation sought relationships valid only below the bubble point. Computations were made for reservoirs initially above the bubble point, but only to ensure that this initial condition did not cause a significant change in behavior below the bubble point.

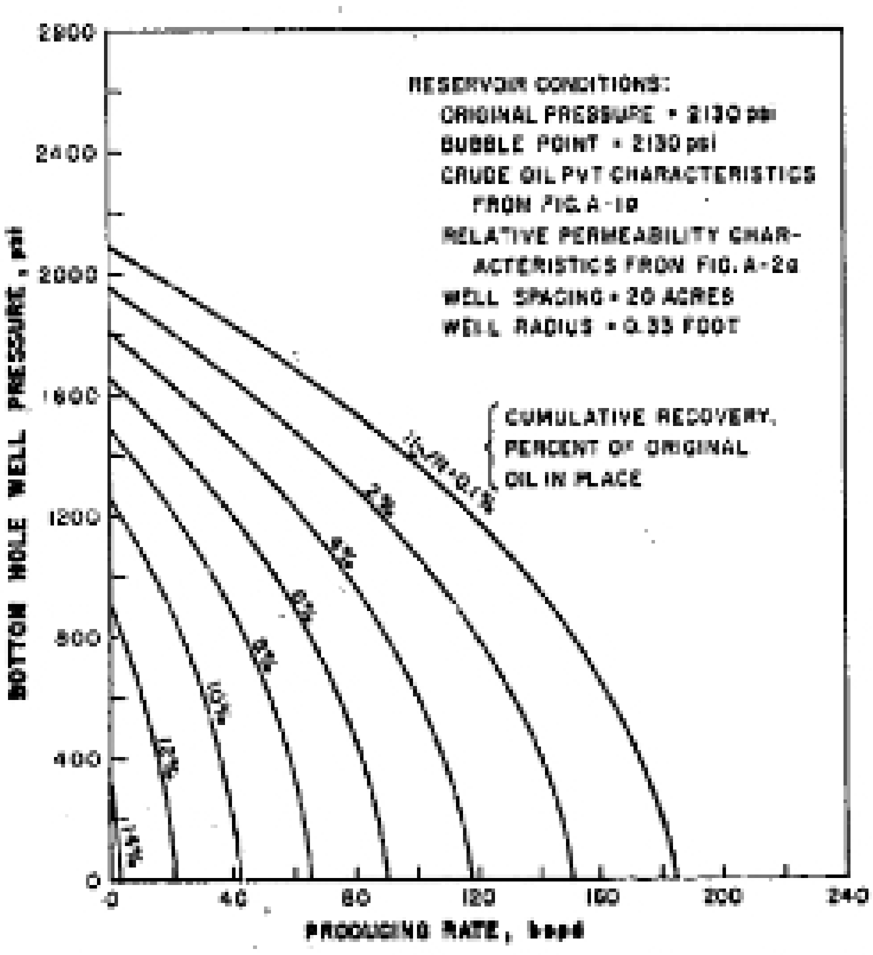

Fig. 2—*Computer-calculated inflow performance relationships for a solution-gas drive reservoir.*

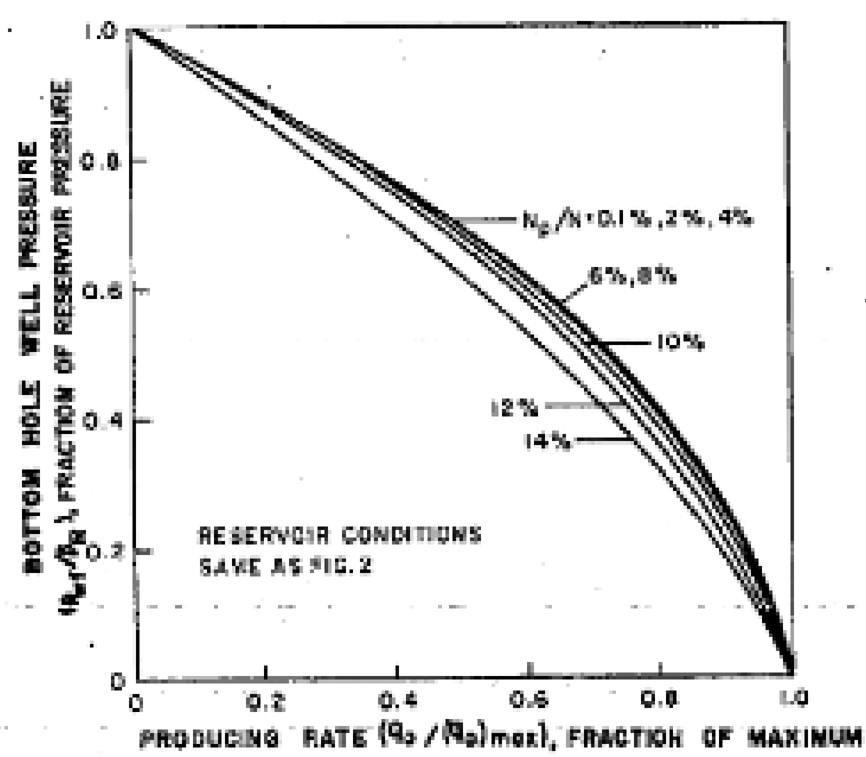

Fig. 3—*Dimensionless Inflow performance relationships for a solution-gas drive reservoir.*

Shape of Inflow Performance Relationship Curves with Normal Deterioration

As depletion proceeds in a solution-gas drive reservoir, the productivity of a typical well decreases, primarily because the reservoir pressure is reduced and because increasing gas saturation causes greater resistance to oil flow. The result is a progressive deterioration of the IPR's, typified by the IPR curves in Fig. 2. Examination of these curves does not make it apparent whether they have any properties in common other than that they are all concave to the origin.

One useful operation is to plot all the IPR's as "dimensionless IPR's". The pressure for each point on an IPR curve is divided by the maximum or shut-in pressure for that particular curve, and the corresponding production rate is divided by the maximum (100 percent drawdown) producing rate for the same curve. When this is done, the curves from Fig. 2 can be replotted as shown in Fig. 3. It is then readily apparent that with this construction the curves are remarkably similar throughout most of the producing life of the reservoir

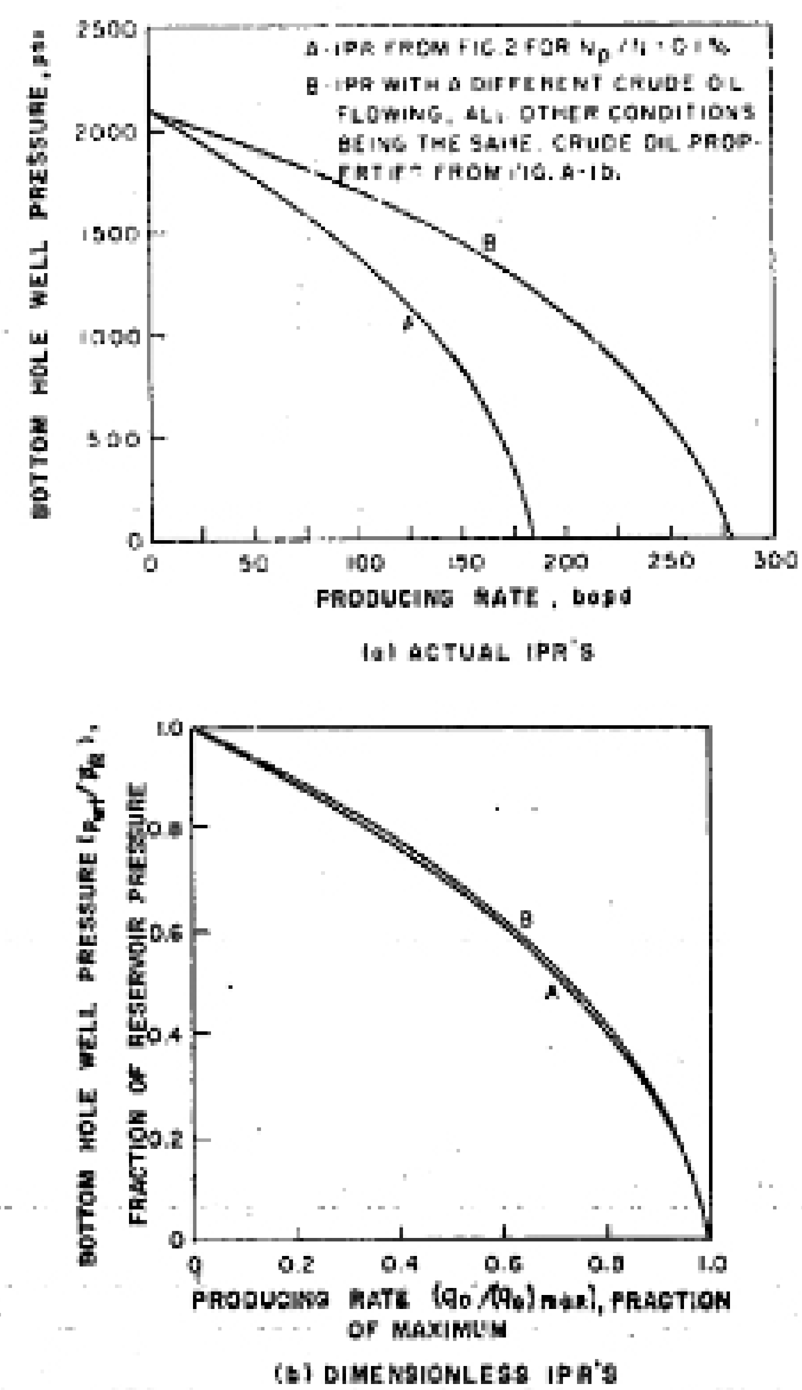

Fig. 4—*Effect of crude oil properties on IPR's.*

Effect of Crude Oil Characteristics On IPR Curves

From the foregoing results it appears that IPR curves differing over the life of a given reservoir actually possess a common relationship. To determine whether this same relationship would be valid for other reservoirs, IPR calculations were made on the computer for different conditions. The first run utilized the same relative permeabilities but a completely different crude oil. The new characteristics included a viscosity about half that of the first and a solution GOR about twice as great.

Fig. 4a compares the initial IPR's ($N_p/N = 0.1$ percent) for the two cases. As would be expected, with a less viscous crude (Curve B) the productivity was much greater than in the first case (Curve A). However, when plotted on a dimensionless basis (Fig. 4b) the IPR's are quite similar. As IPR's for the second case deteriorated with depletion, no greater change of shape occurred than was noted in the previous section. These two crude oils had about the same bubble point. IPR's were then calculated for a third crude oil with a higher bubble point. Again, the characteristic shape was noted.

Two further runs were made to explore the relationship under more extreme conditions. One utilized a more viscous crude (3-cp minimum compared with 1-cp minimum), and the other used a crude with a low solution GOR (300 scf/STB). With the more viscous crude, some straightening of the IPR's was noted. The low-GOR crude exhibited the same curvature noted in previous cases.

Runs were also made with the initial reservoir pressure exceeding the bubble point. During the period while the reservoir pressure was above the bubble point, the slopes of the IPR curves were discontinuous with the upper part being a straight line until the well pressure was reduced below the bubble point. Below this point the IPR showed curvature similar to that noted previously. After the reservoir pressure went below the bubble point, all the dimensionless IPR curves agreed well with the previous curves.

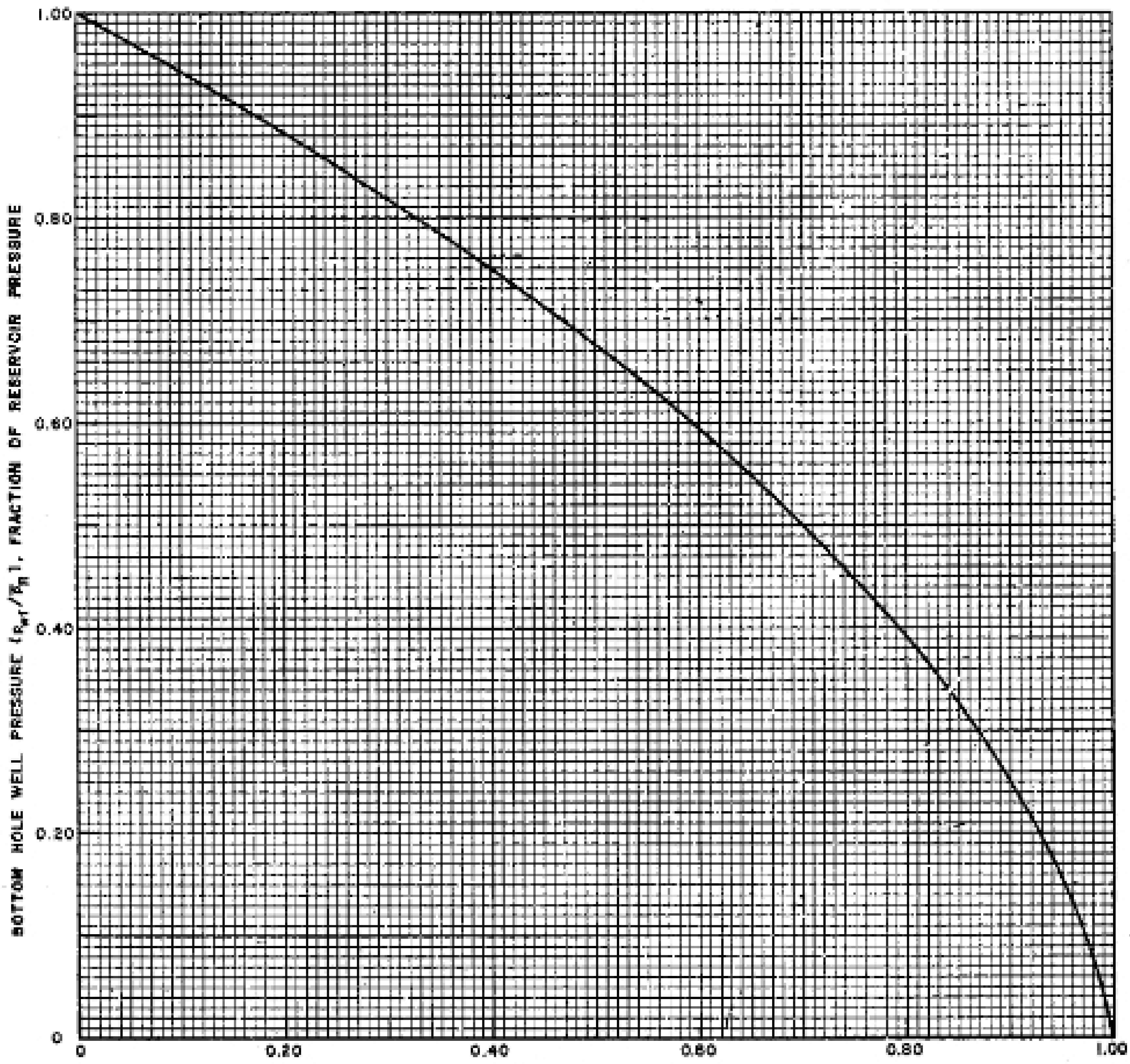

Fig. 5—*Inflow performance relationship for solution-gas drive reservoirs.*