EASTERN GAS SHALES PROJECT OPEN FILES

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NATURAL GAS FROM EASTERN U.S. SHALES

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ABSTRACT

A project has been initiated by the Energy Research and Development Administration (ERDA) to characterize gas-bearing shale formations and develop improved gas-extraction technology for these low-permeability "tight" reservoirs. The Eastern Devonian Shales are very prominent in this assessement, since they underlie a large section of the eastern and central portions of the United States. There is considerable uncertainty in the magnitude of the hydrocarbon resource base since estimates range as high as 460,000 TCF (gas equivalents) in the Appalachian Basin alone; however, a recent estimate places the gas in place at 2,400 TCF. If only 10 percent of this latter figure were recovered, this would be enough natural gas to supply the eastern United States for 30 years at the current rate of consumption. Obviously, the potential payoff from the Eastern Shale is much greater if technology can be developed to increase the rate and amount of natural gas recovery.

The primary reason why the natural gas has not been more fully exploited is that the wells that have been completed normally have low productivities, i.e., they produce at an average rate of 50,000 scf per day. By using advanced fracturing and stimulation methods, this rate may be increased two to four times. Fracturing results have been mixed since many new techniques have been tried. Massive Hydraulic Fracturing (MHF), foam, gas, dendritic, and high yield explosives have already been tested with varying degrees of success or failure.

In comparing data for conventional shot wells and induced hydraulic fracturing, it became evident that hydraulically fractured wells would produce considerably more gas and return higher profits. This was consistently true, even though the completion costs using hydraulic fracturing were 50 percent higher.

INTRODUCTION

The natural gas shortages and curtailments experienced during the winter of 1976-77, coupled with the continually increasing U.S. energy demand, have highlighted the need to develop additional supplies of gas. Natural gas supplied 27 percent of the total energy used in 1976 and will continue to be a major source of energy[1].

The U. S. Bureau of Mines, now the Energy Research and Development Administration, in 1968, began a project to evaluate unconventional natural gas reservoirs which could be future sources of supply. Following this examination, the Eastern Devonian Shales were selected as a gas resource in which a large natural gas potential existed and one in which new extraction R&D technologies would have to be developed.

The Eastern Gas Shales Project was formally initiated in 1976 by ERDA at its Morgantown Energy Research Center[2]. The ultimate objective is to increase production of natural gas from the Eastern Shale Basins through advanced exploration and extraction techniques.

The Project is specifically directed toward:

- Determining the magnitude of potential gas reserves,
- Thoroughly characterizing the shale,
- Improving current state-of-the-art stimulation technology, and
- Providing an R&D technology base for low permeability "tight" natural gas reservoirs.

FIELD DESCRIPTION

The Eastern Gas Shales constitute a vast, essentially unexploited resource of gas. The extent of the Mississippian and Devonian Shales is shown in Figure 1. This area represents a potential producing area of approximately 250,000 square miles of which 160,000 square miles is located within the Appalachian Basin.

Devonian Shales are typically brown to gray to black rocks composed of tightly compacted quartz and clay particles contained in organic matter (1 to 15 percent). These shales were formed by slow and uniform deposition of sediment and organic material during the mid to late Devonian Period when inland

References and illustrations at end of paper.

brackish seas covered much of what is now continental North America.

Natural gas has been produced from the Devonian Shales for more than 150 years[3]. Within the Appalachian Basin, a total of over 9,600 gas wells have been completed in the Devonian Shale in an area of about 4,000 square miles. Production records are not available for all these wells, but it has been estimated that total productivity has ranged as high as 400 million cubic feet of natural gas per well[4] in the higher organic, more densely fractured regions of the basin. This drilling has produced only a very minor percentage of the calculated gas present in the Eastern Devonian Shale. Shale gas wells are typically drilled on 150-acre spacing and are stimulated over an interval of 300 to 1,200 feet. A typical 1,000-foot interval of the Devonian Shale is composed of approximately 600 feet of light-colored shales and 400 feet of dark-colored shales which are the usual source of production (Fig. 2).

Resource Estimates

Estimates for total gas contained within the Devonian Shales of the Appalachian Basin alone range from 2.4 quadrillion cubic feet[1/] to 460 quadrillion cubic feet (gas equivalents)[5]. However, a large portion of this gas equivalent is adsorbed in the shale or is bound liquid hydrocarbons and would require in situ combustion, thermal distillation, or hydrogasification to be recovered.

The ultimate recoverable reserves of the 9,600 productive wells currently producing is three trillion cubic feet (3 TCF) which is calculated to represent much less than one percent of the available gas resource of the basin. As a result of recent ERDA studies on five cores taken in four states during the past year, new data indicates the calculated magnitude of the natural gas resource to be 2,400 trillion cubic feet of gas (40 billion cubic feet per square mile per 1,000 feet of shale and an estimated 60,000 square miles). This amount of gas is staggering and the ultimate values established by ERDA research could be even greater than these figures, since the range of free gas measured was between 40 and 150 BCF/sq.mi/1,000 ft. Table 1 summarizes these results for the five ERDA cores taken in 1976. If only 10 percent of the resource is recovered, this would be enough natural gas to supply the eastern U. S. for over 30 years at its present rate of consumption. These figures indicate that the total reserve estimates need to be firmly established and a concentrated effort is needed toward developing the technology necessary to stimulate the production of this gas.

Gas Production

The production behavior of the Devonian Shale formation is related to two types of porosities with each playing an important part in a complicated reservoir behavior. Primary porosity of the shale ranges from < one to four percent and may or may not be interconnected, but appears as apparent porosity. Primary porosity appears to increase in zones characterized by the higher radioactive zones which are the more organic rich Brown Shale intervals of the rock column. The ultimate recovery from the wells should be related to the effectivenes with which the flow from the primary porosity is stimulated. Little, if any, production from primary porosity will ever be observed in the natural open flow of the well. This production is associated with secondary porosity which is composed of fractures, joints and bedding planes. It is this drainage volume initially that is exploited by a stimulation technique and ultimately determines the rate of initial open flow. The reservoir parameters for the shale are summarized in Table 2.

1/Resource estimate based on data supplied by Battelle Laboratory, Mound Laboratory and Geochem Laboratories, Inc., of initial core analysis studies, to ERDA's Eastern Gas Shales Project Office in January 1977. This figure could be revised upward or downward with additional data base development.

Stimulation

While some wells in Devonian Shale naturally produce at rates which make them commercially feasible, most wells must be stimulated to enhance their productivity. Production of gas has usually been obtained following stimulation of the wells by shooting the entire shale column at one time with 80 percent gelatinated nitroglycerine. However, in the middle 1960's, as development expanded to thinner shale beds, results from shooting diminished and an experimental program in hydraulic fracturing was initiated. Initial results were not encouraging as the open flow rates of fractured wells were not particularly better than those from shot wells. However, after a few years of production history were recorded, it became evident that fractured wells, compared to shot wells in the same open flow category, produced considerably more gas. Specifically, in the low open flow category of 100-200 MCFD, the deliverability of fractured wells exceeded that of shot wells by 75 percent after the third year of production (Fig. 3). This suggests that an increased number of gas filled fractures in the formation are interconnected in hydraulic fracturing as a result of the larger effective well bore radius. The net effect is one of increased deliverability. The deliverability of fractured wells exceeds that of shot wells by a minimum of 55 percent in the first six years of production. The projected 32-year reserves of 350 MMCF per shot well is actually produced in 16 years by hydraulic fracturing. Although a hydraulic fractured wells is more expensive to complete, it results in a significantly higher rate of production that offsets and delivers a greater return on investment. Initial MHF results for several tests in the Devonian Shale have been published[6].

FIELD RESULTS AND EVALUATION

Field results and evaluation were derived from eight years of production data. Production decline curves for 25 wells in the Big Sandy field of eastern Kentucky are illustrated in Figure 4. Decline curve No. 1 represents a composite of those wells that exhibited open flows exceeding 350 MCFD, and decline curve No. 2, those with less than 250 MCFD. A comparison of cumulative production shows that a three-fold increase is forecasted at the end of 20 years for those wells which initially produced in excess of 350 MCFD. Moreover, cumulative production from curve No. 2 exhibits a deliverability that is about equivalent to borehole shooting results and constitutes an economical situation that is best described as marginal at the current price of gas. Thus, an obvious goal of increased production technology is to improve the rate and amount of natural gas recovery. More specifically, if the initial open flows are greater than 350 MCFD, then the likelihood of a good producing well is enhanced. MHF technology warrants increased consideration in this relationship, since this concept can increase the production rates by connecting more natural fractures together in a greatly extended wellbore radius. Experience in using this technique in the Devonian has shown that payout can be achieved in three years, provided curve No. 1 can be achieved (Table 3). Obviously if the production is high enough, the well would be considered a commercial success, no matter which stimulation technology was employed. However, MHF is one of the technologies that promises to take some of the risk out of development in regions of established shale production. Emerging with this technology are the concepts of using foam and cryogenic fluids instead of water as the fracturing medium and experiments are currently in progress to evaluate both as viable alternatives. Preliminary observations indicate that foam might be the primary fluid recommended for fracturing because of its faster clean-up time, comparable performance, and comparative cost. Certain novel techniques such as dendritic fracturing, liquid explosive fracturing and the Dynafrac process have the potential of advancing the state-of-the-art significantly. Dendritic fracturing appears conceptually to offer an alternative to MHF and may be more cost effective, but data to substantiate this is limited at this time.

CONCLUSIONS

The objectives of the Eastern Gas Shales Project are to generate reliable data to delineate the shale natural gas resource, develop improved recovery technology in conjunction with private industry, and promote expanded production from Eastern Gas Shales. The project has collected sufficient information to make several preliminary observations:

- The Eastern Gas Shale resource base is potentially a large natural gas resource for the eastern U. S.,
- Advanced stimulation techniques have been successful and indicate a 55 percent increase over conventional shooting techniques,
- Economics and payout times appear favorable at the current price of natural gas for an average shale well, and
- The potential for developing additional natural gas reserves from these eastern gas bearing shales holds much promise.

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1. U. S. Federal Energy Adm., Monthly Energy Review, May 1977, p.1
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3. Ray, E. O., "Devonian Shale Development in Eastern Kentucky", Symposium on Natural Gas from Unconventional Geological Sources, National Academy of Sciences, 1976, pp 100-112
4. Brown, P. J., "Energy from Shale - a Little Used Natural Resource", Symposium on Natural Gas from Unconventional Geological Sources, National Academy of Sciences, 1976, pp 86-99
5. Brooks, K, Devonian Shale Gas Study presented at Devonian Shale Symposium, Columbus, OH 1972
6. Komar, C. A., "ERDA Sponsored Projects in the Massive Hydraulic Fracturing of Resources in the Appalachian Basin -- A Status Report", Proc. MHF Symposium, Norman, OK, Feb. 29-Mar. 1, 1977.

TABLE 1 - RESOURCE ESTIMATES OF EASTERN DEVONIAN SHALE

WELL NO.	WELL LOCATION	FREE GAS IN PLACE, BCF per sq.mi/1,000 ft. (min/max)
1	Lincoln County, WV #1	40/80
2	Lincoln County, WV #2	40/80
3	Washington County, OH	40/110
4	Sullivan County, IN	40/150
5	Christian County, KY	40/110

TABLE 2 - TYPICAL DEVONIAN SHALE CHARACTERISTICS

Formation	Devonian Shale
Type rock	Shale with 1 to 15% organic carbon
Type production	Natural gas, some oil
Typical depth	3,500 ft.
Bottom hole temperatures, °F	95
Bottom hole pressure, psig	500
Average gross thickness, ft.	1,500
Average net pay - Brown Shale Section, ft.	600
Formation porosity, percent	.1 to 4
Permeability millidarcys	.001 to .05
Modulus of elasticity, psi	4.2×10^6
Well spacing, acres	150
Potential productive area, sq.mi.	60,000 @ depth < 4,000 ft.

TABLE 3 - PAYOUT TIME REQUIRED FOR HYDRAULIC FRACTURING TECHNOLOGY

PRODUCTION DECLINE	TYPE	COST (10^3\$)[1/]	PAYOUT PRODUCTION (MMCF)[2/]	PAYOUT TIME REQUIRED[3/]
CURVE 1 (>350 MCFD)	1,000 Bbl. Fracture Treatment	100	70	2
	MHF	160	113	3
CURVE 2 (<250 MCFD)	1,000 Bbl. Fracture Treatment	100	70	5
	MHF	160	113	9

1/ Total cost = 90K for 3,500 ft. cased well + cost of stimulation (10K - 1,000 Bbl. water frac, 70K - MHF).

2/ Payout Prod. = Total Cost/$1.42 MCF.

3/ Cumulative Production calculated from Figure 4.

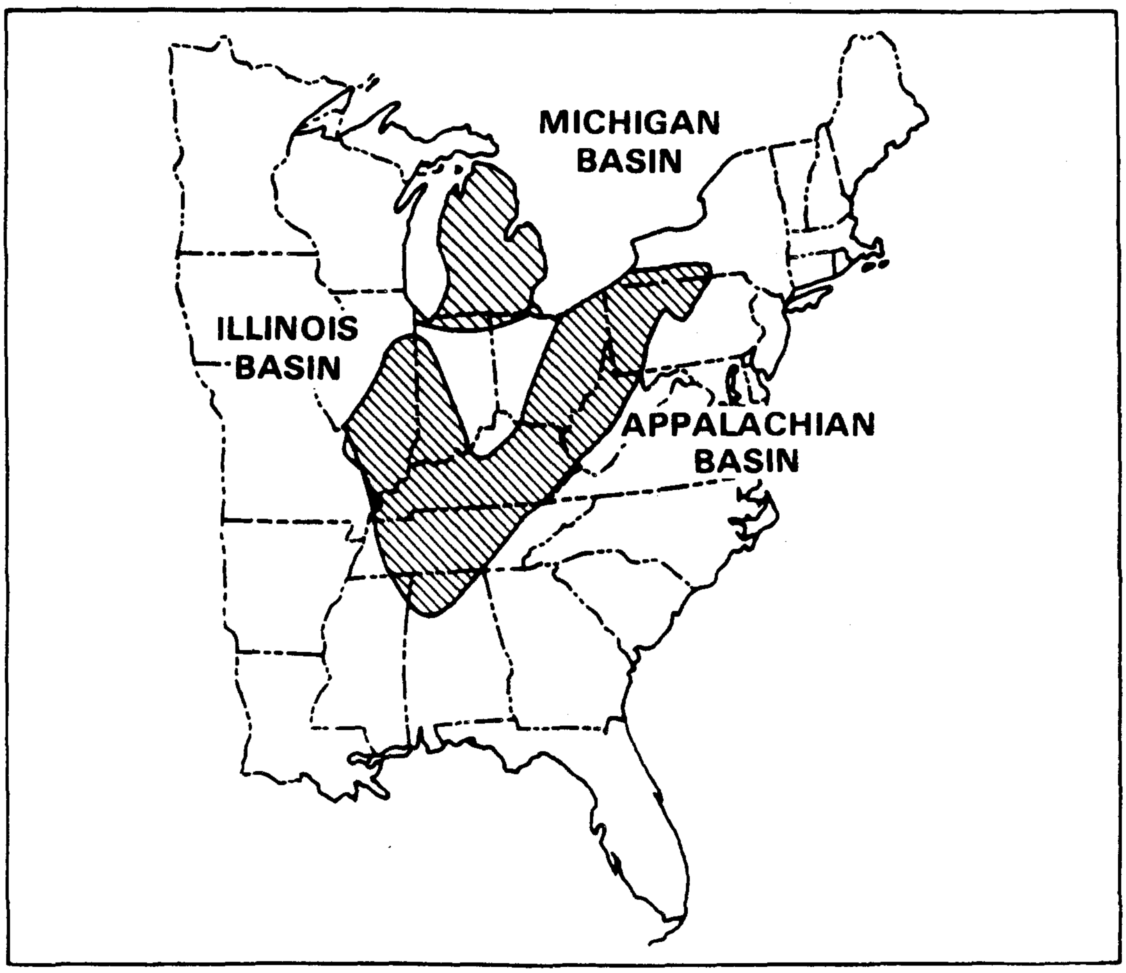

Fig. 1 - Eastern gas shales area of the gas bearing Devonian and Mississippian Shale deposits.

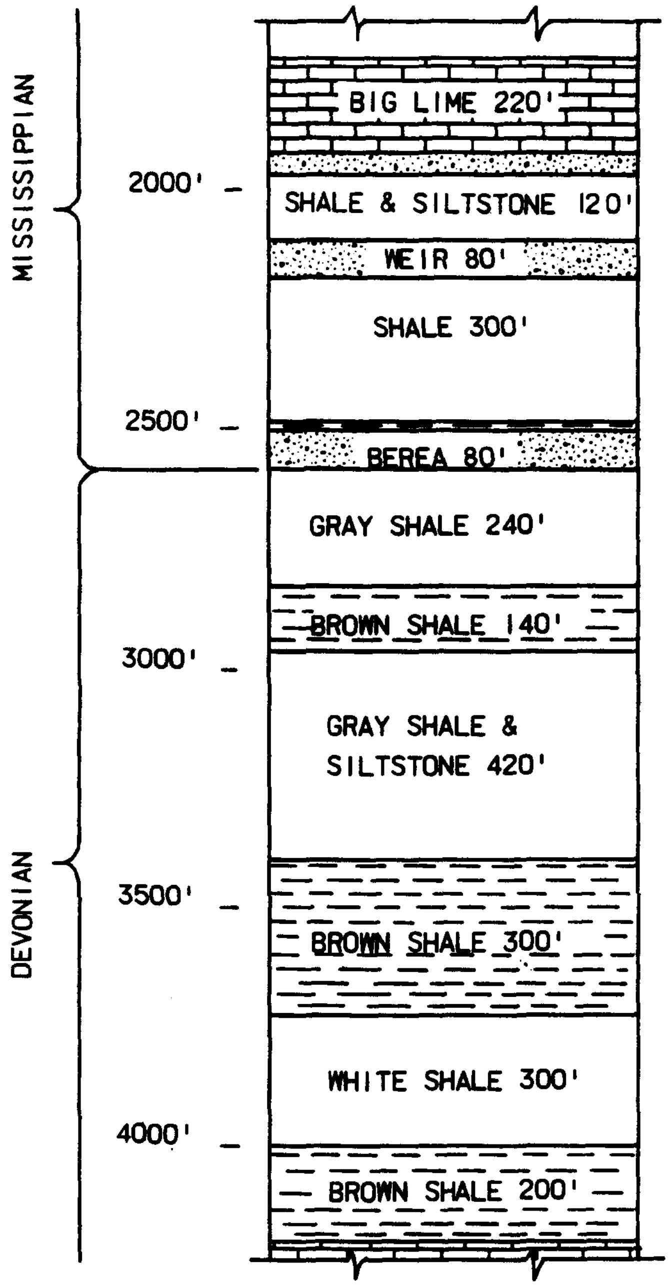

Fig. 2 - Typical driller's log of a Devonian Shale well in Central West Virginia.

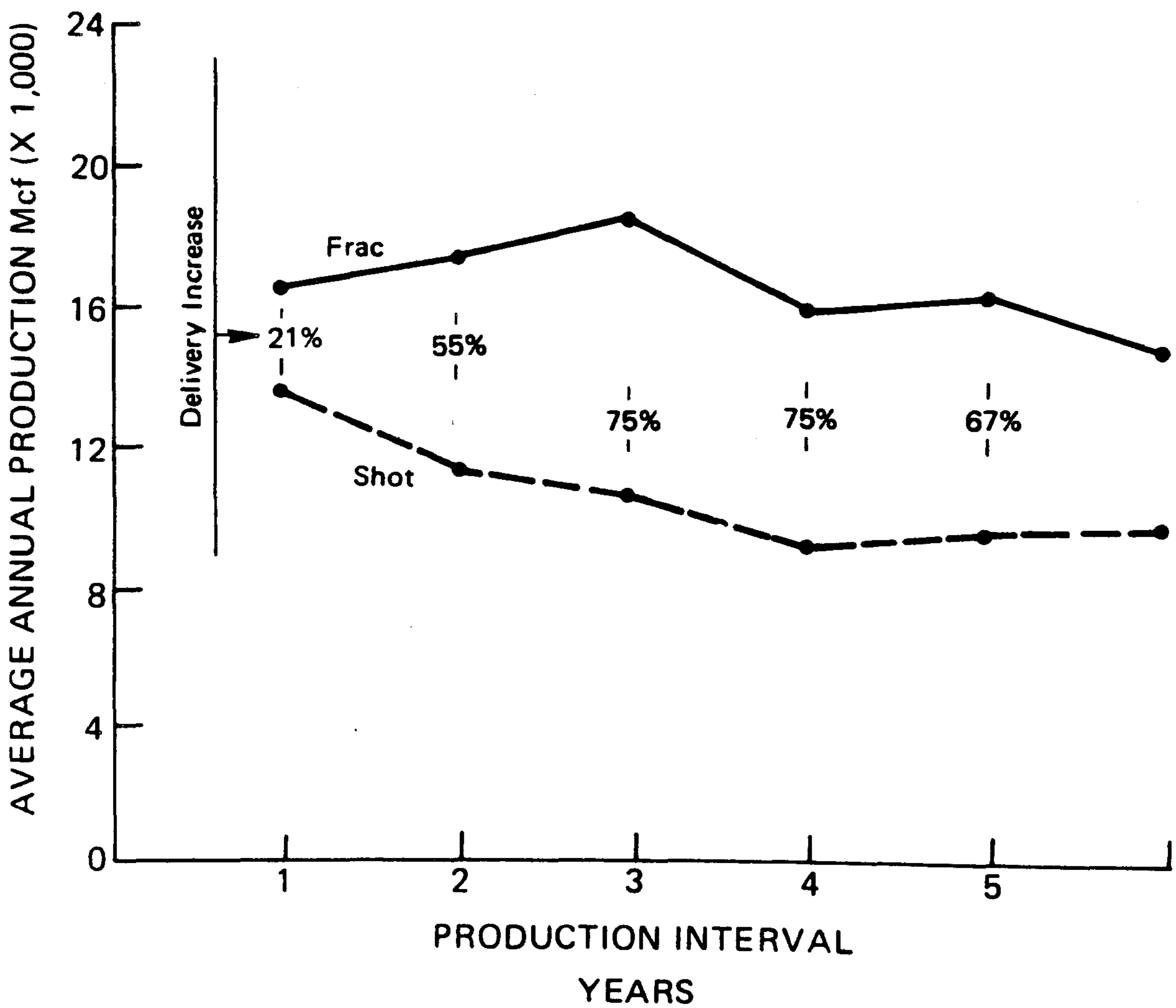

Fig. 3 - Comparison of Devonian Shale gas production by fracturing and shooting at initial open flow between 100-200 MCFD[5].

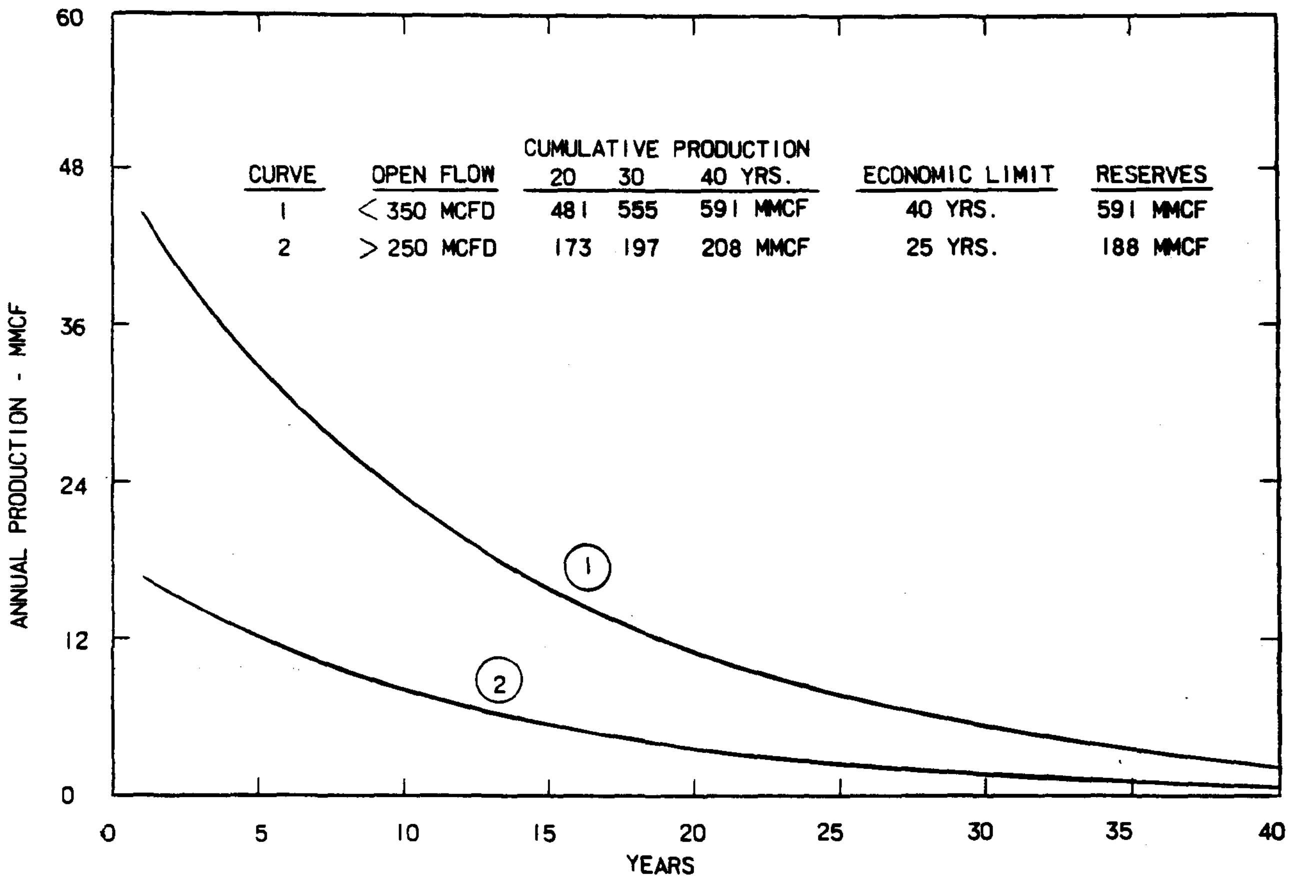

Fig. 4 - Exponential decline curve analysis for hydraulically fractured wells in the Devonian Shale (treatment volume - 1,000 bbls water).