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ECONOMIC EVALUATIONS OF THE PLEASANT BAYOU DESIGN WELL AND OTHER GEOPRESSURE PROSPECTS AND REGIONS

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ABSTRACT

Using the most recent version of the LSU techno-economic model of geopressured resources, both deterministic and stochastic studies were made of the Pleasant Bayou design well, of several prospects in Louisiana, and of a region in Louisiana. New features of the LSU model include: a functional relationship between geopressured drilling costs and well depth, revised forcasts of methane prices, revised cost estimates of facilities, and a Monte Carlo option.

DISCLAIMER

AN ECONOMIC EVALUATION OF THE PLEASANT BAYOU DESIGN WELL

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INTRODUCTION

The selection of the site of the first DOE geopressured-geothermal design test well was based upon a comprehensive geologic study completed in 1978 (Bebout, et al, 1978) of formations in Brazoria County, Texas. Several geopressured sand facies were identified in the Brazoria Propsect and were designated as A, B, C, D, E, and F. A test well site was recommended and it was anticipated that upon drilling to total depth of 16,500' that the well would be completed in sand 'E'. For variety of reasons, which will not be enumerated here, the completion took place in sand 'C' instead. This is pertinant to this paper because two of the Brazoria studies which are reviewed below were based upon the characteristics of sand 'E'. After this review an explanation is given of how the reservoir subroutine of the Louisiana State University Technoeconomic model was 'fine-tuned' using the flow tests conducted at the Pleasant Bayou #2 well. Results of a simulation of sand 'C' is then presented along with an economic evaluation. Sequential production of sand 'C' and sand 'E' is proposed and evaluated in terms of economics and sensitivity to sand characteristics. Finally, the implication of the results on exploration strategy for commercial production of geopressured gas is given.

Review of Brazoria Studies

There have been three studies published recently either solely on Brazoria (Swanson & Osaba, 1979, University of Pennsylvania, 1981) or that incorporate Brazoria (NPC, 1980) which included an economic evaluation of the prospect in some detail. The review of these studies are made with regard to points made later in this paper and consequently will be brief.

The Swanson & Osaba study appears to be a simulation and economic evaluation of sand 'E' in Brazoria since the reservoir parameter assumptions match the estimates for that sand found in (Bebout, et al, 1978). The production characteristics of a well producing from sand 'E' are simulated using a model apparently based on (Parmigiano, 1973). The results indicate that if the well is allowed to flow at a maximum rate of 30,000 BBL/day until the well head pressure declines to zero that production rate of 30,000 BBL/day is maintained for a short period, approximately 1 year. The economic evaluation of this simulation leads Swanson & Osaba (1979) to conclude that "the well will show a small net return on investment if the gas can be sold for $7.50/mcf. This is in spite of the fact that 40 SCF/BBL was assumed and that the 5¢/BBL disposal cost was offset by wellhead brine revenue of 5¢/BBL. The 40 SCF/BBL has not been realized in Brazoria due to the fact that salinities are much higher than expected.

The NPC report completed in 1980 provided a quantitative evaluation of eleven geopressured prospects of which Brazoria was one. A relatively detailed analysis both in terms of economics and reservoir engineering indicated that a single well could return 15% on investment of %6.00/mcf in 1979 for production of gas only despite the fact that investment was 1.7 times that assumed by Swanson & Osaba. This included having the well carry a dry hole burden and no geothermal value. This result is not too surprising in light of the fact that the reservoir simulation indicated that a Brazoria well would produce 30,000 BBL/day continuously for 25+ years at an assumed gas-water ratio of 40 SCF/BBL. The explanation-NPC used the net pay of sands A through F from Bebout, et al, (1978) of 715' as the thickness of the reservoir. This provided the implicit assumption of a continuous sand volume exceeding 2 cubic miles.

The two studies reviewed above were conducted and completed prior to the completion and testing of Pleasant Bayou #2 so the authors did not have the benefit of measurements and test results for their analyses. However, the University of Pennsylvania study was completed in February 1981 and published in April 1981. The authors in this case had access to information from the test well. This study consists of 1) a review and critique of three studies on Brazoria, 2) a description of the resource characteristics, 3) a description of a risk adjusted Monte Carlo financial model, and 4) a set of sensitivity analyses of a hypothetical well. Well production for 20 years was determined by computing the volume of brine in the reservoir and multiplying by a recovery factor, say .045, "and a production path is then assumed. For cash flow modeling, it is assumed that there is a constant flow rate in the early years followed by a steady decline" (University of Pennsylvania, 1981). Four reservoir parameters constitute the input and their "most likely" values are 1) effective drainage area, 16 mi^2; 2) effective sand thickness, 250 ft.; 3) reservoir porosity, .17; and 4) methane solubility, 25 SCF/BBL. These parameters are identical to sand 'E' with the exception of thickness which in the past has been assumed as 230 ft. There were several conclusions to this study but only one is cited since it is comparable to the results reported on the previous two. "A reservoir that possesses our base case parameters (which is based on the best available information for the Austin Bayou Project), presents an acceptable investment opportunity after adjustment for risks, when the initial price is between \$7.00 and \$7.25/mcf, and the price escalates at a nominal rate of 8.5%."

Adjusting the LSU Model to Simulate Sand 'C'

The Phase I and Phase II drawdown and buildup test results were used as a basis for adjusting the reservoir parameters in the LSU model so that the pressure and flow behavior for sand 'C' would correspond to that indicated by the test results. Since the LSU program uses a single well, bounded, cylindrical reservoir model, the match with test results should not be expected to be as close as that attainable with a two-dimensional model, such as those used by Intercomp and S^3.

In Table I are listed the values of reservoir parameters determined to be the most representative for sand 'C' based on test well results. The effective compressibility of 7.7×10^{-6} psi^{-1}, is that used by Garg, et al, 1981, based on a water compressibility of 3.0×10^{-6}, a sand compressibility of 1.0×10^{-6}, and a porosity of 0.176. Using this value for effective compressibility, the volume of sand 'C' was calculated from Phase I static drawdown data to be 0.473 cu. mi. (Garg, et al, 1981). From the Phase II drawdown and buildup tests, Garg recommended a value of 192 millidarcies for the average permeability, k, when the effective sand thickness is taken at 60 ft. (that is equal to the perforation interval). Using a 60 ft. thickness and a volume of 0.473 cu. mil., the area of the sand is 41.4 sq. mi. On the other hand, the sand thickness contours (Bebout, et al) suggest that sand 'C' ranges from 60 ft. to 140 ft. in thickness, and that the areal extent of the sand is not likely to be as high as 41.4 sq. mi. It was decided that an effective sand thickness of 100 ft. would be more representative of the reservoir, giving 115 millidarcies for the average permeability and an areal extent of 24.8 sq. mi. It turns out that for a given volume of 0.473 cu. mi. and a given kH product of (192)(60) millidarcy-ft., the choice of either a 60 ft. or a 100 ft. thickness produced essentially the same pressure flow characteristics.

To match the pressures and flow rates observed in the drawdown tests of Phase II and those observed in later tests (Rodgers, 1981), it was necessary to use a skin factor of 12.5. Comparisons between flows and pressures, from the reservoir simulation with those from the drawdown tests are shown in Table II. These results are reasonably close, and serve to validate the reservoir model based on the available well test data. (It should be noted that in this simplified model, the skin factor is correcting both for the expected change in permeability in the vicinity of the well bore and also for the differences in the unknown geometry of the actual reservoir compared to the assumed circular, constant thickness, symmetrical reservoir of the model).

Economic Evaluation of Sand 'C'

The LSU Technoeconomic Site Simulation model adjusted to be sand 'C' specific as previously described was used to evaluate the economics of producing from sand 'C'. The reservoir subroutine is an analytical simulator of reservoir performance using pre-semi-steady-state and semi-steady-state solutions to the radial diffusivity equation for a bounded aquifer. Economic output results from a straight forward but detailed discounted cash flow model. A complete description of the model, with the exception of some recent refinements, can be found in Operations Research and Systems Analysis of Geopressured-Geothermal Energy in Louisiana: Final Report June 1, 1978, to August 31, 1979, #DOE/ET/27085-1. The major reservoir and economic assumptions are listed below:

Reservoir - Sand 'C'

Area-24.8 mi^2
Thickness-100 ft.
Porosity-.176
Permeability-115 md.
Initial Reservoir Pressure-11,168 psi
Initial Reservoir Temp.-306°
Depth 14,674 ft.
Salinity-.149 lb. salt/lb. water
Compressibility-7.7 x 10^{-6} psi^{-1}

Economic

Well Cost-1 Production
-2 Disposal-
$5,173,600
Surface Equipment-$950,000
Operating Cost-4¢/BBL
Gas Price-$7.14/mcf
Severance Tax-7¢/mcf
Royalty-8.5 %

Project Life-20 years

The operating costs represent a production rate of 40,000 BBL/day and are scaled to lower production rates using the 'six-tenths rate' so as production declines the unit disposal costs increases. The well coast is based upon an analysis of API costs by depth and include a 25% surcharge for a geopressured well.

Production estimates from 20 years from the reservoir section of the model are shown in Figures 1 and 2. Figure 1 shows the brine production of the well begins in year 1 at an average daily rate of 40,000 BBL and drops precipitously to a level of 219 BBL/day in year 20. The proportion of brine recovered from sand 'C' over the twenty years was 3.3%. Figure 2 shows the gas-water ratio of recovered gas over the twenty years of production which does not include the 2 or 3 cubic feet of gas that remains in solution. The recovered gas per barrel drops from 21.15 cubic feet per barrel to 19.85 cubic feet per barrel over the twenty years. This is a result of declining in the sand and resultant exsolving of free gas into pore space in the sand. The combination of declining brine production and declining gas-water ratios results in a decline over the twenty years of the gas production per day as illustrated in Figure 3. Production of gas drops from 846 mscf/day in the first year to 4 mscf/day in the twentieth year.

With these less than encouraging production results it is not surprising to find that the economic evaluation using a constant dollar discounted cash flow analysis is less than encouraging also. Before examining the economics of sand 'C' clarification of the measures of profitability need to be made. In this study the measures of profitability are the net present value of the project given the average opportunity cost of the investment and the rate of return necessary to provide a net present value of zero. The University of Pennsylvania study criticizes such measures since they ignore the return on reinvestment of annual revenue. The authors understand the reinvestment problem but do not agree that not accounting for reinvestment results in inappropriate measures of profitability. This is a methodological question and will not be treated here.

An arbitratily assigned, but generally accepted, rate of return of 15% was used to determine the net present value of sand 'C' given the economic assumptions above. It should also be pointed out that it is further assumed that the developer is single entrepreneur with no related income which essentially prevents him from benefiting from the available investment tax credit of approximately $265,000. This is because a loss is carried for about six years due to the intangible drilling investment expensed in the first year. The net present value at 15% under such conditions is a negative $1,616,230. Even with the full investment tax credit this would only be increased to about a negative $1.5 million. If the rate of return is computed that produces a net present value of zero, a value of 1.13% results. Both of these results are due to declining gross revenues, declining revenue per barrel of brine production, and an increasing unit cost of disposal. A final economic consideration is price. What price would have to be obtained to achieve a 15% rate of return on sand 'C'? When the model is used to solve for this critical value the resultant price is $9.46/mcf. This price is somewhat unrealistic in light of the existing market for deregulated gas.

The above represents the current evaluation by the authors as to the economic potential of Brazoria. It differs somewhat from the evaluation of previous studies, mainly because the others considered sand 'E' or the entire net pay of sands A through F, and it reflects the use of available reservoir data from the Pleasant Bayou #2 test well which was either unavailable or unused by presious studies.

Further Consideration of the Economics of Brazoria

It was the intention of the authors to examine results of a Monte Carlo analysis of sand 'C' after completing the deterministic analysis reported above. However, the determination of the probability of a large loss or the probability of a small loss at a 15% rate of return did not exactly seem to be a very interesting activity. Instead, the original testing plan recommendation was reviewed, namely completing in sand 'E' which of course has been the subject of analysis in prior studies. This review resulted in the realization that most if not all economic evaluation of geopressured gas had their basis in producing from one continuous sand. The question arose "What would be the economics of Brazoria if both sand 'C' and sand 'E' were produced from the same well?" This presents a limitation to our modeling efforts since the LSU model is not currently capable of simulating reservoir production characteristics when producing from two separate sands simultaneously. Therefore, sequential production was considered, that is, "What would the production and economics look like if sand 'C' was produced and then at some point in the future it was shut in and the well re-completed in sand 'E'?

This question was approached by assuming that sand 'C' was produced first (as it is) at the assumed costs stated earlier. The previous simulation then provides the operating cost until the perforation is cemented. A re-completion cost of %500,000 was then assumed for bringing sand 'E' into production and the model was then used to simulate the production characteristics of sand 'E'.

This raises the question, "When should sand 'C' be cemented and sand 'E' recompleted?" In other words, the optimum recompletion date had to be determined. From an economic point of view, the optimum recompletion date would be that date which maximized net present value at a 15% rate of return. Due to the current limitation of the model this could not be done internally and an estimate of net present value(NPV) was used consisting of the discounted sum of the annual value of total revenue net of operating costs and investment to evaluate various dates of recompletion.

Sand 'E' was simulated using the following reservoir parameters:

Area	16 mi^2
Thickness	200 ft.
Porosity	.18
Permeability	15 md
Pressure	10,868 psi
Temperature	325°
Depth	15,750 ft.
Salinity	136 lb. salt/lb.water
Compressibility	7.7 x $10^{-6} psi^{-1}$

This simulation produced a set of cash flow vectors using the previously identified economic assumptions with exception of total investment which is $500,000. These cash flows then replace those generated by the production of sand 'C' after the date of recompletion. The combination of cash flows from sand 'C' before recompletion and cash flows from sand 'E' after recompletion were used to compute NPV*. This was done for all possible recompletion dates, years 2 through 20. The result of this procedure is illustrated in Figure 4. Recompleting in year 2 produces a NPV* of approximately -$1.1 million which rises as the recompletion date is delayed in annual increments until year 5 when it obtains a maximum of-$.23 million. After year 5 the NPV* declines reaching a minimum value of -$1.6 million with recompletion in year 20. This value is consistent with prior analysis of sand 'C' since in it represents a 19 year production of sand 'C' and the discounted contribution of recompletion in year 20 is negligible.

With the optimum date of recompletion identified the specific production schedule that produced it can be examined. Figure 5 illustrated the brine production from sand 'C' and sand 'E' over a twenty year schedule. The sand 'E' production simulation is very similar to that reported by Swanson and Osaba (1978) with initial production near 30,000 BBL/day and dropping to less than 2000 BBL/day in year 20. Also illustrated is the production schedule when sand 'E' is recompleted in year 5 replacing sand 'C'. The difference in brine production from the two sands is distinct. Sand 'C' has a much higher initial production rate (40,000 BBL/day) than sand 'E' but production drops off rapidly and is approximately equivalent sand 'E' in year 6. From that point on sand 'E' production exceeds that of sand'C'; neither sand is particularly attractive. Recompletion of sand 'E' provides a dramatic change in the production schedule of the well. Brine production remains above 20,000 BBL/day through the 7th year instead of dropping to about 10,000 BBL/day; in year 10 it is three times the sand 'C' production of less than 5000 BBL/day.

Methane in solution changes with recompletion because of the difference in temperature of the brine in the two sands. Gas recovery per barrel of brine is illustrated in Figure 6 for the recompletion case. It rises from just over 20 scf/BBL in year 4 to over 25 scf/BBL in year 5. The amount of gas recovered per barrel then drops with an irregular pattern until year 16 when it stabilizes at 24 scf/BBL. The irregular pattern is a result of pressure changes due to discrete reductions in the flow rate of the well to maintain a minimum wellhead pressure of 500 psi.

Figure 7 shows the result of the conbined effects of changes in brine production and methane solubility under recompletion conditions on the toal gas production per day. Gas production begins at a rate of approximately 850 mscf/day in year 1 and drops to rate of 450 mscf/day in year 4. Recompletion brings the rate of production up to 725 mscf/day in year 5 and it then drops annually to a rate of 75 mscf/day in year 20. The contribution of recompletion is obvious, the rate of production remains above 450 mscf/day through year 8 while production of sand 'C' only results in a production rate of 150 mscf/day in year 8. The effect of the greater methane solubility of sand 'E' is apparent if the relative change in daily production of brine from year 4 to year 5 is compared to the relative change in gas produced per day from year 4 to year 5. Brine production per day increased by 27.8% while gas production per day increased by 59.4% from year 4 to year 5.

These changes in production have an expected positive effect on the economic evaluation of Pleasant Bayou #2. It should be emphasized, however, that risk has been ignored in this simulation and the development and production of sand 'E' is less certain than sand 'C'. With this caveat understood, the basic measures of profitability of recompletion after adjusting NPV* for the effect of taxes can be compared to producing sand 'C' only. The net present value of the recompletion case with a discount rate of 15% is -$.58 million compared with the -$1.62 million of producing sand 'C' alone. This reflects a substantial improvement and is evident when the rate of return necessary to produce a net present value of zero is compered. The rate of return for the recompletion case is 12.5%, determined from linear interpolation while the sand 'C' only case produces a return of 1.13%. Although a critical price for a 15% return has not been computed for the recompletion case, it is likely that the price would lie in the neighborhood of $8.00/mcf to $8.50/mcf which is an improvement over the $9.46/mcf found under sand 'C' only case.

A final issue considered is the sensitivity of the selection of optimum date for recompletion of permeability and drainage area of sand 'E'. Two cases were considered:

1) an increase in permeability from the base value of 14 md to 40 md.
2) an increase in drainage area from 16 mi^2 to 30 mi^2.

The method described previously was used to determine the optimum date for recompletion for these two new cases. Figure 8 illustrates the results of this optimization procedure. The base case is included in the figure. The vertical distribution of the NPV* curves are as expected. Higher permeabilities produce higher flows and greater revenues while a larger drainage area allows initial flows to be sustained longer with a more gradual decline in flows over project life. The interesting point is that the optimum recompletion date is changed to year 4 - only one year difference from base case - with substantial changes in permeability and drainage area.

Implications of This Analysis

This analysis has diverged from the authors' previous work in the economic analysis of commerical production of geopressured gas. Prior work has been based upon the notion that only a single equivalent sand would be produced at a site. This same presumption is found in other studies which have evaluated the economic potential of geopressured-geothermal resources. The results of these analyses have been generally that large continuous permeable sands with high gas-water ratios would be required for a commercial grade site. Geological exploration strategy and evaluations have ultimately been influenced by this conclusion. If one believes current opinion about continuity and salinity it appears unlikely that geologists will have very much success in identifying a site that fits the requirement that most economic analysis has focused upon. The initial results of this analysis suggests a different exploration strategy. Rather than attempting to identify a single "ideal" sand perhaps geologists should identify sites that are composed of several separate sands that could be produced sequentially. This is not a complete departure from prior site identification efforts and quite often the resulting economic analysis has suffered from a lack of full utilization of the geologic information available for a prospect.

As for future research efforts at LSU, they will be directed toward the inclusion of the sequential production model described herein into the LSU Technoeconomic Site Simulation model. The existing limitation that prevents the simulation of simultaneous production from multiple sands will be addressed and remedied. The economic subroutines of the model will be modified to include the optimization of the production schedule of multiple sand completion. In the analysis of additional sites more detailed treatment will be given to the sensitivity of optimum production scheldules to reservoir parameters.

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TABLE I

RESERVOIR PARAMETERS USED FOR SAND "C"

Porosity, ρ	0.176	
Compressibility, C	7.7×10^{-6}	psi^{-1}
Volume, V	0.473	cu. mi.
K H product	11520	millidary-ft.
CASE 1:		
Thickness, H	60	ft.
Permeability, K	192	millidaries
Area, A	41.6	sq. mi.
CASE 2:		
Thickness, H	100	ft.
Permeability, K	115	millidaries
Area, A	24.8	sq. mi.
Temperature, T	306	°F
Salinity, S	130,000	ppm
Depth, D	14,674	ft.
Pressure, P	11,168	psi

Table II

Comparison of Reservoir Model Calculations
With Draw-Down Test Results

Flow	Pressure from Test Well, psia	Pressure from* Model psia	DP
6436	10870	10785	85
18184	10200	10088	112
29076	9439	9442	3

*Using skin factor of 12.5

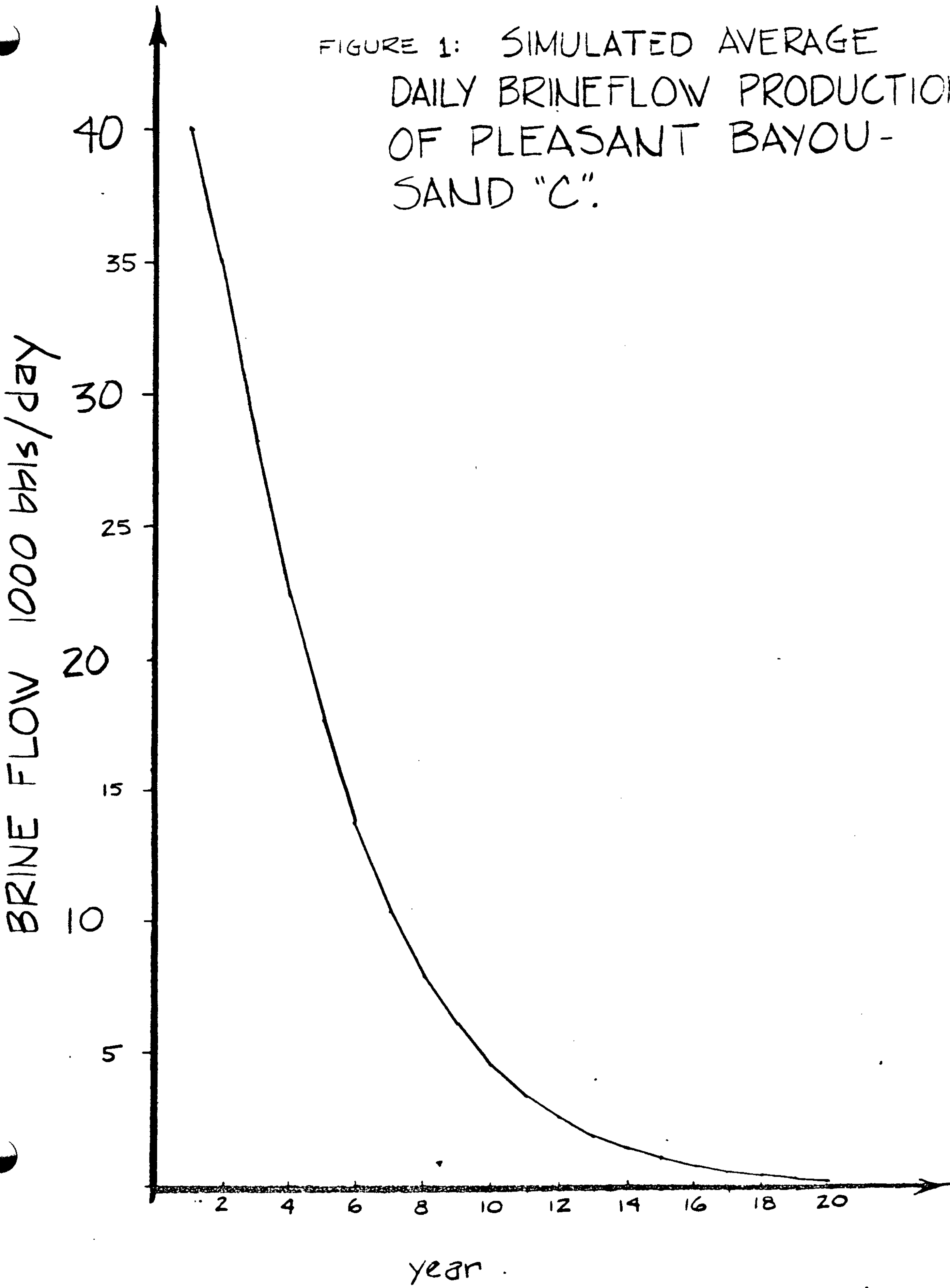
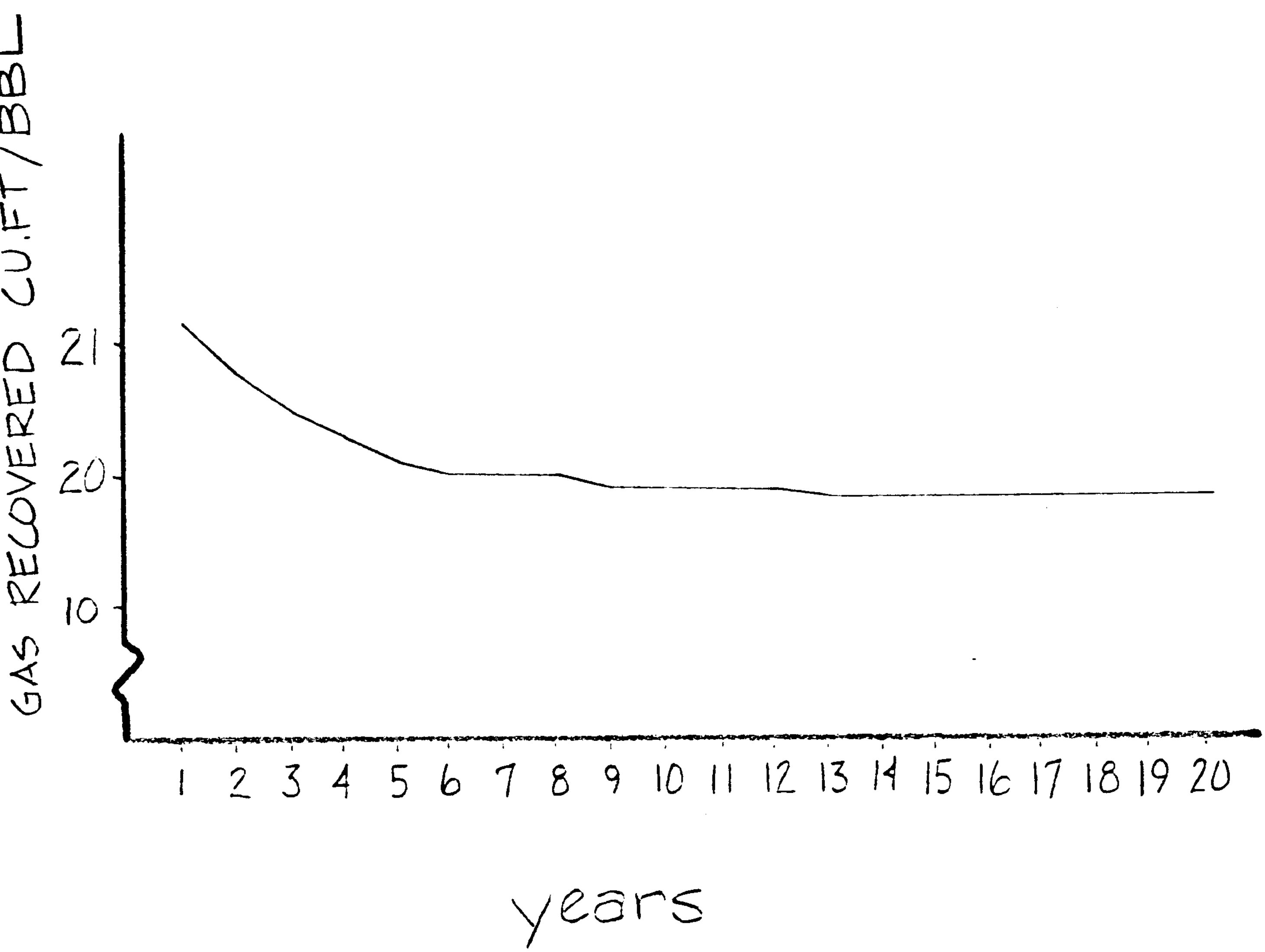


FIGURE 1: SIMULATED AVERAGE DAILY BRINEFLOW PRODUCTION OF PLEASANT BAYOU-SAND "C".

FIGURE 2: ESTIMATED GAS RECOVERY PER BARREL SAND "C".



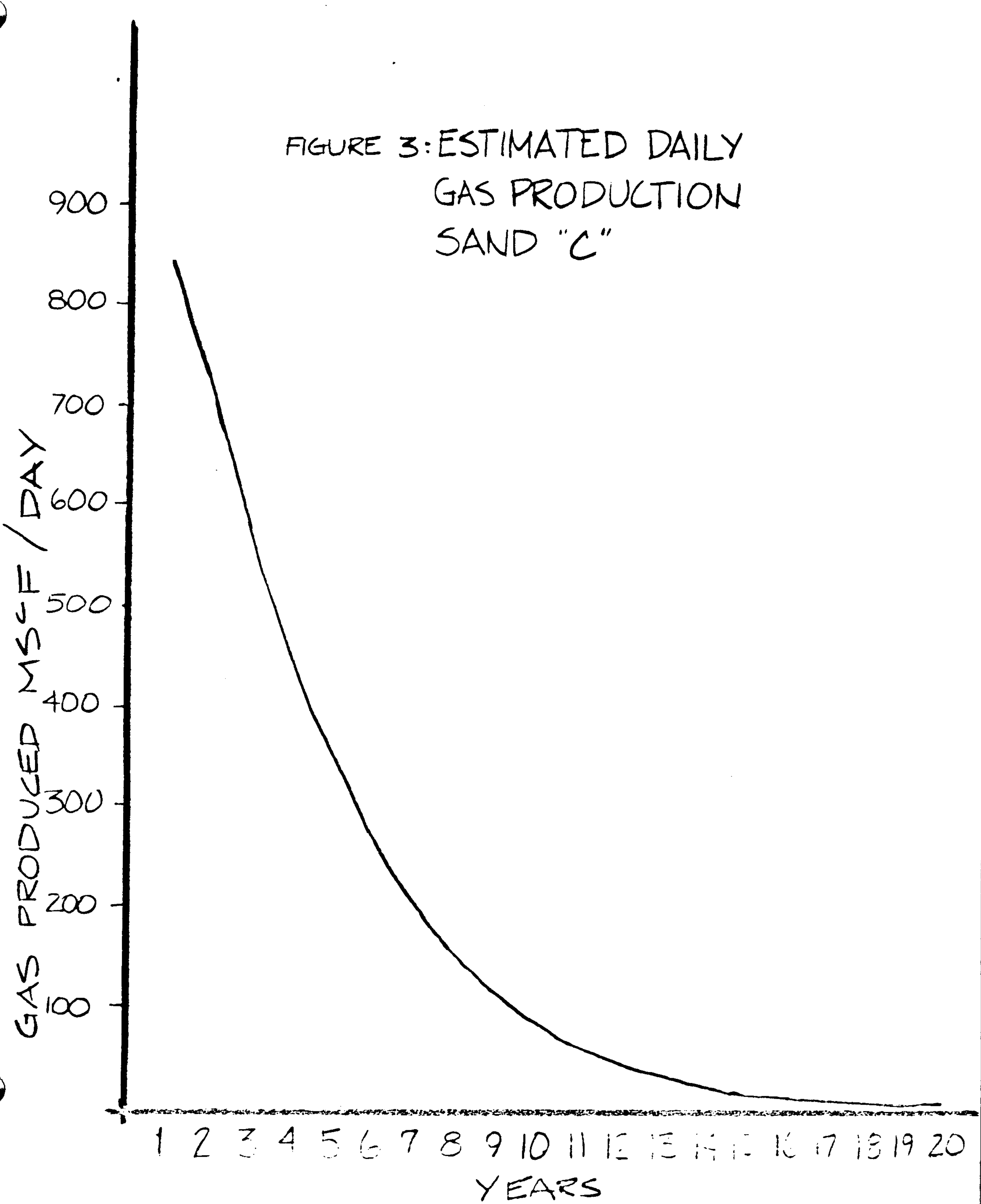


FIGURE 3: ESTIMATED DAILY GAS PRODUCTION SAND "C"

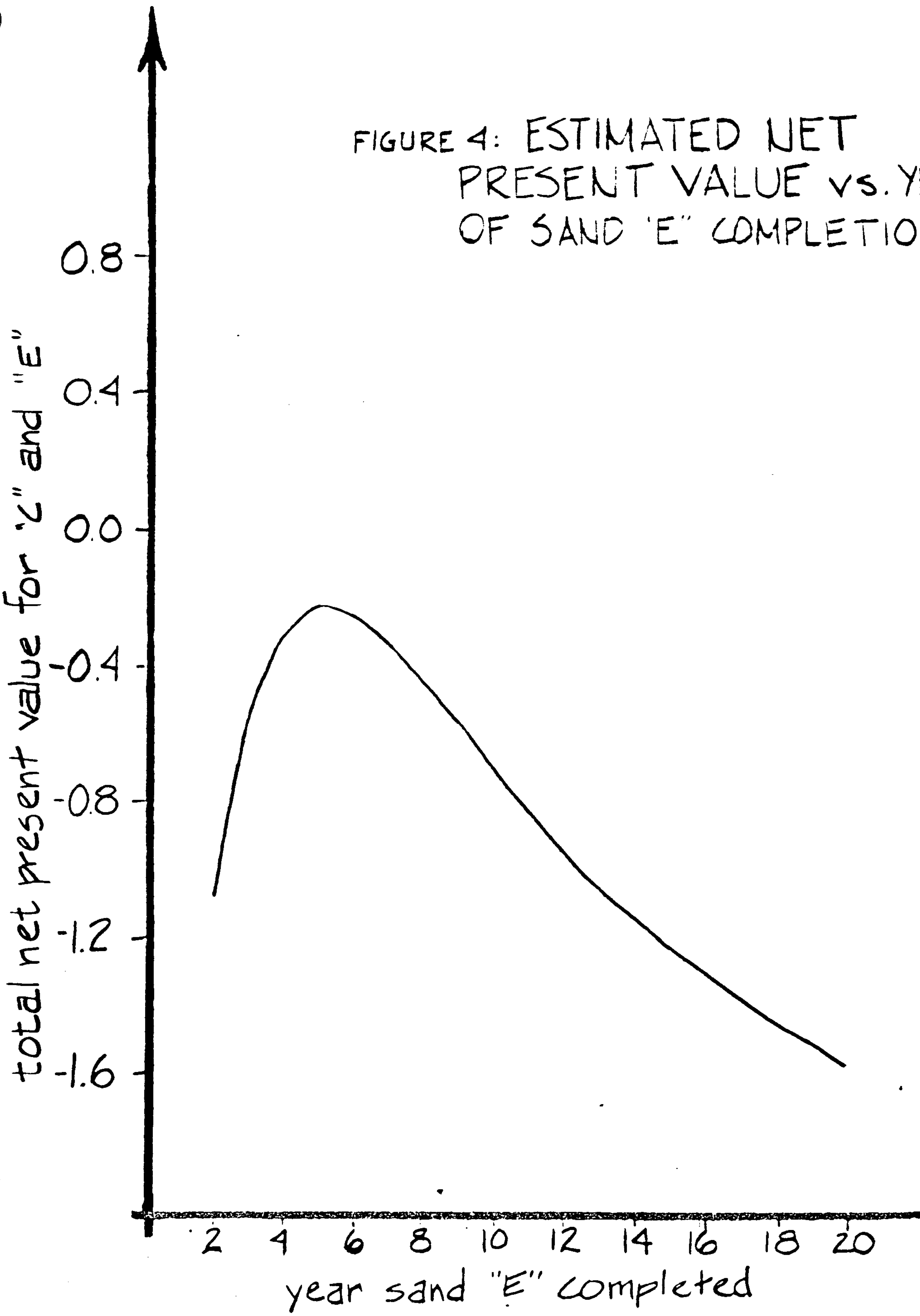


FIGURE 4: ESTIMATED NET PRESENT VALUE vs. YEAR OF SAND "E" COMPLETION

FIGURE 5: SIMULATED AVERAGE DAILY PRODUCTION OF PLEASANT BAYOU #2 W/ MULTICOMPLETION IN YEAR 5

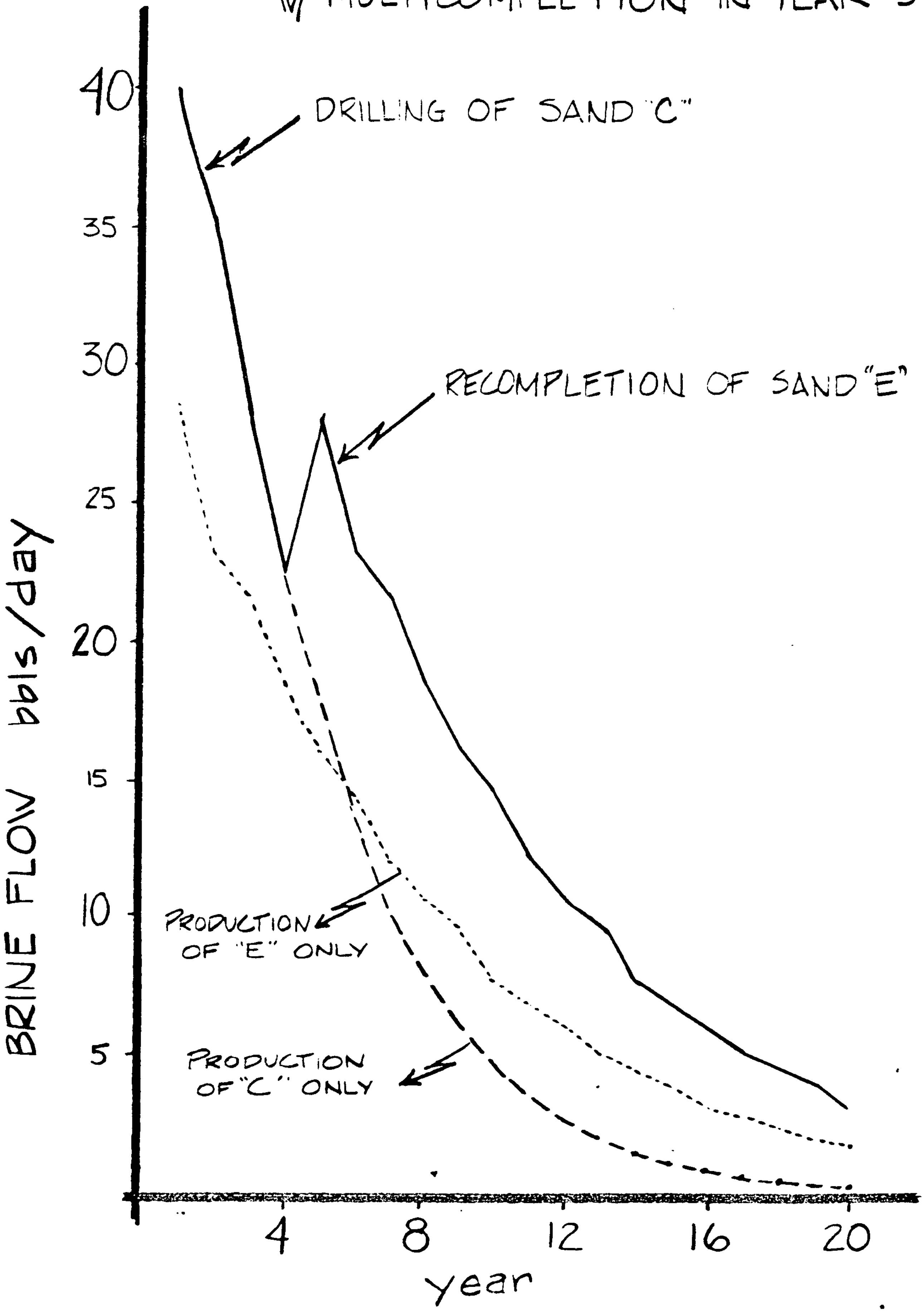


FIGURE 6: ESTIMATED GAS RECOVERY PER BARREL WITH RECOMPLETION OF SAND "E"

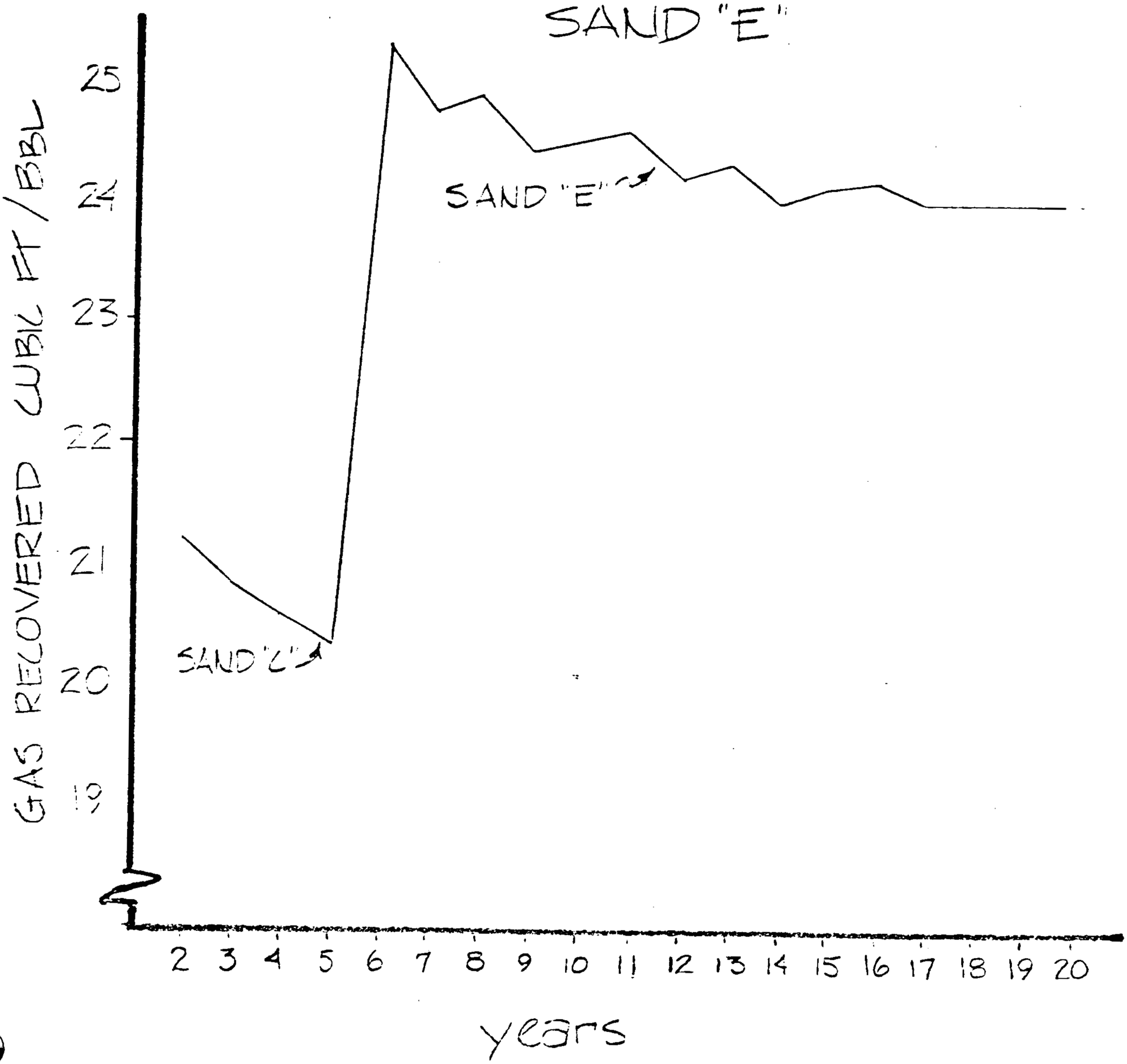


FIGURE 7: ESTIMATED TOTAL GAS PRODUCTION PER DAY WITH RECOMPLETION OF SAND "E".

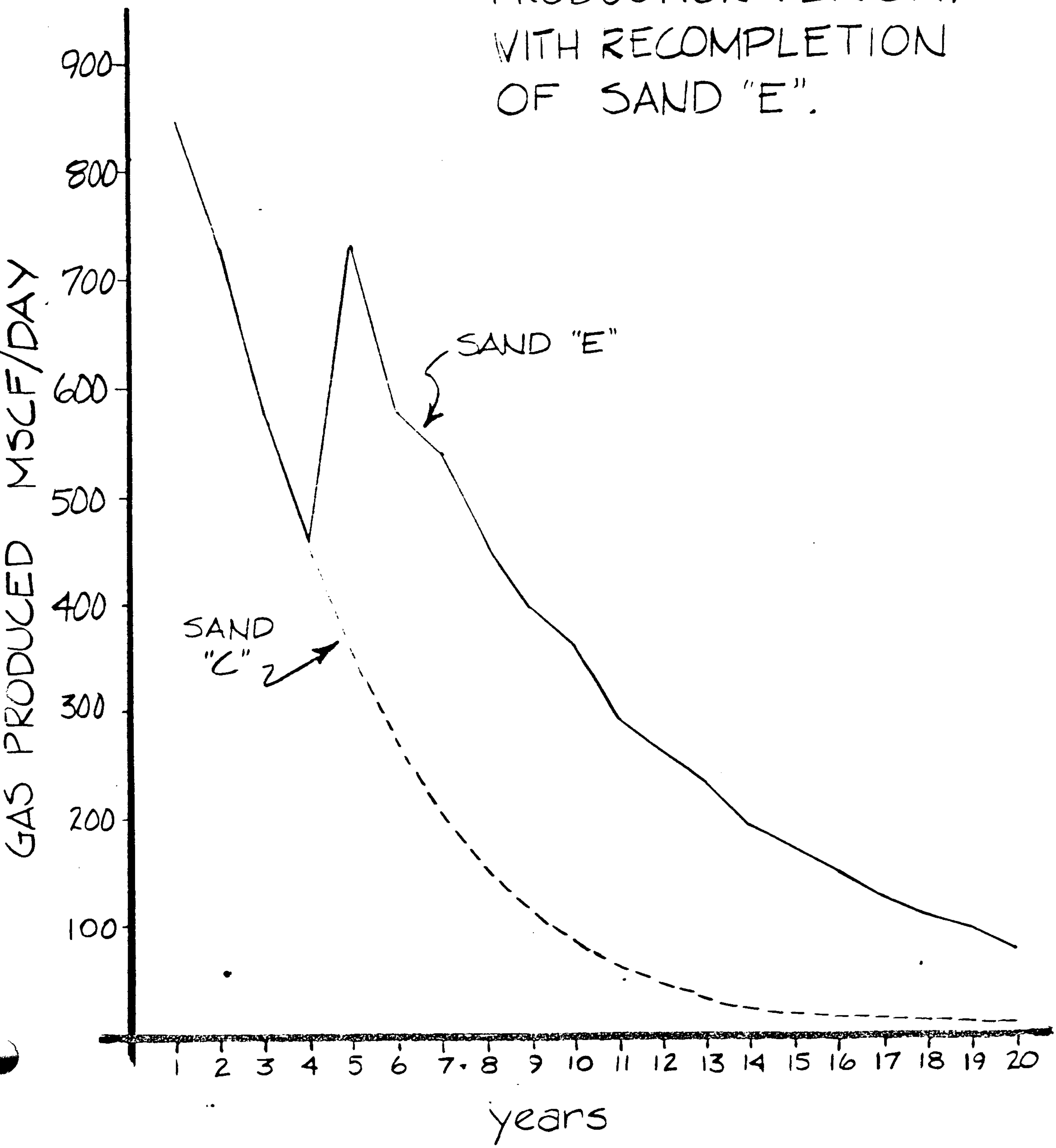


FIGURE 8: N.P.V. AND RECOMPLETION DATE SENSITIVITY TO PERMEABILITY AND AREA OF SAND "E".