Future Petroleum Producing Capacity of the United States

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A discussion of the nature of certain petroleum statistics and estimates and their meaningfulness in appraising the outlook for future supply

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ABSTRACT

Prediction of future petroleum producing capacity should be based on the statistical record of the past, interpreted in the light of the known trends and circumstances that are not amenable to statistical expression. For a dynamic industry such as the petroleum industry, the most recent statistical record should be the most meaningful as to the future.

Recent published predictions of future producing capacity of the United States have been based primarily on either (a) the yearly estimates of proved reserves prepared by committees of the American Petroleum Institute and the American Gas Association, or (b) estimates of the total amount of ultimately recoverable petroleum, including the undiscovered quantity. These two types of estimates have been carefully examined so that the suitability of each as a basis for prediction could be appraised.

Estimates of proved reserves for recently discovered pools are, by their nature, subject to extensive revision in future years, and the historical record shows that such revisions have been almost invariably upward and that the increases have been of very considerable magnitude. The rate of development of a new supply of crude oil in the United States as suggested by recent proved-reserve estimates was found to be ultraconservative when examined in the light of the recent rate of increase in producing capacity, the decline-curve principle, and the major historical trends that affect the ratio of producible reserves to producing capacity. Accordingly, the statistics of proved-reserve estimates are not considered a suitable basis for predicting future producing capacity.

Ultimate "reserves" of petroleum consist of (a) the quantity produced plus the quantity yet to be produced from known pools, and (b) the economically recoverable quantity not yet discovered. History has shown that pre-1950 estimates of the ultimate "reserves" of the United States have already proved unreliable. Past production is measurable, but the amount yet to be produced from known pools is very uncertain because of the limitations of methods of estimating producible reserves, including unpredictability of the quantitative effect of technological progress. Estimation of undiscovered petroleum introduces further, and considerably greater, uncertainties. Only a relatively small proportion of geologically favorable rocks have been explored so far; the full

range of geologic settings of petroleum occurrence is probably not yet known; and present information is inadequate for quantitatively predicting the incidence of known favorable geologic settings in the unexplored rocks. Accordingly, it is concluded that it is not yet possible to predict ultimate "reserves reliably." But from consideration of the large volume of geologically favorable rocks yet to be explored, and the recent record of success in exploring geologically similar rocks, it is concluded that the quantity of undiscovered petroleum will not constitute a limiting factor on producing capacity in the next 10–20 years, at least, and probably for a much longer time.

From study of the nature and probable accuracy of the various types of quantitative data and estimates that might be used as a basis for prediction, it is concluded that the recent rate of growth in producing capacity itself is the most realistic basis. Producing capacity consists of the current rate of production, which is measurable, and the reserve producing capacity, which is virtually the amount by which production is curtailed to prevent overproduction with respect to market demand. The reserve producing capacity is an estimate, but is not subject to much error. Thus, estimates of producing capacity are intrinsically more accurate than estimates of either proved or ultimate "reserves"; moreover, by their nature, estimates of producing capacity are sensitive to recent trends and are verifiable on a short-term basis.

From near the end of World War II, when crude-oil wells in the United States were producing virtually at a capacity rate of approximately 4.7 million barrels daily, crude-oil producing capacity steadily increased to a level of about 9.9 million barrels daily at the beginning of 1957, according to a series of estimates based on surveys sponsored by the National Petroleum Council and the Petroleum Administration for Defense. This increase in producing capacity was principally due to the high and increasing rate of completion of new crude-oil wells. The relatively high capacity of these younger wells more than offset the normal slow decline in capacity of older wells. The increasing number of new oil wells was in turn the result of a great expansion in total number of wells drilled yearly—from about 25,000 at the beginning of the period to a peak of more than 57,000 in 1956—and maintenance of a consistent success ratio through extensive and increasing reliance on technical advice in locating and testing wells. Widening application of engineering advances, which tend to arrest decline in productivity both of old and new wells, and to rejuvenate some old wells, has also been an important factor.

If demand for domestically produced crude oil during the next 10–20 years justifies an expansion in drilling comparable to the expansion during the post-World War II period, an increase in producing capacity comparable to that of the recent past may be expected.

Past estimates of producing capacity for natural gas and natural gas liquids comparable to those for crude oil are not available to serve as a basis for prediction. These commodities are genetically associated with crude oil, however, and certain inferences as to future capacity to produce may be drawn from presently known quantitative relations to crude oil. From present knowledge of underground quantities and rates of extractability, it is evident that the capacity of existing wells to produce these commodities (without regard to pipeline or processing-plant capacity) is greater, relative to current production rates, than for crude oil. This will probably continue to be so for many years to come, for discovery of greater relative quantities of natural gas and natural gas liquids may be confidently expected with increasing average depth of exploration in the future.

INTRODUCTION

Any forecast of the future petroleum producing capacity of the United States obviously must be based on available measurements or quantitative estimates pertaining to petroleum, and there are several possible approaches to the problem, depending on which set of measurements or estimates is chosen as fundamental. Recent published predictions as to the future producing capacity of the United States have been based primarily on either the yearly estimates of proved reserves prepared by committees of the American Petroleum Institute and the American Gas Association or estimates of the total amount of ultimately recoverable petroleum, including the undiscovered quantity. A third possible basis for prediction is the recent record of increase in producing capacity, as shown by a series of recent surveys sponsored by the National Petroleum Council and the Petroleum Administration for Defense. Careful consideration was given to the nature and intrinsic accuracy of each type of data or estimate and the historical trends affecting them. From this study, it was concluded that the recent record of development of producing capacity is the most meaningful as to what may be expected in the foreseeable future. The reasoning that led to this choice is summarized in this paper.

The study was concerned entirely with domestic sources of fluid petroleum from natural subsurface reservoirs; supplemental sources such as oil shale were not included. A basic assumption in the study was that economic incentive to discover and produce petroleum in the future will continue comparable to that since World War II.

This summary is based in part on a staff study in which many members of the Geological Survey participated. Also, the author gratefully acknowledges many helpful suggestions from those who critically reviewed the manuscript.

RATE OF PRODUCTION AND PRODUCING CAPACITY

Rate of production is, of course, the rate at which petroleum is brought to the surface; producing capacity is the maximum rate of production possible under existing production practice. As discussed below (p. H-6), historical changes in general production practice have somewhat changed the meaning of the term "producing capacity."

Rate of production and producing capacity are commonly expressed as barrels per day for crude oil and as thousands of cubic feet (MCF) per day for natural gas. The units of volume are those under standard conditions of temperature and pressure at the earth's surface. In moving from the higher pressures in subsurface reservoirs to the lower pressures at the earth's surface, crude oil generally shrinks in volume because of loss of dissolved gas, whereas natural gas expands. Pressure increases with depth—consequently, the magnitude of these volumetric effects increases.

Production rates of individual wells or groups of wells are directly measurable by means of mechanical gauges inserted into gathering flow lines, or by the use of calibrated storage tanks for a measured period of time. However, the usual statistical data in terms of barrels daily or thousands of cubic feet daily represent *average* rates, derived by dividing monthly or yearly total production by the number of days in the month or year. Many oil wells in the United States are allowed to produce during only a certain number of days each month; so the statistical *average* rate of production is lower than the actual rate when the wells are continuously producing.

DECLINE CURVES

Experience with hundreds of thousands of wells has shown that the rate of production of an individual oil well, if continuously produced at the maximum possible rate and without change in production practice, declines steadily with time. A plot of the rate of production against time is called a decline curve. An example of one common type of decline curve—the "constant percentage (semilog, exponential)" curve—is shown, plotted on regular coordinate paper, in figure 1*A*. In this particular type of decline, the production rate at the end of each successive equal period of producing time is a fixed percentage of the rate at the end of the preceding period; a straight line results when the rate of production is plotted against cumulative production on regular coordinate paper (fig. 1*B*). Individual decline curves vary considerably in shape,[1] but virtually all are roughly similar in that they on regular coordinate paper are convex toward the origin when rate of production is plotted against time, as in figure 1*A*. Artificial stimulation of production by any of numerous present-day methods may rejuvenate a well and start a second cycle of decline. The rate of production eventually declines to a level too low for profitable operation and the well is abandoned. As stated by Ball (1940, p. 143), "No one can understand the oil business who has not grasped the universality of the decline curve * * *."

EFFECT OF CONSERVATION

Before about 1930 the petroleum industry attempted to recover oil at the maximum possible immediate rate. When a new field was found it was literally punched full of closely spaced wells, which were

[1] For theoretical analysis of the various classes of decline curves, see Arps (1945) and Pirson (1946).

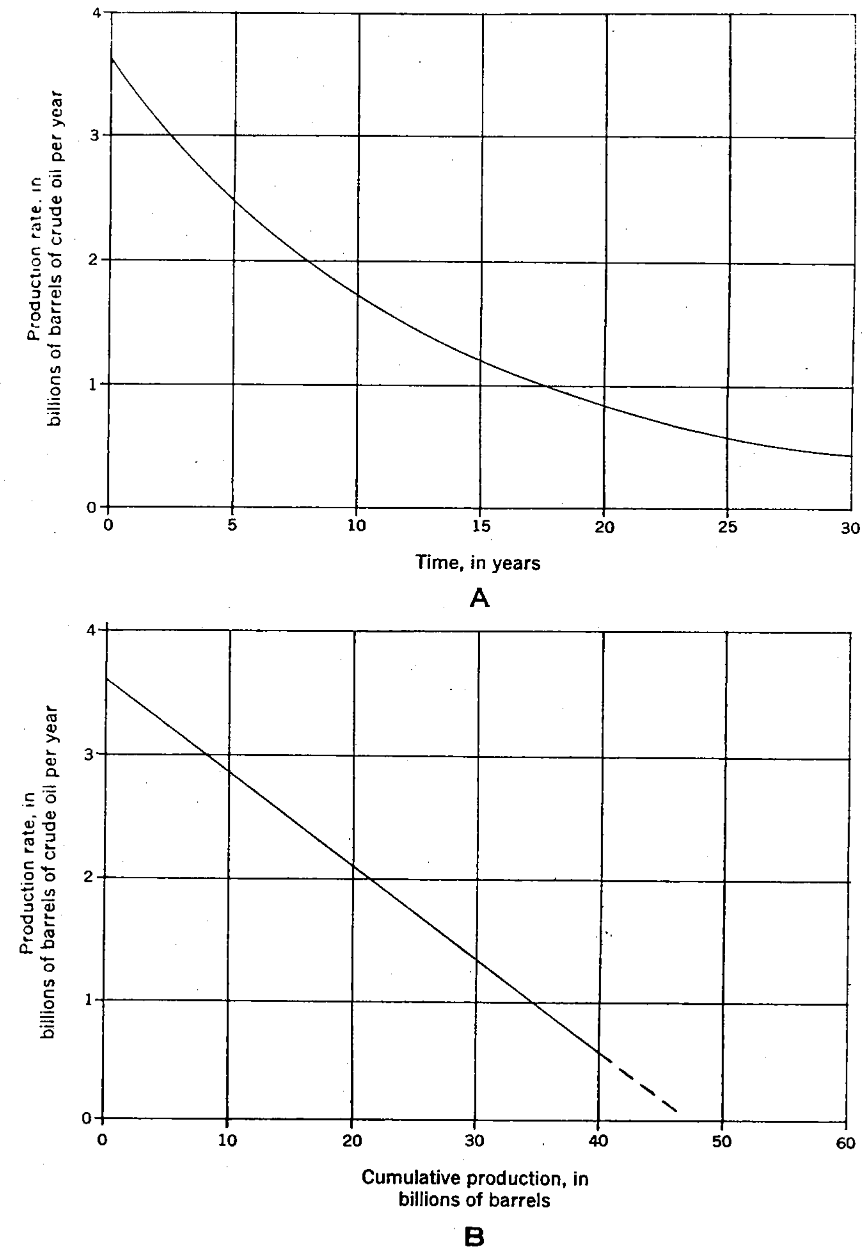

FIGURE 1.—Constant percentage decline curves.

pumped or allowed to flow without restriction. When natural gas was found ahead of, or with, the oil, it was generally withdrawn as quickly as possible to minimize delay in the production of oil. An ever-increasing mass of evidence before 1930 from field, laboratory, and theoretical research in reservoir engineering had shown, however, that such production practices were extremely wasteful. Investigation had proved that a much higher proportion of the total oil in the reservoir could be removed by restricting the rate of production from the outset in order to utilize more fully the natural energy in the reservoir. A massive conservation movement,[2] which got underway in earnest about 1930, has gradually changed general production practice from rapid early withdrawal, closely spaced wells, and reduced ultimate recovery, to restricted early production rates, wider spacing of wells, and increased ultimate recovery. Many major oil-producing States now have laws that prohibit wasteful production practices, and some States further restrict production to predicted market demand. Growing realization of the ultimate benefits of controlled production has led to ever-widening application of conservation measures on a voluntary basis.

With the advent of conservation, the meaning of the phrase "producing capacity" changed. Instead of being the maximum rate at which a well could produce, it became, for many wells, the highest producing rate commensurate with maximum economic ultimate recovery. This is generally called the "maximum efficient rate," usually abbreviated "M.E.R.". The M.E.R. is not an absolute value; it differs for different types of reservoirs and is subject to change as the reservoir is produced. Engineers do not always agree on the precise M.E.R. for a given reservoir. Moreover, the M.E.R. is determined by economic as well as physical factors—production rates lower than the M.E.R. would in most cases result in still greater ultimate recovery, "but once the rate is sufficiently low to permit the basic requirements [avoidance of waste] to be met, the incremental ultimate recovery obtainable through further reduction of the rate of production may be insufficient to warrant the additional deferment of a return and the additional operating expenses that would result from a prolongation of the operation" (Buckley, 1951, p. 151–152). However, the value of the M.E.R. concept in increasing ultimate recovery has been enormous, and a steadily increasing proportion of the oil wells in the United States is being produced under this philosophy.

When there is sufficient demand for domestically produced crude oil, the wells are produced at the M.E.R. producing capacity, or at total physical producing capacity for those wells (1) which need no

[2] For a recent full discussion of the history and effects of the conservation movement in the petroleum industry, see Zimmermann (1957).

restriction to avoid waste, or (2) which are operated without regard to good engineering practice. When there is oversupply of crude oil, the wells in most States are produced at average rates well below the M.E.R., in accordance with the allocations of the State regulatory bodies. The amount by which producing capacity exceeds the average producing rate is termed the "reserve producing capacity."

In summary, producing capacity of the United States is the sum of (1) the M.E.R.'s of those wells operated under the M.E.R. concept, and (2) the maximum producing rates of wells that need no restriction and of those not operated under good engineering practice. It is considerably less than the rate of production would be if all wells were "opened wide." The effect of restricted early production under the M.E.R. concept is to increase greatly the ratio of recoverable reserves to current producing capacity; any further restriction of the average rate of production to levels below M.E.R., to avoid overproduction, tends to increase this ratio still more for it tends to increase ultimate recovery still more.

During the era of unrestricted production, typical decline curves showed a steep decline in rate of production during the early life of the well, then a protracted period of slow decline. The effect of conservation practice—restricting early rates of production in the interest of greater total recovery—has been to flatten the steep decline and extend the average decline curve. The initial M.E.R. producing capacity can be maintained at the same level for a considerable length of time for many new wells operated under the M.E.R. concept, but eventually decline will set in (Ball, 1940, p. 143).

The spacing of wells has a decided effect on producing capacity. The sum of the producing capacities of two wells drilled close together is greater than the capacity of a single well, but is considerably less than twice the capacity of the single well because of mutual interference (Muskat, 1949, p. 899). Therefore, the general effect of wider spacing of wells (and, consequently, fewer wells) is to increase capacity-per-well, to decrease the producing capacity for the pool as a whole and to increase the time required to achieve ultimate recovery. Theoretically, the M.E.R. should be determined for the pool as a whole, and divided among the wells in the pool regardless of number, but in practice the more densely drilled pools are allowed to produce at a relatively higher rate for economic reasons. Majority opinion is that the ultimate recovery is virtually the same whether the spacing is the widest that will permit drainage from all parts of the reservoir, or whether the spacing is very close (Zimmermann, 1957, p. 337). Therefore, the trend toward wider average well spacing is another factor that tends to increase the ratio of producible reserves to current producing capacity.