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THE EVOLUTION OF PETROLEUM ENGINEERING IN THE LAST 40 YEARS[1)]

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The discussion on the Evolution of Petroleum Engineering in the Staring Lecture covered drilling engineering and production engineering, as well as reservoir engineering.

DRILLING ENGINEERING

During the past 40 years there has been a consistent trend toward:

1. *Lower cost per unit of depth,* mainly through increases in drilling rates.
2. *Improved formation evaluation;* better and more timely information on the nature of the penetrated strata and the reservoir fluids contained therein.
3. *Greater depths.*

In reviewing these evolutionary trends, Mr. Arps discussed in some detail:

a) *Shallow core drilling,* with particular emphasis on the counterflush method as developed and practiced in the former Netherlands East Indies. This method was in effect "continuous coring", with 100% core recovery obtained by circulating the cores to the surface through the drill string by means of reverse circulation. With small hand operated units which could reach depths of 150 m, the cost was very low and the geological information obtained from the cores unusually complete.

b) *Cable tool drilling,* with particular emphasis on the type of equipment used in prewar years in the former Netherlands East Indies. With this method, formation evaluation by means of examination of the cuttings brought up by the bailer was quite satisfactory, and the information on formation productivity also was excellent, especially when a small amount of fluid was carried in the hole while drilling. It was, in effect, "continuous testing". At shallow depths this method was quite effective and low in cost.

c) *Rotary drilling in soft formations.* For modern deeper drilling the rotary method is now exclusively used everywhere. Very high drilling rates in soft formations with rotary have been attained by increasing pump horsepower at the surface and maximuzing the mud hydraulics at the bit nozzles. However, compared to cable tools, the drilling is essentially "blind" and normally little or no information on formation character or productivity is available while drilling. Such information may be obtained later at intervals, after the string is withdrawn from the hole by conventional logging methods or formation testing. Mr. Arps then discussed in some detail an advanced technique of continuous logging while drilling, which is still in the experimental stage. (Ref. "Continuous logging while drilling – a practical reality" – by J.J. Arps and J.L. Arps – Journal of Petroleum Technology, May 1964 p. 487–493.)

The most remarkable improvements in drilling rates in soft formations have been made with modern

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1) Staringlezing gehouden op 21 oktober 1971 in de Aula van de T.H. te Delft.

2) Meadows Building Dallas, Texas 75206.

offshore drilling units, which have truly become "drilling factories", with everything permanently assembled and practically no limitations on available horsepower.

d) *Rotary drilling in hard formations.* In these formations faster drilling with rotary has been achieved by increasing the length and weight of the drill collars up to the maximum capacity of the bearings of the rock bit cones.

e) *Rotary Drilling with compressed air.* In hard formations carrying not too much water, spectacular increases in rate and decreases in bit wear have been obtained by circulating the cuttings out with compressed air. The character of the formation from these cuttings and the presence of hydrocarbon bearing strata is easily detected while drilling. Limited water influx is handled by adding detergents. In effect, this method approaches again "continuous testing".

f) *Ultra deep drilling.* Improvements in equipment and facilities and drilling technology during the last 40 years have made it possible to drill very deep wells. At present routine completions are now being made below 6,000 m. depth in the Delaware basin of West Texas and in the Gulf Coast area of Louisiana and Texas.

PRODUCTION AND RESERVOIR ENGINEERING

During the last 40 years there has been a consistent trend toward:

1. Lower unit production cost, and
2. Increased recovery efficiency.

In reviewing these evolutionary trends, Mr. Arps discussed in some detail:

a) *Better understanding of the recovery mechanism.* He specifically discussed the results of an industry-wide study made by the Subcommittee on Recovery Efficiency of the American Petroleum Institue based on case histories of some 312 reservoirs. Statistical regression analysis of the data by means of computers led to some remarkable empirical relationships between recovery efficiency and the statistically most significant groups of parameters for both water drive and solution gas drive mechanisms. (Ref. "A Statistical Study of Recovery Efficiency" by J.J. Arps et al, API Bulletin D-14, November 1967; and "Reasons for Variations in Recovery Efficiency" by J.J. Arps, SPE Symposium on Petroleum Economics and Evaluation, Dallas, March 1968, p. 77.)

b) *Better reservoir information.* Mr. Arps discussed in some detail the improved reservoir data which have become available during the postwar period through quantitative analysis of electric and other well logs, and through quantitative analysis of bottom hole pressure buildup and drawdown surveys. He also mentioned that Shell's technical staff has done much of the pioneering work in both fields.

c) *Hydraulic Fracturing.* The impact of the development of hydraulic fracturing on the productivity from tight formations was discussed. He also mentioned that recent findings indicate that such hydraulically induced fractures have a tendency to close up, or "heal" with time. Mr. Arps also mentioned that the direction of vertical fractures, natural or induced, have been found to be predominantly perpendicular to the direction of folding. This latter observation may have considerable bearing on future development well drainage patterns.

d) *Thermal methods.* Mr. Arps discussed the development of steam flooding since the early 1960's, and in particular some of the techniques developed in the last few years, such as the new steam drive method through an underlying bottom water zone. (Ref. "Operation and Performance of Slocum Field Thermal Recovery Project" by A.L. Hall and R.W. Bowman, Shell Oil Company – SPE 2843 March 1970, Fort Worth, Texas.)

e) *Large volume withdrawal.* Substantial increases in recovery are currently being obtained in waterdrive fields by sharply increasing the rate of total fluid production per well. This is only possible if lifting costs can be kept low and economic disposal facilities are available.

f) *Automation of operations and data processing.* Important cost and labor saving has been obtained in many fields in the U.S. through full automation of field production operations, "contract pumping" and the processing of production data and paper work by modern computer facilities.

g) *Reservoir modeling by computer.* An entirely new field of reservoir engineering has opened up through the availability of high speed computers, which make it possible to develop and drain a reservoir "on paper" in different ways, thus making optimization possible.

h) *Significance of "time" in reservoir engineering.* There is an increased awareness of the significance of gravity and imbibition effects on rejuvenation of reservoirs. The importance of this time factor has not always been fully appreciated before, and in some cases advantage is now taken of the resaturation which may take place during long rest periods (of the order of 10 or 20 years).