Secondary Recovery Services -- Fact or Fiction

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INTRODUCTION

The production of hydrocarbons from a reservoir is a pressure depletion process. When a reservoir which has existed as a closed system is penetrated, the resulting release of pressure causes fluids to move through the formation toward the point of lowest pressure in the system, the producing well. Drilling and completion processes may have caused vertical communication extending a short radius from the well, but fluids will seek the lower pressures, and there may be no noticeable effect on the primary production.

Layered permeability variations within the producing interval may not be detrimental since the internal matrix pressures provide the energy for fluid movement. Pressure distribution insures that any fluid movement is ultimately toward the producing well.

Continued production under these conditions eventually lowers the pressures in the formation to the degree that they no longer force the fluids to the well and production drops below the economic limit. Pressure distribution still exists in the same patterns but is too low to sustain fluid movement.

Secondary recovery efforts consist of forcing fluids downhole in selected wells to repressure the system and again provide sufficient energy to move the production toward the alternate wellbores. Consider the pressure distribution under these new conditions.

The point of highest pressure in the system is the injection well and injected fluids move toward the lower pressure immediately accessible. Communication to a barren or thief zone now channels away most of the injection. Vertical permeability barriers existing between formation and zones cannot contain the pressure system because of the local damage radius around the wellbore. Layered permeability sections that provided production paths to the well become zones that are preferentially swept causing premature breakthrough. Water-to-oil permeability ratios change and transition zones that retained their competence with formation fluids "weather" and erode under the influence of injection fluids. The total effect of any or all of these conditions decreases the efficiency of the secondary effort and since the success of the operation depends on a predetermined percentage of residual recovery, the project may become an economic failure.

Reservoirs that have a long history of predictable primary production and corroborating data (production decline, reservoir pressure decrease, etc.) are logically assumed to be contained systems in the natural state. The only vertical damage or communication exists at or near the wellbore. This being true, identifying and correcting the undesirable conditions in and near the wellbore should result in the closed system needed for efficient secondary recovery.

The detection and analysis of local fluid behavior and the correction of undesirable conditions has become a highly specialized art. Many tools, materials and techniques have been employed and a few have emerged as being more nearly successful. Unfortunately, there is no single analytical tool or method which will identify all existing conditions.

Competitors in these specialized services tend to develop dependence on one tool or technique and in an effort to expand their participation, impute capabilities and features to their respective programs that do not exist, or that must at least be modified by other existing conditions.

The selection of the services to be performed on the wells depends on the type and extent of the information needed. A complete analysis might necessitate two or more complementary tools or techniques, but in many instances, prior information or the economics of a particular project preclude a total series of surveys. A survey determining only the immediate data needed can then be run at a greatly reduced cost. A discussion of the various tools, methods and services should assist in selecting the proper service to determine the required data.

MECHANICAL TOOLS

Mechanical tools include all of the monitoring techniques incorporating impellers or turbines for measuring fluid volumes or velocities. The continuous or "free" spinner has no diverting element and measures fluid velocity by use of a propeller or inclined vane exposed to the fluid stream. The impeller must be sized to the borehole diameters for proper interaction. These tools are usually used with high rates of injection since minimum rates of 150-200 BPD are needed to energize the tool. Use is restricted to injectors with no tubing since the tools must extend to the limits of the well diameters. Accuracy is poor due to bypass and no close definition of thin zones is possible.

The "flowmeter" adaptation of the spinner incorporates a series of deflecting vanes or an expandable packing element to divert the fluids through a mandrel in the tool. The total volume of fluid is impressed across a turbine mounted inside the mandrel and the rate of rotation is related to the volume of fluid passing through the tool. The turbines are very accurate in detecting slight changes in the rates inside the wellbore providing complete pack-off can be accomplished. The ability to set, release and reset the packing elements at selected depths provides a means of closely determining the point of fluid entry or exit from the well.

Problems are incurred when communication exists outside the pipe or slight erosion extends beyond the perimeter of the wellbore. Fluid passing outside the tool mandrel is not measured and the total volume of fluid actually moving downhole is then in error. These errors in measurement can exceed 60 per cent of the total volume.

The packing elements also have limitations. Operation in wellbores of more than seven inches in diameter is extremely difficult and temperatures limit the operation of one element type (polyurethane) to 180°F. Another element type (impregnated nylon) can withstand higher temperatures, but the porosity of the material allows leak-off and it is difficult to maintain complete pack-off pressures. Operation of this tool in compressible fluids (gas, air) is almost prohibitive.

The mechanical tool's ability to monitor continuously at any given interval adapts it to production logging where the rates are constantly changing. A time monitor of rates at any depth may be converted to time-volume calculations and an average production pattern or profile may be constructed.

Fluid identification tools may be run in conjunction with the flowmeters to identify rate of production and type of fluids produced from the interval. The identification of the borehole fluids is accomplished by means of sampling density, resistance, dielectric constant and pressure differential at various stations downhole and relating these to the reactions of the total produced volume of fluid at the surface. The samplings are necessarily the average of all the fluids in the well at each interval and are only relative to the prior readings. Definition of two-phase production is comparatively simple but three-phase flow becomes difficult in interpretation. The mechanical tools can only be used to make measurements inside the wellbore. No formation characteristics or fluid movement behind pipe (channels, etc.) can be determined.

RADIOACTIVITY TOOLS

The radioactivity tools used in fluid movement monitoring combine an element capable of detecting the presence of radioactivity and some means of introducing radioisotopes to the fluid stream at selected intervals in the wellbore. The path of fluid travel is monitored by tracing the movement of the radioisotope from the point of introduction.

Several methods of isotope placement are in use at this writing; electrically operated downhole dump bailer for both soluble and insoluble isotopes, surface introduction for inaccessable areas (annular space, extremely small diameters, etc.) and several variations of a positive displacement piston in the downhole tool, termed an ejector. The ejectors are confined to the use of soluble isotopes.

The gamma rays' ability to penetrate varying thicknesses of materials makes the radioactivity tools extremely flexible in application. Fluid movements may be detected through several thicknesses of pipe and a short distance into the formation itself. This allows investigation of conditions in zones that are not physically exposed to the tools and enables the tools to detect channels, packer or tubing leaks, fluid distribution in adjacent strings or annular spaces, and zones of fluid acceptance behind pipe, etc. The radioactivity tools are the only tools with a true depth of investigation, actually measuring the energy of an emitter (radioisotope) introduced at the wellbore and displaced into the formation. This depth of investigation is relatively shallow however, usually considered to be 12 to 18 inches from the wellbore.

Information gathered by radioactivity techniques can be both quantitative and qualitative. Interpretive results vary specifically with the materials, method of isotope placement and movement tracing.

Selection of the materials used must give consideration to the conditions expected in the well. Zones of high porosity and permeability (lost circulation, high injection rates in thin zones) may need insoluble or "plate-out" materials to allow adequate time for the monitoring runs to locate the deposition of materials. The tendency for these materials (flakes, matched-density resins and particles) to plate-out and remain in place must be considered if any further investigation by radioactive means is anticipated. The particles will remain in place and interfere with any other radioactive readings that are to be made later. All investigations other than the "accumulation" series should be made with soluble materials before introducing the insoluble ones.

The practice of measuring the accumulations of insoluble materials and relating them to the fluid distribution profile can be grossly in error since the material tends to collect in turbulence traps and bridge in channels and fractures. The greater intensities recorded may well be a zone that has accepted no fluid at all but has afforded a trap or bridging conditions for the particles.

The only quantitative measurement that can be accomplished with insoluble material is velocity inside the wellbore, and the techniques used lend a high degree of error in calculation.

Soluble materials mix completely with an increment of the fluid stream. Both quantitative and qualitative information are available by various logging methods. The intensity of radiation may be related to the volume of contaminated fluid and as the losses of fluid occur, the radioactivity intensity decreases proportionately.

The completely soluble materials move with the fluids that contain them and their paths may be traced to the final extremity, or until they are displaced into the formation to a depth that shields the radiation entirely. Quantitative measurements may also be acquired by velocities inside the wellbore by any of three methods. These methods each consider a different characteristic of fluid flow and when compared, lend a higher degree of accuracy to the results. Wells that have highly irregular flow characteristics may be quantitatively analyzed by modifying the erratic velocity readings by the volumetric method of calculation. Production wells may also be quantitatively analyzed by the velocity readings, and a continuous time plot derived by taking a series of velocities at each station to observe the variations in rate. Fluid identification tools may also be run in conjunction with radioactive surveys. Thin zones of injection or production may be determined by detector spacing and operating technique, and relative rates of fluid acceptance may be determined by comparing rate of activity dissipation. Radioactive tools provide the most flexible and inclusive analysis of fluid movement in and for a small radius around the wellbore. They quantitatively identify problems within their scope with an efficiency factor of approximately 85 per cent. Radioactive tools can only identify dynamic or current conditions, however, and cannot be expected to show results from previous conditions of injection or production. The investigations are only for a limited distance from the wellbore; occurrences behind thick cement sheaths or at a greater radius from the well than eighteen inches may go undetected.

TEMPERATURE TOOLS

Temperature analysis is based on the comparison of three basic types of data—absolute temperature, differential temperature (Delta-T) with time, and differential temperature (Delta-T) with depth. This information is collected in the wellbore by tools employing two logging principles—the absolute, or single-point temperature sample and the differential, or dual-point temperature sample. Vertical Delta-T sampling techniques employ two types of operating tools. True differential tools (two elements physically separated by some distance) and the a-priori tools (single-element tools stimulating two-point sampling by means of an electronic delay circuit). These tools are all limited to one basic measurement—the temperature of the wellbore fluids at the instant of sampling. There is no "depth of investigation" past the perimeter of the wellbore, but the tendency of the borehole fluids to assume the temperature of adjacent dominant temperature fields allows interpretations to infer a "radius of investigation" into the anomalous zones. No rates or quantitative fluid movements can be derived from temperature data, but attempts are being made to correlate the recorded rates of temperature recovery to fluid distribution patterns. Temperature log data cannot identify thin zones of fluid acceptance, with close resolution due to boundary equilibrium effects, but cooling or heating outside the investigation limits of other tools affects the borehole temperatures and may be interpreted as gross interval of injection or production. Channels cannot be detected by temperature analysis unless peripheral temperature changes are extended beyond the normal changes incurred by fluid movement in the wellbore. Production temperature logs may identify thin zones of fluid entry provided the localized cooling or heating exceeds the average temperature of the moving fluids in the wellbore. Some interpretation may be applied to the slope of the absolute curves in moving fluid. Extrapolations of rate of temperature-change under controlled conditions affords identification of relative zones of temperature stability. Accurate interpretation of temperature data depends upon the comparison of current temperature indications with established base information. The base data for comparison may be derived from prior records and/or logs, or may be gathered as part of the current temperature survey program, but there must be a basis for comparison or the temperature data is meaningless. Two general misconceptions contribute more to the misapplication of temperature surveys than any other factor. They are:

1. Temperature data collected inside the wellbore is identical with the instantaneous temperature conditions in the formation.
2. "Differential" curves present true temperatures by deflection and are a separate dimension of temperature determination.

Temperature data collected in the wellbore is not identical with the formation conditions. Wellbore data are the terminal result of a very complex energy transfer and do not represent the formation temperatures past a short radius from the well.

Differential curves are only instantaneous slope change indicators. They do not represent "hot" or "cold", but only negative or positive changes in slopes for a given interval. The Delta-T curve is derived from the absolute curve and is not a separate measurement.

SUMMARY

All of the tools and techniques mentioned in this writing have specific applications and each collects data not available by other means. Each method reveals overlapping information that may be correlated with other services or data. Determination of the type and extent of data needed can effect noticeable savings by choosing the proper methods of evaluation, and avoiding errors incurred by misapplication or overextension of technique.

CONCLUSIONS

1. Reservoir reactions to secondary recovery differ from expected and proven primary reactions.
2. Fluid movement monitoring can be used to determine reservoir reactions to secondary efforts.
3. Fluid movement analysis consists of several parameters of investigation—each one accomplished by a different application of tools and methods.
4. Logging tools and methods are complementary, not conflicting.
5. Fluid movement data is available through the logging services of several companies.
6. Complete well analysis dictates the use of two or more of the available services.
7. Study of well conditions and previous information will assist in the selection of the proper service.
8. Familiarity with the capabilities and limitations of each service is essential to proper selection.

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