EARLY DETECTION OF TAR USING REAL-TIME DATA FROM ADVANCED LWD TO PLAN RECOVERY PROCEDURES

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ABSTRACT

Generally tar oil is defined as hydrocarbons that are very heavy in nature and therefore immobile in the reservoir. Tar has a very large viscosity and acts as a permeability barrier. Tar mats are often observed near the oil water contact. Tar mats effectively isolate oil column from the aquifer. In such fields, injection wells are needed for adequate oil recovery. These injection wells must be placed within a narrow oil column window above the tar mat to insure adequate injectivity and minimize any oil trapped behind the injectors.

While there are various ways to identify tar once the well has been drilled, real-time detection of tar is essential for accurately placing our wells and avoiding costly remedial action.

Deficit in porosity from MagTrak when compared with total porosity from Lithotrak is used as the first indicator of tar. Mobility information from TesTrak is then used to confirm presence of tar.

This paper discusses possibility of early detection of tar with deployment of LWD technologies for real-time solutions. Data from LithoTrak, TesTrak and MagTrak are interpreted in real time for geosteering for proper placement of wells.

INTRODUCTION

The terms tar, bitumen, and heavy oil are often used interchangeably. As defined by Oil-Tracers (Oil Tracers, 2006), tar is "Any black viscous petroleum residue produced in petroleum refining or occurring naturally". In this paper we refer to tar as a hydrocarbon phase that occurs naturally, is highly viscous, immobile and cannot be produced using conventional production technology.

Density is the commonly used oilfield standard for categorizing crude oils. Density is usually defined in terms of degrees American Petroleum Institute (API) gravity which is related to specific gravity—larger the density of oil; lower the API gravity. Liquid hydrocarbon API gravities range from 4º for Tar rich bitumen to 70º for condensate.

Tar mats can be, though are not always, present at or close to the oil/water contact in a reservoir. Tar mats hamper the natural water drive and also are a challenge in secondary/tertiary recovery projects.

In the primary stage of depletion, the presence of a tar layer can lead to an alarming increase in gas/oil ratio early after the onset of production.

Tar mats may have variable thickness and they may not have horizontal continuity. This may lead to severe water coning issues and further complicate production.

In secondary recovery, injectors are normally perforated at the original oil/water contact. However, injecting water under a tar mat might result in inadequate pressure support due to poor communication across the tar mat. The challenge here is to place the horizontal well path in a mobile fluid layer above the tar. Real-time detection of tar is therefore very critical. If the only hydrocarbon in the reservoir is tar oil, then this is another challenge for recovery.

A clear solution to all above problems would be early detection of tar and efficient modifications in drilling program so that costs can be minimized. This is achieved by deploying LWD technologies for real-time solutions and geosteering for proper well placement.
In recent times there is an increased interest in the technical and economic feasibility of converting tar oil into new reserves. Tar oil reservoirs have not seen much development because of the ease and low cost of producing petroleum from conventional sources. An increase in the cost of producing conventional petroleum has now led to serious development of various enhanced oil recovery and production methods appropriate for extracting heavy oil from tar layers.

There are many fields in India which do not produce much oil because of its high density and viscosity. The oil from Panidhing field in Assam is one of them. The wells PD-2 and PD-6 are the current producers. The formations encountered in these wells have high permeability. Both the wells produce lot of water as well as some heavy oil/tar oil. Total recovery of oil is only about 5 to 6%. Steam injection is difficult because the formation's depth is about 4000m.

In Mehsana field, the current production method is in-situ combustion. The problem here is seepage of gases around the well bore. This creates a fire hazard at the surface.

In Rajasthan, Baghewala field near Jaiselmer is also considered as heavy oil field.

In this paper we discuss a method for early detection of tar oil in real-time. Steam injection and in-situ combustion approaches for recovery and geosteering the wells with use of real-time data from advanced LWD sensors is also presented.

REAL-TIME TAR DETECTION METHOD

At best, the conventional resistivity based well log analysis provides the quantity (saturation) but not the quality (viscosity and viscosity distribution) of heavy oil. Thus, the conventional triple-combo LWD suite by itself is not sufficient for tar detection as one cannot distinguish tar based on porosity and/or water saturation alone.

NMR can be added to the logging program. Quantification of permeability, oil saturation and viscosity are the main objectives for acquiring NMR logs. But NMR based analysis also has some limitations such as poor sensitivity of diffusion and the overlapping T2 between bound water and heavy oil.

A more practical approach for real-time tar detection is the use of mobility information from the formation tester. Mobility \( \mu \) is defined as:

\[
\mu = \frac{k}{\eta}
\]

where \( k \) is absolute permeability and \( \eta \) is viscosity. Tar oil has practically zero mobility, and very low mobility readings from the formation tester can be used to confirm tar zones.

However, because mobility is the ratio of permeability to viscosity, either very low permeability or very high viscosity can lead to very low mobility readings. Thus there can be cases where low mobility may be due to reasons other than the presence of tar. A single sensor is thus not sufficient and one must adopt an integrated approach for tar detection. The optimal solution for real-time tar detection would then be triple combo, NMR and formation tester data.

NMR data is used to flag tar zones and presence of tar is then confirmed using mobility data from formation tester.

DETECTION PROCESS

Pre requisite to the analysis is that real-time logs should be monitored closely by a competent analyst. Inability to correctly interpret the logs can lead to tar zones being missed or non tar zones being tested for tar leading to loss of valuable time.

MAGNETIC RESONANCE PRINCIPLES

In magnetic resonance a static magnetic field from an array of magnets orients the hydrogen nuclei like tiny little magnets. Therefore Magnetic resonance is sensitive to Hydrogen Index.

The static magnetization of the hydrogen is perturbed by a series of radio frequency pulses, followed by hydrogen spin precession. Eventually an echo train decaying in time is obtained.

Signals from hydrogen in movable fluid decay slowly. Signals from hydrogen in capillary trapped water decay faster. Signals from hydrogen in clay bound water decay even faster. The echo train decay can be represented by a multi-component exponential function. Hydrogen chemically bound to the matrix or to dry clay has such a fast decay rate that it is not seen by magnetic resonance tools.
The shape of the decay curve is controlled by a number of factors like pore size distribution, water saturation and the relaxation properties of water, oil and gas. The decay curve is decomposed into a distribution of relaxation times which are associated with pore diameters and hence into mobile and immobile fractions of the pore space.

Figure 1 attempts to summarize this graphically. A typical spin-echo decay curve is shown on the left-hand side. This is an example of the raw data from an NMR tool. In this example there are two exponential decays evident. An illustrative T2 distribution is shown on the right-hand side of the figure. The T2 distribution can be split into three regions: movable fluid, bound fluid, and clay-bound water. The cutoff between bound fluid and movable fluid is about 33 msec for sandstone, and can vary between 90 and 220 msec for carbonates. The cutoff between bound fluid and clay-bound water is 3 to 4 msec.

Fig: 1 Conversion of T2 decay curve in determining fractions of movable and immovable fluids in the pore space. (Fletcher, 2008)

Hydrocarbon signals are usually found in the movable fluid, but in case of tar or ultra heavy oil, the NMR signal decays too fast and overlaps with clay bound water, giving false indication of shale.

By comparison, a neutron tool sees all hydrogen nuclei equally, including clay-bound and matrix contained hydrogen. Neutron tools are equal opportunity hydrogen detectors. Magnetic resonance can be seen as a spectral neutron without a source.

LWD Magnetic Resonance service employs T2 magnetic resonance logging, the industry standard for oilfield MR measurements, to differentiate between immobile and producible fluids in complex lithologies. It provides real-time, lithology-independent porosity without any nuclear sources. It also offers a real-time T2 distribution derived from compressed raw echo trains transmitted to surface. Formation properties such as porosities and fluid fractions can be calculated from the T2 distribution, delivering extra value in complex lithologies, for which standard cutoffs are not applicable.

Thus a combined approach needs to be taken to identify zones with tar oil.

MISSING POROSITY AND EXCESS BOUND FLUID CONCEPT

Akkurt et al (Akkurt, 2008) have described the method of detecting tar in real-time with NMR data with two concepts. One is missing porosity and second is excess bound fluid. We will briefly review the concepts.

The missing porosity concept of tar detection involves integration of conventional porosity logs with NMR. Missing porosity is defined as

$$\Delta \Phi \equiv \Phi_t - \Phi_{nmr}$$

where $\Phi_t$ and $\Phi_{nmr}$ correspond to total porosity from conventional and NMR logs, respectively. Tar is identified when following condition is satisfied:

$$\Delta \Phi \geq \Phi_{min}$$

Total porosity $\Phi_t$ is computed from combination of neutron, density and/or acoustic logs, $\Phi_{min}$ is a threshold porosity representing mostly the uncertainty in the NMR log. It is typically 1 porosity unit (pu). The porosity difference in Eqn 1 is caused by the under call in the NMR porosity when there is tar. Due to its nearly solid nature, tar causes the NMR signal to decay too fast to be detected, resulting in a porosity value that is less than actual porosity. Complete capture of the NMR signal from tar is not possible because this requires extremely short interecho times. NMR wait time and inter echo time need to be optimized specific to tar analysis. Tar detection needs short TE and adequate wait time based on past field experience, type of formation and minimum effect on vertical resolution and ROP.

Missing porosity is a straightforward method for tar detection, but its results are highly dependent on correct total porosity from conventional logs. Use of incorrect parameters like matrix and fluid densities or bad hole...
condition can be a cause of error in the correct calculation of total porosity from conventional logs. The second concept described by Akkurt is the excess bound fluid method. It requires calculation of water saturation in addition to total porosity and NMR logs. In the standard NMR porosity model

$$\Phi_{\text{nmr}} = \Phi_{\text{bf}} + \Phi_{\text{ff}}$$

(3)

$$\Phi_{\text{ff}} = \Phi_{\text{fw}} + \Phi_{\text{h}}.$$  

The subscript bf denotes bound fluid, ff is free fluid, fw is free water and h is hydrocarbon. Equation 3 assumes that the only bound fluid is water. When the hydrocarbon spectrum overlaps the bound fluid spectrum (which is the case in tar), the bound fluid volume calculated by NMR has contribution not only from bound water but also from tar. Excess bound fluid is defined as

$$\Phi_{\text{xbf}} \equiv \Phi_{\text{bf}} - \Phi_{\text{tSwt}},$$

where S wt is the total water saturation. If the bound fluid volume computed by NMR is more than bulk volume of water calculated from conventional logs then excess amount is due to tar. Finally the presence of tar is confirmed using mobility information from the formation tester.

THE RECOVERY METHODS:

Most of the time, the oil companies overlook heavy oil and tar oil as available resources because of complexity in recovery and cost involved. The reservoir behavior is generally determined by porosity, permeability, and pressure, but oil density and viscosity will also play a role in deciding on a production approach. During the life of a well, oil recovery has three stages, primary, secondary and tertiary. Methods other than primary methods are sometimes referred to as EOR techniques. All the E&P companies try to produce as much oil as possible with primary production methods. Mining and tunneling methods are sometimes used for recovery when the reservoirs are shallow. These techniques are used in the heavy oil areas in Canada. If the recovery by primary methods like, artificial lift and injecting light oil or chemicals to reduce viscosity is not economically viable, then the next approach is to go for secondary or tertiary recovery methods. These methods can be divided into two major types, thermal and non-thermal. Many methods are available for thermally enhanced recovery, e.g. permanent steam injection, cyclic steam injection, combination with chemicals, hot water injection, fracture/conduction stimulation or in-situ combustion. For any of these methods a proper well placement is of utmost importance. The success of the project depends upon drilling horizontal wells with minimum cost. Compared to cost of drilling new horizontal well, multilateral wells offers attractive solution.

Reservoirs benefit most from multilateral drilling as a field development strategy to increase drainage area per well. But more laterals will not be effective unless they are placed accurately. Geosteering is one of the options. With improved lateral placement, different types of multilaterals can be used in different fields depending on reservoir thickness, oil viscosity, lateral extent and other geological factors. If necessary, the well path can be modified or sidetracked to optimize well placement. If cyclic steam injection with viscosity reducers is the planned recovery method, then the distance between two laterals depends upon the viscosity of the oil and type of viscosity reducers. Major types of multilateral wells are dual stacked, tripled stacked, dual lateral and fishbone structure. Normally dual stacked or tripled stacked multilaterals are used for the steam assisted gravity drainage (SAGD) process (Curtis, 2002) Illustrations of these well trajectories are shown in fig. 2 and fig. 3 respectively. In both cases, the well trajectories are in a vertical plane. The steam is injected in the upper lateral and penetrates the formation surrounding the well bore thus heating the oil and reducing its viscosity. The oil then drains into bottom lateral, which acts as a producing well. To design this process, the three major parameters required are oil viscosity, permeability and formation pressure. The mobility value as measured with the formation tester can be useful in estimating these parameters. The dual lateral is normally used in insitu combustion. An illustration is shown in fig. 4. Here the well trajectories are in a horizontal plane. Other multilateral combinations may also be chosen based on geology, thickness, disconnected sand bodies, and permeability.
Design of wells is beyond the scope of this paper and will not be discussed here.

**Fig: 2 showing dual stacked multilateral wells**

**Fig: 3 showing triple stacked multilateral well**

**Fig: 4 showing two multilaterals in same horizontal plane.**

**GEOSTEERING:**

Geosteering is the process of utilizing any real-time data (in most cases, drilling and LWD data) to accurately position the well bore relative to specific subsurface references and three-dimensional spatial coordinates. The overall objective is to optimize placement of the well bore relative to the reservoir and remaining within the physical constraints of the drilling and completion program. Once the tar oil is detected and the mobility is measured with formation tester while drilling, the lateral can be planned in real-time and monitored whether it is on the planned target or not.

**CONCLUSION:**

The approach presented in this paper can be a possible solution for developing heavy or tar oil fields, especially in India. The real-time data from triple combo, NMR, and formation tester while drilling can be used for effective tar oil detection. The real-time detection of tar oil, formation pressure and mobility from formation tester can also be effectively used for optimal well placement. Depending on the local geological structure, nowadays there many options available to drill multilateral wells, which will suit the recovery methods.

**REFERENCES:**


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