ICA 2013 Montreal
Montreal, Canada
2 - 7 June 2013

Physical Acoustics
Session 3aPA: Borehole Acoustics Logging for Hydrocarbon Reservoir Characterization I

3aPA4. Evaluation on fracturing effects in a low-permeability reservoir using acoustic logging data
Baohua Huang*, Hao Chen, Jianqiang Han and Xiao He

*Corresponding author’s address: Institute of Acoustics, Chinese Academy of Science, 21, North 4th Ring Rd West, Haidian District, Beijing, 100190, Beijing, China, huangbh@mail.ioa.ac.cn

Low-permeability reservoirs are frequently discovered worldwide. More than 50% of oil and gas reservoirs are of low permeability. Formation fracturing technique is the most common way to develop oil production in this type of reservoirs. The fracturing effect, however, is hard to be evaluated in practice. And thus arguments always exist between constructors and geologists. We developed a favorable method to evaluate the effect from the reservoir anisotropy analysis results provided by cross dipole logging technique. The data will be measured in boreholes when formation is before and after fractured, respectively. The formation anisotropy can be estimated from the logging data. The fracturing effects can thus be evaluated by comparing the results of perforation intervals. Small differences of anisotropy estimation results indicate failure fracturing; while good fracturing effect can be confirmed if the anisotropy of a fracturing reservoir is stronger than before. Fracturing intervals can also be predicted by the anisotropy curves of a fracturing reservoir as well as the new oil production. This approach has been applied for the evaluation of deep tight reservoirs in Daqing Oilfield and low-permeability reservoirs in Hailar. Efficient evaluation results have been obtained, which provided useful information for further explorations.

Published by the Acoustical Society of America through the American Institute of Physics
INTRODUCTION

The petroleum oil exploration comes into the age of low-permeability reservoir as more than 50% of the global oil and gas reservoirs are the ones with low permeability. Daqing oilfield in north-eastern China has been exploited for more than 50 years. Hence most primary oil reservoirs of high porosity and permeability have been discovered, and the explorations are extending to deeper layers and outer areas. Now more than 80% of reservoirs in this region are the lowly-permeable formations. For example, the Song-Liao Basin is a lowly-permeable gas reservoir discovered recently. The reservoir is mainly composed of metamorphic and igneous rocks of low permeability and porosity. Most of these kinds of reservoirs need to be fractured for economic exploitation. Hailaer oil field is another oil field located in the outer area of Daqing. This oil field is underdeveloped due to several aspects, e.g., heavy clay, low permeability and porosity, and lack of output. To encourage production of oil and gas in such a kind of reservoirs, the fracturing technique is effective and necessary, and has been applied in thousands of wellbore in every year. Thus a practical issue, that is, how to evaluate the fracturing quality, is raised. Arguments exist frequently between fracturing engineers and geologists. Cross dipole acoustic wave logging technique is an effective downhole method to provide the fracturing quality. In this article, we will present several example of fracturing quality evaluation based on the cross dipole acoustic wave logging data.

ANISOTROPY ANALYSIS BASED ON CROSS-DIPOLE ACOUSTIC WAVE LOGGING DATA

Cross-dipole acoustic wave logging tool contains two groups of acoustic transducers oriented X and Y directions respectively (depicted in Fig. 1). Each group in a certain direction consist one dipole transmitter and eight receivers. Hence it can record waveform arrays in both X and Y directions. While the rock in the reservoir is fractured, the direction of maximum principal stress is parallel to the crack extending. Due to the imbalance of the rock pre-stress produced by the cracks, the elastic properties around the wellbore can exhibit evident azimuthal anisotropy. This particular kind of anisotropy can be well detected by the cross-dipole sonic logging technique. In such a situation, the recorded signals behave a shear-wave splitting phenomenon. Both the fast shear wave polarized in the maximum principal-stress direction and the slow shear wave whose polarization is normal to that direction are generated. In Fig. 1, the red and blue axes denote the polarizations of the fast and slow shear waves, respectively. We apply a simulated annealing method for the inversion of angle between the tool transmitter and the polarization of fast shear wave. And the orientation of the two shear wave polarizations, i.e., the anisotropy orientation, can thus be determined. The anisotropy level which reflects the fracturing quality can be estimated by extracting the velocity difference of the fast and slow shear waves.
APPLICATION EXAMPLES

To validate the reliability of the logging data before fracturing and after casing, we compare the logging data in a certain before fractured wellbore after and before casing, which is shown in Fig. 2. The green solid line in the first column from the left hand side represents the data from natural Gamma ray, which can be used to judge the formation is a reservoir or not. The red dotted line is the CAL curve to show the borehole radius measurement. The blue dashed line denotes the rock density measurement results. The second column denotes the depth of logging. In the third column, the red curve presents the anisotropy level processed from the cross-dipole acoustic wave logging data before casing; while the black curve refers to the situation after casing. The green line in the same column shows the difference between the data for the red and black curves. In the forth column, the pink dotted curve denotes the slowness of P wave (DTC) and green dotted curve is the slowness data of S wave (DTS). The results presented in the third column show that the anisotropy levels of the formation in every depths are almost unchanged. It fully reveals that cross-dipole acoustic wave logging data and the processing results are reliable in a cased wellbore.
Fig. 3 depicts the fracturing quality evaluation of one wellbore in Daqing. In the third column, the red solid line represents the anisotropy level before fracturing while the black line denotes the anisotropy for the fractured formation. The green region indicates the difference between those two sets of data which reveals the quality of fracturing. Meanings of other curves are the same as those in Fig. 2. It is evident that the fracturing quality is quite satisfied in the well depth of 3791 to 3821 meters, although the depth range of perforation is only 3802 to 3812 meters. And thus the production of oil significantly increases after fracturing in this section.

![FIGURE 3. One comparison of logging data before and after fracturing.](image)

Figure 4 shows another comparison of data before and after fracturing, which are recorded from another wellbore in Daqing. The perforation section range is from the depth 3723 to 3732 meters and the anisotropy difference appears between 3707 to 3732 meters, which indicates that the rocks above the perforation section are more brittle. The fracturing quality is good due to improvement of the oil output. Figure 5 is the logging data from a wellbore in Hailaer oil field. The perforation section ranges from 2285 to 2305 meters. However, the difference of anisotropy is inapparent. Actually, the oil production has little increase in practice. Hence the fracturing quality can be considered bad.

![FIGURE 4. Another comparison of logging data before and after fracturing.](image)
CONCLUSIONS

(1) The anisotropy of reservoir can be effectively evaluated from the cross-dipole acoustic wave logging data.

(2) The depth range of well fractured formation can be confirmed by comparison of the anisotropy before and after fracturing.

(3) The quality of fracturing can thus be estimated. The results can provide significant basis for the determination of exploitation.

REFERENCES

