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Prospects of microseismic monitoring of hydraulic fracturing in Ukraine

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SUMMARY

In spite of the wide use of hydraulic fracturing in Ukraine, microseismic monitoring of hydraulic fracturing is used to a very limited extent. This can lead to situations where the fracture zone does not meet the design objectives. The lack of microseismic control reduces the economic efficiency of hydraulic fracturing. To solve this problem, specialists from the Institute of Geology of the Taras Shevchenko National University of Kyiv have initiated a development and production program of modern methods of microseismic monitoring of hydraulic fracturing. One of the areas of work is the creation of technology and software for the imaging of microseismic events using the continuation of the microseismic wave field in the geological environment.

Introduction

In recent years, microseismic monitoring has gained considerable popularity. It is spreading quite rapidly as a mapping technology for mineral deposits. Visualization of the results of hydraulic fracturing is one of the most common applications of it.

The main approaches to microseismic research take their roots from the study of the earthquake seismology. The first application of induced seismicity was recorded in the mining industry. Monitoring of hydraulic fracturing in the oil and gas industry began in the 1970s. Several pilot projects were carried out during the 1980s and 1990s. Many early commercial projects focused on Barnett shales (Maxwell et al., 2002). In 2000, the first successful hydraulic fracturing project was completed in Barnett shales in the Fort Worth Basin. At that time, the Barnett field was at the initial stages of development. Shortly afterwards, it became the third largest natural gas field in the United States and encouraged the interest to the shale gas.

Today, hydraulic fracturing is widely used in hydrocarbon deposits in Ukraine. However, microseismic fracturing monitoring is still at the implementation stage. Taking this into account, specialists from the Institute of Geology of the Taras Shevchenko National University of Kyiv have started the development of a fracturing technology and its implementation in the exploitation of oil and gas fields in Ukraine. One of the areas of work is the creation of technology and software for the imaging of microseismic events using the continuation of the microseismic wave field in the geological medium.

Basic principles of microseismic monitoring

Microseismic acquisition is the main technology for determining the geometry of fracturing and its relationship to the existing system of fractures (Maxwell, 2011). A typical measurement of microseismicity is the volume of the microseismically active region as an indicator of the stimulated volume of the geological medium. The additional inflow of hydrocarbons will be proportional to the stimulated volume, as well as the density of fractures formed as a result of fracturing. The relationship of microseismic data to rock physics or geomechanics is an important aspect of microseismic monitoring. Typically, microseismicity corresponds to the phenomena of shear deformation. The opening of fractures probably occurs simultaneously with the shear deformation and the increase of the pore pressure. Typical microseismic data have large amplitudes of S-waves compared to the amplitudes of P-waves, which indicates a significant shear component for most microseismic deformations. Shear deformation creates a geomechanical paradox regarding the classical view of the hydraulic fracturing mechanism. It can be the result of activation of stresses around the formed fractures.

Microseismic acquisition involves continuous passive seismic monitoring using sensors and different types of seismic arrays. Usually, the sensors are placed on the surface of the geological medium or in wells. The advantage of downhole microseismic monitoring is the proximity of the receivers to the fracturing zone. This allows to obtain fairly high values of the signal-to-noise ratio for seismic events that are situated at the distance within one km from the well (Akram, 2020). At the same time, microseismic monitoring on the surface of the medium is economically justified, as there is no need to drill control wells or place control and measuring devices in wells. In addition, surface microseismic monitoring requires the presence of a significant number of seismic channels, which increases the informativeness of this approach (van der Baan et al., 2013).

One of the most important problems in microseismic monitoring is obtaining high-quality seismic signals with high signal-to-noise ratio values. Traditionally, fracturing monitoring is rather a short-term procedure. Its beginning and end are related to the injection period. However, continuous and post-injection monitoring is becoming more common (Maxwell, 2014).

Early downhole microseismic fracturing monitoring projects applied groups of several three-component sensors in one, almost vertical well (Maxwell et al., 2010). The number of sensors deployed in the well has increased over time. Surface microseismic monitoring offers an alternative configuration without the need to use control wells. For most hydrocarbon deposits, the temperature in the wells may exceed the performance characteristics of downhole sensors, making surface monitoring a more appropriate monitoring option. Several lines of vertical or three-component ground-based sensors are a typical surface receiving arrangement for microseismic monitoring (Maxwell, 2014). Figure 1 (Akram, 2020) shows an example of a monitoring system.

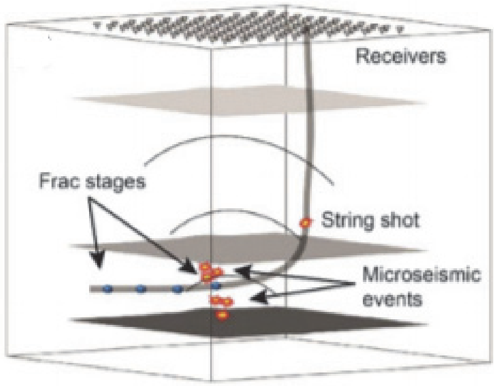

Figure 1 *An example of a microseismic monitoring system (Akram, 2020)*

Processing of microseismic monitoring data includes calculation of coordinates of microseismic sources or events using registered microseismic signals. In addition, the processing also includes the calculation of quality control attributes. These results form the basis for the interpretation of the fracture geometry. Determining the volume distribution of seismic wave velocities is important to create a reliable microseismic model. Velocity models can be constructed using a wide range of data, including acoustic logging, static geological models, VSP data, or 3D seismic tomography. The use of poor-quality velocity models can lead to significant errors in determining the position of the cloud of microseismic events during fracturing (Warpinski, 2014).

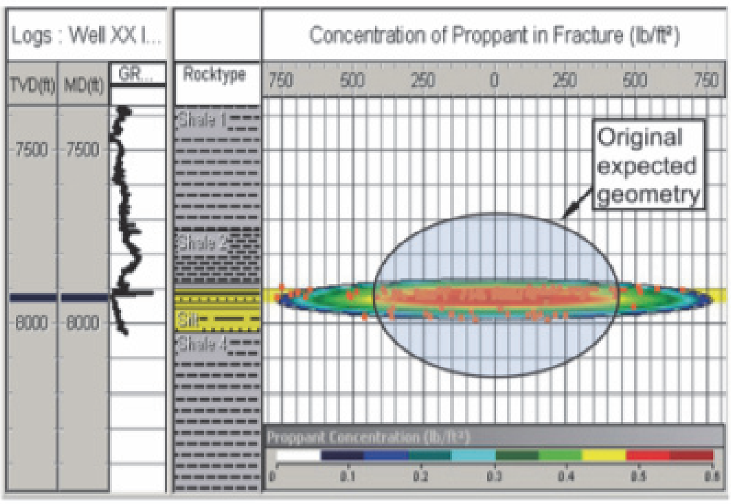

Figure 2 *An example of visualization of the fracture geometry based on the results of microseismic monitoring (Warpinski, 2014)*

Determining the position of hypocenters of microseismic events and their arrival times is the main task of basic processing of microseismic monitoring data.

Figure 2 (Warpinski, 2014) shows the result of determining the location of microseismic events. The cloud of microseismic events allows to control the quality of fracturing results, as well as to detect their undesirable results due to fractures of the rock cap, etc.

A modern approach to determining the data is solving the systems of equations that contain delays in the arrival times from the hypocenter of the microseismic event to the receivers on the surface of the geological medium. A similar approach is used to determine the positions of earthquake hypocenters (Gibowicz and Kijko, 1994). The method can use the times of arrival of P or S waves to the sensors on surface.

An alternative approach to determining the locations of the microseismic sources is seismic imaging. This technology is similar to the imaging of the geological medium using the reflectiom seismograms. However, in this case a constant wave field detection time is used instead of a variable time for the method of converting the reflection seismograms into seismic images. This approach is known as seismic imaging of imaginary sources (Timoshin, 1978; Lisny, 2002). It is based on the reverse extension of the registered wave field from a microseismic event to the geological medium. Various computational schemes can be used for this, in particular the Kirchhoff integral (Duncan and Eisner, 2010).

Cross-correlation methods are used to detect wave signals from weak microseismic events. Relatively strong microseismic events with large signal amplitudes can be used as main events. Then the cross-correlation can find weaker signals of smaller amplitude with similar characteristics of the waveform.

Conclusions

The current state of hydraulic fracturing in Ukraine is characterized by the lack of systematic observations using microseismic monitoring. To determine the appropriate directions of the implementation of these methods, the world experience of using microseismic monitoring during the hydraulic fracturing is analyzed. Based on the analysis, it was concluded that it is necessary to develop new technology and software to solve the problems of microseismic monitoring of fracturing. Specialists of the Institute of Geology of the Taras Shevchenko National University of Kyiv have started developing appropriate applied technologies. The new approach to microseismic monitoring is based on the existing developments of the Department of Geophysics of the Institute of Geology in the area of reverse wave fields continuation and seismic imaging of the geological medium.
The results of the technology development of hydraulic fracturing microseismic data processing are undergoing production tests in oil companies of Ukraine.

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