Steam chamber detection through seismic attributes

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Summary

Heavy oil reservoir monitoring is a challenging topic, which is of significant value for thermal production. The injected hot steam can drastically affect the reservoir's properties by reducing oil viscosity, which will further leads to velocity and impedance change. The drop in impedance can cause abnormally strong reflections on the top of steam chamber. In addition, the mixture of steam, oil, and water inside the steam chamber can cause strong dispersion and intense attenuation of seismic energy, resulting in obvious anomaly in frequency domain.

In this paper, we show the velocity and impedance changes of oil sands before and after steam injection by lab measurements. Then by extracting the seismic attributes of both the baseline and monitorline seismic profiles, we analyzed the differences between them and found that several seismic attributes are very effective in detecting the steam chamber. These attributes either reflect the strong reflections caused by extremely low impedance of steam chamber or reveal the intense energy attenuation inside the steam chambe caused by the pore fluid mixture.

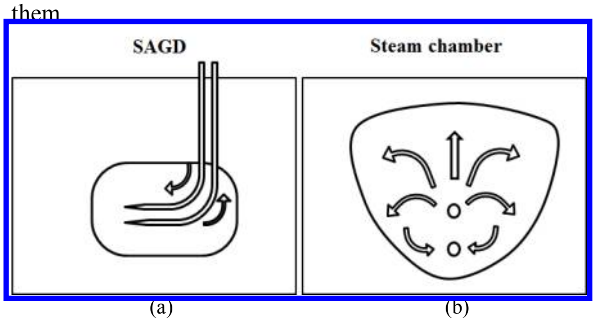
Introduction

With enormous amount, heavy oil is an important potential alternative to conventional hydrocarbon resources. Nevertheless, due to the high viscosity, heavy oil cannot be produced directly, and many thermal production methods are devloped, among which Steam Assisted Gravity Drianage (SAGD) is a significant one.

SAGD is an enhanced heavy oil recovery technology that involves drilling two horizotnal wells. The two wells are 4-6 m apart, with one on top and the other on bottom. The well on top is used for injecting steam. As the hot steam enters the reservoir, it heats the heavy oil, makes them flowable, and mixes with the liquid oil. Due to gravity, the fluid mixture will flow downward and then is produced by the bottom well. The steam-washed zone is called steam chamber, as shown in Figure 1.

One problem of thermal production is to determine the size of steam chamber, which is important since it is directly related to the effectiveness of SAGD and is indispensable for further well location optimization. Many approaches have been developed to monitor the steam chamber. Eastwood et al. (1994) utilized time delay to detect the steam zone. Zhang et al. (2002) applied the reflection image to show the monitored zone. The time difference and amplitude-anomaly method was also adopted to simulate the production zone (Zou et al., 2004). Reflectivity change was also used to monitor the steam injection (Schmitt et al., 1999). Marcano et al. (2013) applied geochemical proxies for the detection of the steam chamber. Yuan et al. (2017) combined lab measurements and time-lapse inversion to characterize the steam chamber zone. However, few people have tried seismic attributes to detect the steam chamber.

In this paper, we used seismic attributes to detect the steam chamber. We first measured the velocity of the oil sands sample under different temperatures, then by combining the density, the impedance variations were also obtained, which can qualitatively explain the strong reflection anomalies on seismic profiles. After carefully analyzing the properties of steam chamber, we found that the drastic changes can be detected through reflection-related and energy-attenuation related attributes. Hence, several seismic attributes were extracted (through OpendTect software) from seismic profiles, all of which successfully detect the steam chamber, suggesting the effectiveness of them.



(a) (b)

Figure 1. (a) schematic illustration of SAGD; (b) schematic illustration of steam chamber.

Measurements

Seismic attributes have been widely-used since 1970's and they are becoming more and more important in reservoir characterization and lithology prediction. According to Brown (1996), seismic attributes can be classified in four groups, time attributes, amplitude attributes, frequency attributes, and attenuation attributes. In general, time attributes can provide information about structure, while amplitude attributes can reflect stratigraphic information; frequency attributes can reveal reservoir information; and attenuation attributes are related to fluids and permeability.

The properties of the steam chamber is distinct from in-situ original reservoir rocks in that the temperature of steam chamber is much higher and the pore fluids are mixture of steam, water, and oil with quite low viscosity. The high temperautre can drastically decreases the oil sands' velocity (Yuan et al., 2013; 2016), as displayed in Figure 2. It can be seen that as temperature rises from 10^0C to 120^0C, the Vp of oil sands drops from 2.18 km/s to 1.77 km/s, close to 19% drops, let alone the much higher temperature inside the steam chamber. Considering the density variation of oil and water at different temperatures, the oil sands density is also predicted, as shown in Figure 3. Then the corresponding P-impedance of the oil sands can be calclualted in Figure 4. It can be found that the impedance drops about 22% from 10^0C to 120^0C, indicating the intense influence of temperature on oil sands.

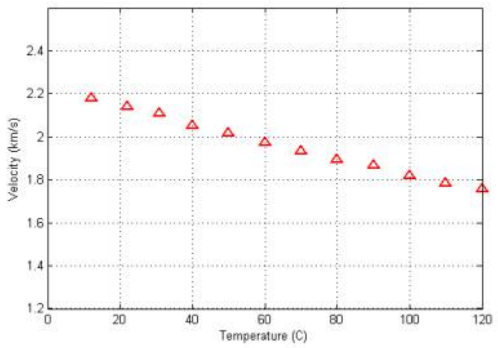


Figure 2. Heavy oil sands P-wave velocity vs. temperature.

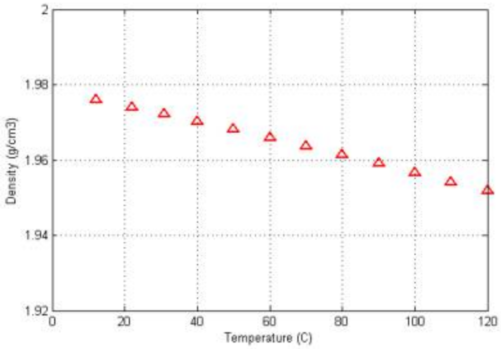


Figure 3. Heavy oil sands density vs. temperature.

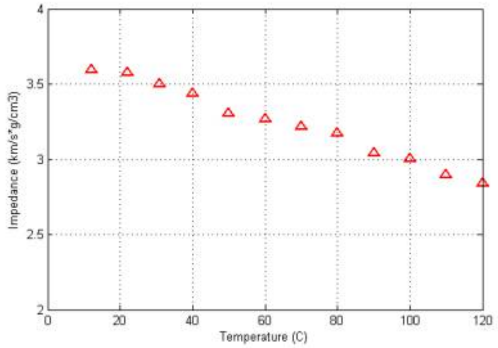
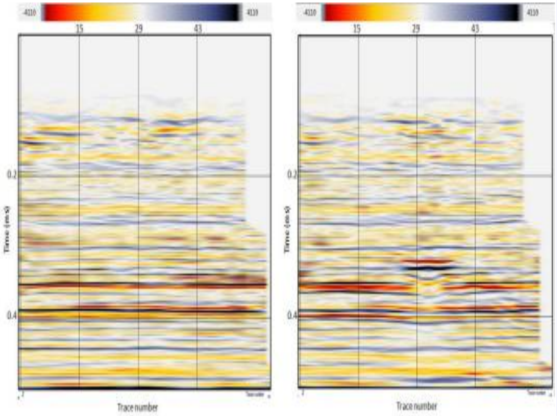


Figure 4. Heavy oil sands P-impedance vs. temperature.

The huge change of impedance with temperature provides possibility to detect the steam chamber. The extremely low impedance of steam chamber can cause huge impedance-constrast between steam chamber and overlying cap rocks, which can further lead to strong negative reflections and form 'bright spot' -like phenomen. Moreover, as the heat is transferred from steam to oil, the oil viscosity drops and part of steam turns to water, forming a mixture of liquid oil, steam, and water. The mixture, plus the loose frame of the oil sands, can cause strong dispersion and intense attenuation of the seismic energy. Therefore, the corresponding seismic attributes can be extracted to detect the anomalies induced by steam injection.

The seismic profiles of baseline and monitorline survey are displayed in Figure 5. It can be seen that most of the seismic events are consistent from baseline to monitorline, except that obvious anomaly occurs on monitorline profile around 320 ms -340 ms, suggesting the location of the steam chamber. On top of the anomaly, strong negative reflections appear, which is like 'bright-spot', indicating that the steam injection causes the steam chamber to have extremely low impedance. Below the steam-washed zone, the seismic events are dented downwards, which is induced by the longer travel-time of the seismic energy inside the steam chamber. As explained above, the high temperature and the steam itself effectively reduce the oil sands' velocity inside the steam chamber. In addition, two strong reflections occur at 350 ms and 390 ms, which, according to petrophysical analysis, are caused by two calcite layers with extremely high density and large velocity. Even with above observations, the anomaly is still not clear enough to determine the exact boundary of the steam chamber, and other seismic attributes are needed to solve the problem.

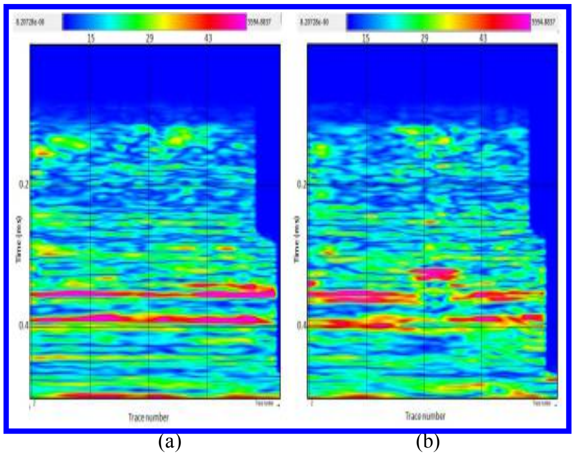


(a) (b)

Figure 5. Seismic profiles of (a) the baseline survey and (b) the moinorline survey.

Instantaneous amplitude

Instantaneous amplitude is one measure of acoustic-impedance contrast (reflectivity). Mathematically, it is defined as the square root of the sum of energy of the real and imaginary part. It can reflect changes of energy. Geologically, it can reveal the changes of bed, thin-bed tunning effects, and variations in porosity and lithology. The low impedance of the steam-chamber zone generates a large impedance-contrast, which enables the instantaneous amplitude to detect the steam chamber. As shown in Figure 6, the instantaneous amplitude of the monitorline survey shows an apparent difference from that of the baseline survey at 320-340 ms, between trace 24 and 38, indicating the location and size of steam chamber. The two calcite layers at 350 ms and 390 ms are also quite clear in the figure.

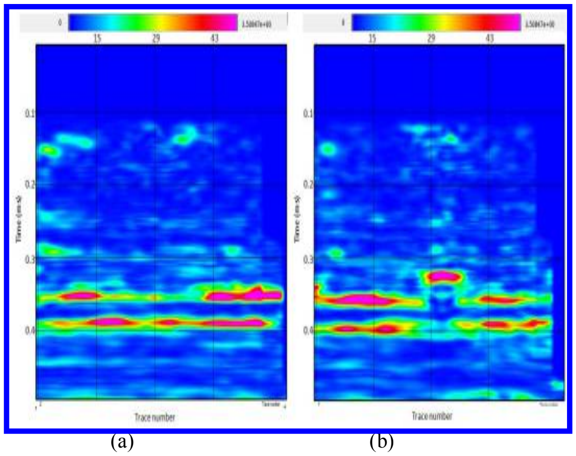


(a) (b)

Figure 6. Instantaneous amplitude of (a) the baseline survey and (b) the moinorline survey.

Maximum spectrum amplitude

Maximum spectrum amplitude is one type of frequency attribute. It is the maximum amplitude of the frequency spectrum and is usually the amplitude at the dominant frequency. Since the maximum spectrum amplitude is the amplitude in the frequency domain, it involves Fourier transform of the data. Similar as instantaneous amplitude, the maximum spectrum amplitude works well on detecting the steam chamber, as shown in Figure 7. The anomaly of maximum spectrum amplitude on monitorline survey clearly reveals the location of the steam chamber, indicating the effectiveness of this attribute. The two calcite layers are also clear on this maximum spectrum amplitude. Besides, unlike the instananeous amplitude, this attribute displays a more clean result without much disturbance around the target area, demonstrating the effectiveness of this attribute.

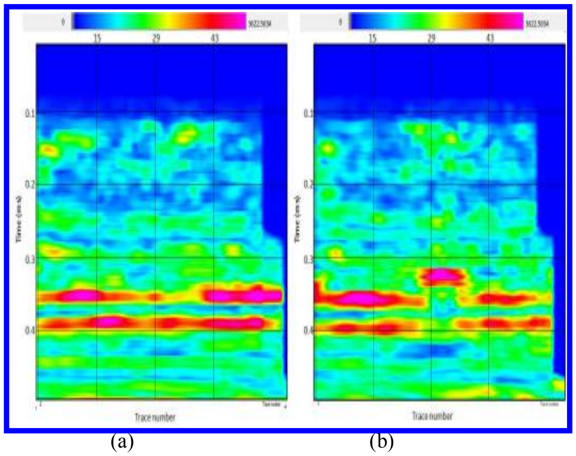


(a) (b)

Figure 7. Maximum spectrum amplitude of (a) the baseline survey and (b) the moinorline survey.

Energy

Energy is another measure of reflectivity and it is the sum of squared amplitudes in a specified time-gate averaged by the number of samples in the time gate. It increases with amplitude and can reflect the amplitude strength. Since energy is related to reflectivity, it is also related to rock properties and bed thickness. Energy is usually a useful attribute to detect geology bodies. In Figure 5, the strong reflections on top of the steam chamber causes the large amplitude and strong energy. The energy attribute can clearly show the energy variation. Changes in energy successfully detect the steam chamber, as can be seen in Figure 8. Compared with the instananeous amplitude attribute, this energy attribute show a more smooth but still clear result for steam chamber identification, even that the boundary is somewhat blurred.

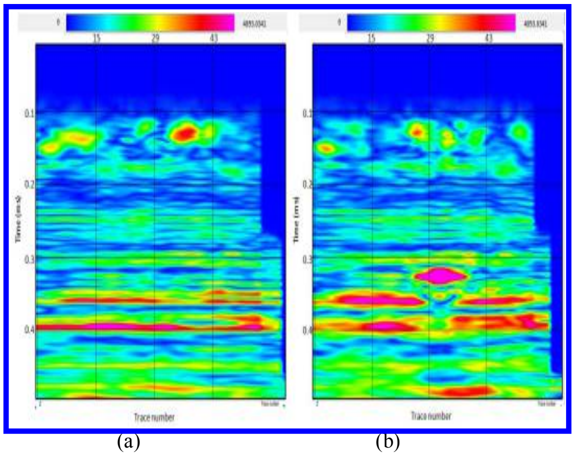


(a) (b)

Figure 8. Energy of (a) the baseline survey and (b) the moinorline survey.

Spectral decomposition

Spectral decomposition is one type of frequency attribute that is related to the wavelet coefficients (based on continuous wavelet-transform) and the amplitude spectrum (based on fast Fourier transform). It can decompose the seismic signal into different frequencies, separating the specific phase and amplitude at specific wavelengths. It can be used for charactering the variations of bed thickness and detecting lateral heterogeneity. The hot steam increases the temperature of the reservoir and reduces the viscosity of the heavy oil. Meanwhile, due to energy loss, the steam partially turns into water. Hence the pore fluid inside the steam chamber becomes a mixture of oil, water, and steam, which can result in a loss of seismic-wave frequency. In Figure 9, the spectral decomposition around the steam chamber shows distinct anomaly from surrounding reservoir rocks. The steam chamber and calcite layers are both apparent on the figure. Thus, spectral decomposition can work effectively to detect the steam chamber. However, the shape of the steam chamber is somewhat distinct from the prediction results of the other attributes, which may be related to the fast Fourier transform.

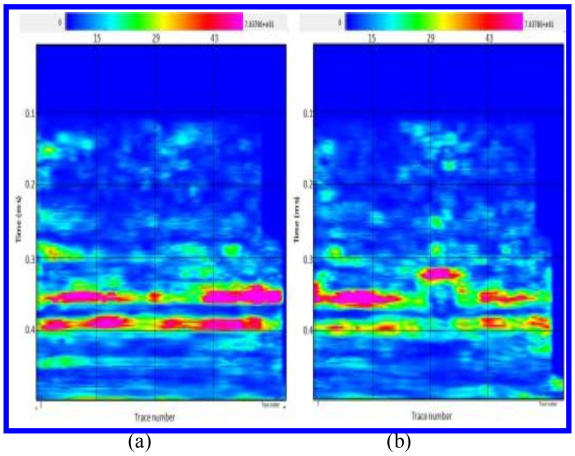


(a) (b)

Figure 9. Spectral decomposition of (a) the baseline survey and (b) the moinorline survey.

Absorption quality factor

Absorption quality factor is a parameter related to energy loss. It is the area beyond the dominant frequency weighted by the whole frequency band. The absorption of high frequencies is suitable for hydrocarbon detection. As discussed previously, the fluid inside the steam chamber is a mixture of oil, water, and steam, and is distinct from the surrounding layers, leading to an attenuation of the wave energy. This attenuation can be characterized by quality factor. As shown in Figure 10, the absorption quality factor also successfully detects the steam chamber. In addition, the prediction result is also clean with little distrubance, similar as the maximum spectrum amplitude attribute, illustrating the validness of this attribute.



(a) (b)

Figure 10. Absorption quality factor of (a) the baseline survey and (b) the moinorline survey.

Conclusion

The oil sands velocity is quite temperature-dependent. The Vp drops about 19% as temperature rises from 10^0C to 120^0C. Besides, the oil sands density also declines with rising temperature, as oil volume will expand when heated. The temperature-dependent velocity and density lead to the temperature-dependent impedance, and P-impedance decreases 22% during the heating process.

The high temperature and the steam inside the steam chamber give rise to small velocity and low impedance, which results in downward-curved seismic events and strong negative reflections. Moreover, the mixture of steam, oil, and water mixture causes strong attenuation, which can be detected by seismic attributes.

All the five attributes can work effectively on identifying the steam chamber. They sucessfully detect the steam chambe zone and clearly show the boundary, suggesting that seismic attributes could be alternative choice for heavy oil reservoir monitoring during thermal production. In addition, among the five attributes, the maximum spectrum and absorption quality factor are the two most reliable ones that can provide estimations with least distrubance.

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EDITED REFERENCES

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