The Application of High Frequency Bright Spot Based on T-K Energy Wavelet Transform in Hydrocarbon Detection

Introduction

Strong seismic reflection often represents the oil and gas reservoir, or the lithology change, or the tuning caused by thin layer. In the process of oil and gas exploration and development, it is very important to accurately and effectively identify the true and false bright spots. The study of thin reservoir has become a hot spot, many scholars have done a lot of research and have achieved some results. Gao et al (2003) researched seismic response analysis of thin interbed, put forward to improve the identification ability of thin layer by using the generalized S transform. Yang (2006) researched the relationship between tuning frequency and frequency spectrum and proposed quantitative inversion technique with certain interpretation meaning, which is based on tuning frequency and frequency decomposition. Based on generalized S transform, Chen et al (2009) utilized low frequency shadows to detect oil and gas reservoir, characterized lithologic reservoir boundary and spatial distribution, reduced multiple solutions of reservoir detection. Castagna et al (2003) used instantaneous time-frequency analysis to detect the low frequency shadow related with hydrocarbon, pointed that time-frequency analysis had the advantages of hydrocarbon detection. Based on the Teager energy operator (1990), Kaiser (1990) proposed a local discrete nonlinear energy density algorithm, namely the TK energy operator, which is more effective for single frequency signal analysis. Since the TK energy operator is established for single frequency signal (2009), the seismic signal is a non-stationary signal composed of many frequency components and has complex time-varying characteristics, its spectrum must be decomposed into single frequency signal to carry on the TK energy calculation. Although these research results are helpful to thin layer detection and identification, but not all of the layers are thin rock oil and gas reservoir, thin bed tuning can also lead to strong seismic amplitude.

The reservoirs with a certain thickness have obvious bright spots on conventional seismic sections and -90 degree phase shift sections. Compared to thinner oil and gas reservoirs, the thick water layer shows abnormal bright features, how to distinguish true from false bright spots, which has always been a dilemma in hydrocarbon detection. In this paper, we propose a new hydrocarbon detection method based on the TK energy wavelet transform to detect the hydrocarbon reservoir with “high frequency bright spot” characteristic. Firstly, using the wavelet transform based on the TK energy, we can get different frequency divisions. The comparative analysis can identify the spectral characteristics of the thick water layer caused by the low frequency tuning, while the thin oil layer still has strong energy at high frequency. Then the frequency components are extracted, which is sensitive to the difference of oil and water layers. After weighted by the power index and merged of these selected frequency band seismic information, we can obtain the fluid indicator factor. Finally, the result of hydrocarbon detection is obtained by multiplying the fluid factor by the -90 degree phase shift result. The result effectively identifies the false bright spots caused by thick water layer and enhances the recognition ability of thin reservoirs. Thereby the model test and actual application show that the proposed method is feasible and effective, which provides a new idea of recognition the false bright spots.

Basic principle

The reservoirs with a certain thickness have obvious bright spots on conventional seismic sections and -90 degree phase shift sections. Compared to thinner oil and gas reservoirs, the thick water layer shows abnormal bright features. Most of the conventional post-stack hydrocarbon detection methods are based on the principle of low frequency enhancement and high frequency attenuation in the amplitude spectrum of the original seismic data. However, the seismic amplitude spectrum in the target area is that the thick water layer has higher low frequency energy(due to tuning)than that of thin oil reservoirs, while its high frequency energy is apparently lower(due to its absorption attenuation) than that of thin oil reservoirs, as shown in Figure 1. Therefore, the conventional hydrocarbon detection method based on the principle of low frequency enhancement and high frequency attenuation can not effectively identify the true and false light spots caused by thin oil and thick water layers.
By using the continuous wavelet transform (Wei, 2009) to process seismic signal, time-frequency information of reflected signal can be obtained, and then we extract different frequency data and make energy normalization, finally, we can get the required frequency division data. The continuous wavelet transform of the signal is defined as

$$X_w(\sigma, \tau) = \langle x(t), \psi_{\sigma,\tau}(t) \rangle = \int_{-\infty}^{\infty} x(t) \frac{1}{\sqrt{\sigma}} \psi\left(\frac{t-\tau}{\sigma}\right) dt$$

(1)

Where $\tau$ is translation factor, $\sigma$ is scale factor, $\psi(t)$ is basic wavelet.

After the continuous wavelet transform, the time scale distribution is obtained instead of the time frequency information, so the scale is converted to frequency. In time domain and frequency domain, wavelet transform can make the local analysis of signal at the same time. Time frequency characteristics depends on the scale factor and shift factor.

The expression of single frequency seismic wave energy is

$$E_s = \frac{1}{2} \rho \omega^2 A^2 = 2\pi^2 \rho f^2 A^2$$

(2)

Where $\rho$ is the density, $f$ is the frequency, $\omega$ is the angular frequency, $A$ is the amplitude. It can be seen from the above equation that the seismic wave energy is proportional to the density of the medium, the square of the frequency and the square of the amplitude.

Using the particle-spring physical model, Kaiser (1990) deduced the discrete form of signal energy expression

$$E_s = \frac{1}{2} m \omega^2 A^2 \equiv x^2[n] - x[n-1]x[n+1]$$

(3)

Where, $m$ is the quality of the particles hanging on the spring, $x(n)$ is the discrete time signal. Formula (3) is called Teager-Kaiser (TK) energy, which is a non-linear signal energy tracking operator. According to the signal energy expression of the discrete form of the TK energy operator, the single frequency signal obtained by the spectral decomposition of the continuous wavelet transform is brought into the formula (3). The TK energy spectrum based on the wavelet transform is obtained, which has higher frequency-time focusing.

Strong amplitude on seismic profiles may be due to gas reservoir, lithologic difference, or the tuning effect of thin layer. For the first two kinds of circumstances, strong amplitude is independent of frequency, while the strong amplitude caused by thin formation interference is associated with the frequency, what’s more, the reflection energy is the strongest corresponding to the tuning frequency. Therefore, for strong seismic reflection, using wavelet transform, we can divide frequency. Then extracting different frequency and normalizing energy, if the reflection amplitude differences are large between different frequency components, and the maximum reflection amplitude occurs at a certain frequency, thus the strong seismic reflection is formed by thin layer interference, otherwise the strong reflection is caused by other factors.

Then the frequency components are extracted, which is sensitive to the difference of oil and water layers. After weighted by the power index and merged of these selected frequency band (include frequency from low to high) seismic information, we can obtain the fluid indicator factor. Finally, the result of hydrocarbon detection is obtained by multiplying the fluid factor by the -90 degree phase shift result. The result effectively identifies the false bright spots caused by thick water layer and enhances the recognition ability of thin reservoirs.

**Model Test**

The modelling data is used to test the method proposed. The oil(green) and water(blue) sand was embedded in the thick mud layer, whose thickness varied from 5m to 30m. The density and $Vp$ of oil sand are 2070kg/m³, 2800m/s, the density and $Vp$ of water sand are 2110kg/m³, 2666m/s, the density and $Vp$ of mud are 2280kg/m³, 2857m/s. Using viscous wave equation for forward modelling, the Ricker wavelet spectrum range is from 10Hz to 70Hz, the main frequency is 40Hz. Utilizing different
hydrocarbon detection methods, we can obtain the HDI results of models, as shown in Figure 2. We can find that the low frequency enhancement method can identify the oil sand from 15m to 25m, the high frequency attenuation method can identify the oil sand from 20m to 30m. The HDI results of the proposed method can identify the oil sand from 8m to 20m, in which the 25Hz-50Hz frequency was weighted by the power index and merged. The model test result effectively identifies the false bright spots caused by thick water layer and enhances the recognition ability of thin reservoirs.

![Model Synthetic seismograms](image)

**Figure 2 The HDI results of models.**

**Application of actual data**

This method has been applied in Bohai oilfield. In the research area, there is no special lithology, but the reservoirs with a certain thickness (the target sands A, B, C, D) have obvious bright spots on the seismic data section, as shown in Figure 3. Therefore it is very important to distinguish true from false bright spots before A well is drilled. The effective frequency range of seismic data spectrum is about 8Hz-55Hz. Thus, we make the frequency division result, as shown in Figure 4. For A, C, D sands, there are large differences between each frequency division components, the strongest response occurs at about 20Hz, which is tuning frequency. However, for B sand, strong reflection is keeping in each frequency division component. So we weight by the power index and merge of 20Hz-50Hz frequency components, the HDI result can be obtained, which show that B sand bears oil. The analysis result before drilling is agree well with the actual drilling result (B is oil sand, A, C, D are thick water sands). The new HDI result is better than low frequency enhancement result and high frequency attenuation result, as shown in Figure 5. The application shows that the proposed method is feasible and effective.

![Figure 1 The amplitude spectrum characteristics.](image)

![Figure 3 The seismic data cross A well.](image)
Figure 4 The frequency divisions cross A well (a)20Hz (b)30Hz (c)40Hz (d)50Hz.

Figure 5 The (a)-90 degree phase shift and (b) new HDI result (c) low frequency enhancement result (d) high frequency attenuation result cross A well.

Conclusions

How to identify true and false highlights, which plays a very important role in oil and gas exploration and development. In this paper, we propose a new hydrocarbon detection method based on the TK energy wavelet transform to detect the hydrocarbon reservoir with "high frequency bright spot" characteristic. Firstly, using the wavelet transform based on the TK energy, we can get different frequency divisions. The comparative analysis can identify the spectral characteristics of the thick water layer caused by the low frequency tuning, while the thin oil layer still has strong energy at high frequency. Then the frequency components are extracted, which is sensitive to the difference of oil and water layers. After weighted by the power index and merged of these selected frequency band seismic information, we can obtain the fluid indicator factor. Finally, the result of hydrocarbon detection is obtained by multiplying the fluid factor by the -90 degree phase shift result. The result effectively identifies the false bright spots caused by thick water layer and enhances the recognition ability of thin reservoirs. The model test and actual application show that the method proposed in this paper is feasible and effective, which has a certain industrial application value.

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