Singularity Spectrum of Hydrocarbon Fluids in Synthetic Seismograms

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Abstract - **Oil and gas exploration is the quest for hydrocarbon deposits trapped underneath the earth surface. Seismic is one of the hydrocarbon exploration tools. Recently significant efforts have been directed, in seismic processing and interpretation, to the development of methods such as spectral decomposition used for tuning hydrocarbon reservoirs and delineating it. In addition, statistical techniques are required to analyze variations in seismic traces. This research work is an alternative technique based on singularity spectrum analysis for detecting and delineating hydrocarbon reservoir. Singularity spectrum captures the singularities occurring in a signal. The technique is applied on synthesized seismograms and three attributes of the singularity spectrum namely width, correlation dimension and α_{peak} are determined. Results show that by using these attributes the reservoir fluids are detected and delineated. Singularity spectrum analysis will potentially improve the performance of Oil & Gas industry by reducing drilling uncertainties, producing accurate geological models of 2D seismic data and for correct production estimates of reservoirs.**

I. INTRODUCTION

Seismic technology is one of the extensively exploited hydrocarbon exploration tools. It is a remote-sensing technique that takes advantage of the elastic properties of the earth formations. It is produced by reflection of sound waves from different layers of the earth and is processed to obtain an image of the geological formations. In exploration, seismic images of the earth's surface are scrutinized by interpreters who search for patterns correlated to possible hydrocarbon reservoirs. Successful hydrocarbon exploration and productions is dependent heavily on signal processing algorithms for extraction of maximum possible amount of information from each seismic data set [1, 2].

Currently spectral decomposition methods (Continuous Wavelet Transform, Matching Pursuit decomposition, Discrete Wavelet Transform) are used to detect hydrocarbon zones. Spectral decomposition involves the frequency analysis of the seismic data. Hydrocarbon reservoirs are detected at low frequencies [3-8]. The analysis of seismic model and real seismic data indicates that the holder exponent spectrum obtained from spectral decomposition is sensitive to changes in lithology and pore fluid types and therefore can be used to estimate reservoir properties [7].

Delineation of hydrocarbon zones is essential particularly in the production phase. Development of a gas field requires the installation of a large number of pipelines and processing plants. Thus planning of infrastructure would be done appropriately. Accurate production estimates and 2D seismic geological models are all dependent on proper delineation of reservoir fluids.

This paper describes the use of wavelet transform to extract the singularity spectrum attributes from a seismic trace. The paper discusses the application of singularity analysis on seismic traces to delineate reservoir fluids for reservoir modeling.

II. SINGULARITY SPECTRUM ANALYSIS

Singularity is a rapid change in variable values for a very small change in time. Holder exponents quantify singularities. Singularity spectra represent the probability distribution of local holder exponents. Singularity spectra has gradually become a powerful method in quantifying time series coming from biology, physics, economics, technical science and many others. Various realistic models are simulated by incorporating the multifractality nature of the data. Various applications [9-19] are developed based on the attributes (width, generalized fractal dimension and α_{peak}) that are extracted from a singularity spectrum. The width of spectrum $f(\alpha)$ indicates the strength of multifractality of a signal. The greater is the width, the more complex the multifractal is. The width of the spectra is the difference of the minimum to the maximum holder exponent values. The set of generalized Fractal Dimension is captured by the singularity spectrum. The peak of the spectrum represents the hausdorff dimension. The correlation and information dimension can also be acquired from the singularity spectra. The Position of Maxima α_{peak} is the holder exponent value of the maximum fractal dimension.

The objective of this research work is to apply singularity spectrum on seismograms for reservoir fluid delineation. Wavelet transform is applicable in the detection of singularities in a signal and hence is used in the above application. The singularity spectra are obtained based on the wavelet transform modulus maxima method. The behaviour

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of the singularity spectra attributes for the various reservoir fluids is investigated.

III. Methodology

In this work, singularity spectrum analysis is applied on synthetic seismogram generated from earth models and well logs.

A. *Earth Model Seismograms*

In the beginning, seismograms of earth models with Oil and Gas as reservoir fluids are developed. These seismograms are generated, at a sample rate of 2msec with Ricker wavelet having a dominant frequency of 60Hz, using MATLAB software. Known density and velocity values of the reservoir fluids are used. Singularity spectra of the seismograms are analyzed, at a frequency range of 20-80 Hz using '*Morlet'* wavelet (first derivative of Gaussian). The moment order 'q' was kept at a range of -6 to +6 with an increment of 0.5 to capture weak and strong transients at positive and negative moment orders respectively, using FracLab software. The singularity spectral attributes namely correlation dimension, width and α_{peak} are measured and recorded accordingly.

B. *Well Log Seismograms*

Well logs (specifically the sonic and the density logs) of five different wells (known to have gas, oil reservoir fluids) are used to generate seismograms at a sample rate of 2msec and with a Ricker wavelet of 40 Hz dominant frequency using Syntool™ software.

The portions of seismogram corresponding to hydrocarbon zones are then subjected to singularity spectrum analysis. The singularity spectra of the zones were analyzed at a frequency range of 20-80 Hz and using a "*Morlet*" wavelet. The moment order was calculated at 'q' values of -6 to +6 to encompass the positive and negative singularities in the selected zones. The singularity spectra attributes namely correlation dimension, width and α_{peak} are measured and recorded accordingly.

IV. Results And Discussion

A. *Earth Model Seismograms*

The singularity spectra of earth model seismograms for an oil and gas based reservoir are shown in Fig.1. It is observed that gas occupies low width, high sets of fractal dimension, low α_{peak} as compared to oil. Table 1 displays the singularity spectra attributes.

Width is dependent on the two extreme positions of holder exponent specifically $\alpha_{\min}$ and $\alpha_{\max}$. In general α represents the degree of regularity with low values of α corresponding to high singularities and vice versa. Hence $\alpha_{\max}$ represents the existence of weak singularities in the signal. Gas is a high energy signal as it contains high transients as compared to oil i.e. why $\alpha_{\max}$ does not take high value ($\alpha_{\max} = 2.46$), while in case of oil due to the presence of weak singularities $\alpha_{\max}$ takes value of 2.9. Hence overall the width of the Oil spectrum becomes wider as compared to gas.

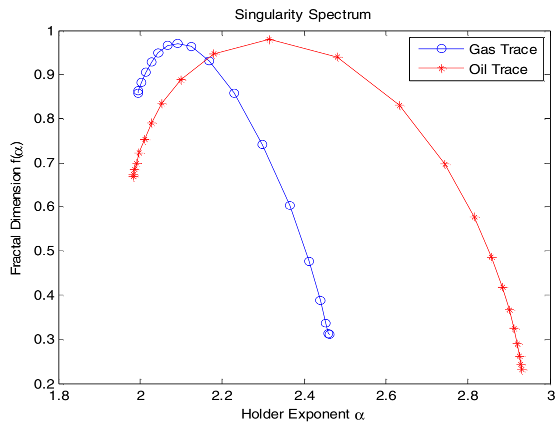

Fig. 1. Singularity Spectra of the Earth Model Seismogram

Table 1

Singularity Spectral Attributes of Earth Model

Reservoir Fluid	Correlation Dimension	Width	α_{peak}
GAS	0.934	0.46	2.09
OIL	0.82	0.948	2.31

α_{peak} is the position of holder exponent of high fractal dimension value. Due to the highly irregular nature of gas α_{peak} attains lower value.

The frequency of occurrence of a singularity is measured by its fractal dimension value denoted by $f(\alpha)$. Left half of the singularity spectrum represents positive moments while right half singularity spectrum represents negative moments. Gas traces exhibit sharp variations hence the frequency of existence of strong singularities is high. Thus i.e. the reason for gas occupying higher fractal dimension values as compared to oil.

From the above discussion, capturing the strength of singularity and analyzing it by observing the various attributes of the singularity spectrum can provide insights to the behaviour of the seismic traces. Developing an analysis tool based on singularity spectrum should help in delineation of oil and gas reservoir fluids.

B. *Well Log Seismograms*

It was observed that the behaviour of the singularity spectrum and its attributes remained the same for reservoir having the same fluid (which is also what we recorded from our model analysis).

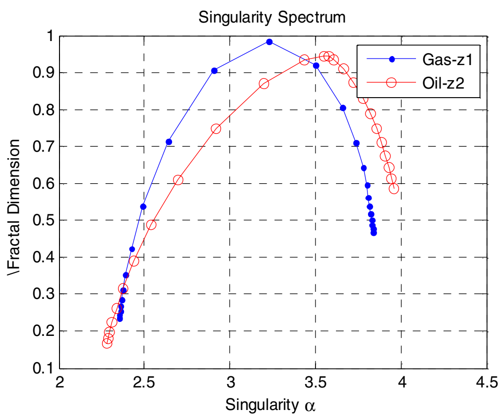

Fig. 2. Singularity Spectra of gas and oil Seismograms

The singularity spectrum of the Gas zones z1 and oil zones z2 are shown in Fig. 2. The singularity spectra attributes are tabulated in Table 2. The same behaviour is observed as in the seismic models with gas occupying low width, high sets of fractal dimension, low α_{peak} as compared to oil.

V. CONCLUSION

The analysis of singularity spectrum attributes namely width, correlation dimension and α_{peak} provides deeper insights into the underlying complexity of seismograms. The analyses of various earth modeled seismic traces and well log seismograms show that singularity spectrum attributes were significantly affected by change in reservoir fluid. Width is affected by the presence of weak and strong irregularities. With weak singularities in oil, oil thus occupies greater width than gas. As gas is high-energy signal, we observed low α_{peak} and high sets of fractal dimension values. These attributes should be used in conjunction with other analyzing techniques for enhancing the interpretation process of reservoir delineation. Singularity spectrum analysis will potentially improve the performance of Oil & Gas industry by more effective well placement, reducing drilling uncertainties, producing accurate geological models of 2D seismic data and estimating correct production of reservoirs.

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TABLE 2

SINGULARITY SPECTRAL ATTRIBUTES OF OIL AND GAS ZONES IN SEISMOGRAM

Zones	Correlation Dimension	Width	α_{peak}
GAS - z1	0.72	1.483	3.13
OIL – z2	0.649	1.67	3.55

REFERENCES

[1] R McQuillin M Bacon W Barclay, An Introduction to Seismic Interpretation, Graham & Trotman Limited, 1979.

[2] Joseph.Dessing,, “A wavelet transform approach to seismic processing”, University of Delft, Netherlands, 1997

[3] Avijit Chakraborty and David Okaya, “Frequency time decomposition of seismic data using wavelet based methods”, SEG Geophysics, Nov 1995

[4] John P. Castagna,, Shengjie Sun, “Comparison of spectral decomposition methods”, First Break, March 2006

[5] L.Guan, Y.Du , L.Li, “Wavelets in Petroleum Industry: Past, Present and Future”, SPE 89952 , 2004

[6] Praveen Kumar, Efi Foufoula-Georgiou, polis-St. Paul “Wavelet Analysis For Geophysical Applications”, American Geophysical Union , 1997

[7] K.R Sandhya Devi,, TX A.J, “Wavelet Transforms and Hybrid Neural nets for improved pore fluid prediction and reservoir properties estimation”, SEG , 2004

[8] J.J.Staal, **“**Characterizing The Irregularity Of Measurements By Means Of The Wavelet Transform”, Delft University of Technology , 1995

[9] W. Kinsner, Winnipeg, A Unified Approach To Fractal Dimensions, IEEE 2005.

[10] Mallat S. and Hwang W.L, “Singularity detection and processing with wavelets”, IEEE Transaction on Information theory , 1992

[11] Tatijana Stosic, Borko D.Stosic, “Multifractal analysis of human retinal vessels”, IEEE Transaction, August 2006

[12] B.Enescu, K.Ito, Z.R.struzik, “Wavelet Based Multifractal analysis of real and simulated time series of earthquakes”, Annuals of Disas.Prev.Res.Inst.,Kyoto Univ., No.47 B , 2004

[13] R.L. Westra, “The Analysis of Fractal Geometry using the Wavelet Transform With Application to Gene Expression Analysis” - Proceeding of EUNITE-conference, Albufeira (Portugal), 19-21 September 2002.

[14] Zhang Xiaofei Xu Dazhuan, “Singular Signal Detection With Fractal”, IEEE Int. Conf. Neural Networks & Signal Processing, Nanjing, China, December 14-17,2003

[15] R.L Barry and W.Kinsner , “Multifractal characterization for classification of network traffic”, IEEE 2004.

[16] Sandar Kumar Nath, Pawan Dewangan, “Detection of seismic reflections from seismic attributes through fractal analysis”, Geophysical Prospecting 2002

[17] W.Kinsner, V.Cheung, K.Cannons, J.Pear , T.Martin, “Signal Classification through Multifractal Analysis and Complex Domain Neural Networks”, Proceedings of 2nd International Conference on Cognitive Informatics, IEEE 2003

[18] S.Fekkai, M. Al-Akaidi, J.Blackledge, “Fractal Dimension Segmentation: Isolated Speech Recognition” , IEE 2000 UK

[19] T.Ehtiati, W.Kinsner and Z.K.Maussavi, “Multifractal characterization of the electromyogram signals in presence of fatigue”, IEEE 1998

[20] Fraclab 2.03 - A Fractal Analysis Software by INRIA - http://fractales.inria.fr/

[21] Syntool™ by Landmark - http://www.lgc.com/ Landmark/integrated+solutions/geophysicaltechnologies/syntoo/index.htm

[22] MATLAB® - http://www.mathworks.com/