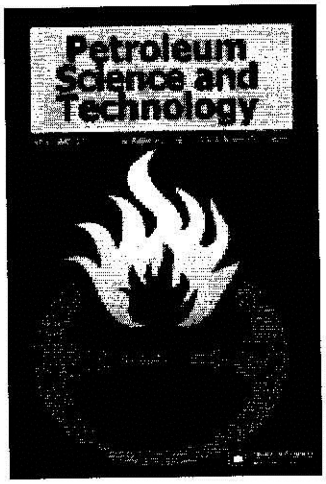

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Diagnosis of Well Production Operations on the Basis of Nonparametric Criteria of Production Data Variations

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Abstract *The relevance of application of different parametric indices of time series variations, such as variance, variation coefficient, normalized deviation, Theil's criteria, etc., for assessment of technological processes is analyzed in this work.*

Different nonparametric criteria of time series variations are suggested that allow diagnosis of changes in the conditions of the process analyzed, when application of other criteria are incorrect or inappropriate.

The applicability and simplicity of realization of nonparametric criteria for practical engineering calculations in analysis of multifractal and chaotic fluctuations are shown.

The applicability of the suggested criteria of time series variations for early diagnosis of qualitative changes in behavior of dynamic systems is proven on model examples as well as on practical examples of oil and gas production.

Keywords diagnosis, dynamic system, fluctuation, fractal dimension, nonparametric criteria, oil wells, pressure, time series, water cut

1. Introduction

Timely diagnosis of the hydrocarbon formation condition is very important for regulation of oil and gas production processes.

It is known that a formation well system is a complex system impacted by internal and external factors (Mirzajanzadeh et al., 2004). Hydrodynamic surveillance results are mainly used in oil–gas field practice for diagnosis of the internal condition of a formation well system, assessment of reservoir properties of the near-wellbore zone, and determination of well performance parameters.

However, carrying out hydrodynamic surveillance is technologically complicated, requires additional financial expenditures and undesired well shutdowns, etc. Therefore, it is necessary to use indirect methods of production data analysis, which allow diagnosing the condition and properties of formation (Mirzajanzadeh et al., 2004) based on normal well operation data (oil rate, wellhead and bottomhole pressure, temperature, etc.) without carrying out additional surveillance operations.

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2. Application of Parametric Criteria of Variation

Most production data are of a fluctuating nature, it is important to use methods that allow assessing the condition, degree of nonequilibrium, and self-organization of the formation system on the basis of fluctuation analysis, diagnosis of fluid movement, and a decision on its regulation (Mirzajanzadeh et al., 1997, 2004).

Different criteria for variations of time series are often used in solution of these kinds of problems, such as variance, coefficient of variation, normalized deviation, Theil's criteria, etc. (Mirzajanzadeh et al., 1997). These criteria are parametric and their use is only correct if the analyzed time-series corresponds to a normal distribution (Gaussian distribution).

Most natural processes do not submit to a normal distribution (Peters, 1996; Mandelbrot, 1997). Fractal theory (Mandelbrot, 1967, 1982), which is currently widely used in many areas, allows stating that the characteristics of many natural processes submit to fractal distribution of Pareto (Peters, 1996; Pareto-Levy distribution or L-steady distributions, Mandelbrot, 1997), the particular cases of which are normal and Cauchy distributions.

Processes that submit to a fractal distribution, excluding the particular case of normal distribution, have infinite variance and have no average value, characterizing the whole selection. Therefore, the application of parametric criteria, developed for normal distribution, during analysis of most natural processes is incorrect (Mandelbrot, 1997).

3. Nonparametric Criteria of Variation of Time Series

Many time series related to monitoring of the investigated system in time are known to submit to the laws of fractal geometry (Mandelbrot, 1982, 1997; Moon, 1987). Fractal curves are highly irregular due to scale invariance and the degree of irregularity is described by the value of the fractal dimension.

However, due to the finiteness of the measurement step, there are a few difficulties in reliable calculation of fractal dimension for time series, such as the necessity for prolonged surveillance to obtain a greater number of measurements, variance in behavior of dynamic processes during measurements, etc.

Limited application of fractal analysis for time processes is also due to the fact that many processes described by fluctuation of technological data do not straighten in the fractal plane (for example, multifractal processes; Mandelbrot, 1982; Feder, 1988). Therefore, it is often impossible to use the Hurst exponent (Feder, 1988; Peters, 1996). In addition, application of the Hurst exponent to study fluctuation processes with an obvious trend is incorrect (Peters, 1996, 2003).

The following nonparametric criterion of time series variation is suggested in the current work for assessment of features of fluctuation in technological data:

$$I = \frac{\sum_{1}^{n-1} |y_{i-1} - y_i|}{n-1} = \frac{|y_1 - y_2| + |y_2 - y_3| + \ldots + |y_{n-1} - y_n|}{n-1},$$

where y_i is the value of the time series of some dynamic process, measured at equal time intervals, and n is the number of measurements.

The following modification of nonparametric criterion can be used for assessment of dynamic process conditions:

$$I_1 = \frac{n}{2(n-1)} \frac{\sum_{1}^{n-1} |y_{i-1} - y_i|}{\sum_{1}^{n} |y_i|} = \frac{n}{2(n-1)} \frac{|y_1 - y_2| + |y_2 - y_3| + \ldots + |y_{n-1} - y_n|}{|y_1| + |y_2| + \ldots + |y_n|}$$

or

$$I_2 = \frac{\ln\left(\sum_{1}^{n-1} |y_{i-1} - y_i|\right)}{\ln(n-1)} = \frac{\ln(|y_1 - y_2| + |y_2 - y_3| + \ldots + |y_{n-1} - y_n|)}{\ln(n-1)}$$

Qualitative changes in a given process can be diagnosed based on changes in given nonparametric criteria values.

The differences in time series $y(t)$ and $z(t)$ during their analysis can be assessed by comparing the values of nonparametric criteria of variations.

Initial time series $y(t)$ and $z(t)$ are normalized relative to their maximum and minimum values $Y_i = \frac{y_i - y_{min}}{y_{max} - y_{min}}$, $Z_i = \frac{z_i - z_{min}}{z_{max} - z_{min}}$. Normalization of time series allows tracking the changes in the process at different stages of development and comparison of different properties of the process, measured in the same period of time.

The suggested variation criteria I, I_1, and I_2 are changing in an interval from 0 to 1 when the normalized values are used.

Next we examine the applicability of the suggested criteria in an example model case, where fractal curves will straighten in logarithmic coordinates. The values of the Weierstrass-Mandelbrot fractal function $C(t)$ (Peters, 2003; Mirzajanzadeh et al., 2004) with a given fractal dimension D are used as values for the analyzed process $C(t) = \sum_{i=-\infty}^{\infty} \frac{(1-\cos(b^i t))}{b^{(2-D)i}}$.

The variability of the function $C(t)$ increases with increasing values of D. It is also reflected in the slope of the trend in the fractal plane (Suleymanov et al., 2009).

The value of suggested index I for given curves also significantly increases from 0.0017 to 0.0074 with increasing values of D.

The next example shows that the suggested criteria allow capturing even insignificant variations in the analyzed process, which are indistinguishable by fractal dimension value. Let us consider normalized values of $C(t)$ function with the same value of $D = 1.4$, $n = 1{,}000$, and different $b = 1.2$ and 1.5.

Initial data points lie on a straight line in logarithmic coordinates and there is little difference in values of fractal dimension, estimated from the trend slopes (Figure 1).

The values of criteria I, I_1, and I_2 for given curves significantly differ from one another and are equal to 0.0032 and 0.0044; 0.0023 and 0.0036; 0.167 and 0.214, respectively.

Similar analysis was conducted for random numbers ($n = 1{,}000$), given with normal and uniform distributions (data are normalized; Figures 2 and 3).

Initial data points lie on a straight line in logarithmic coordinates, and D values, estimated from trend slopes, are very close, which does not allow distinguishing the processes on the basis of fractal dimension application.

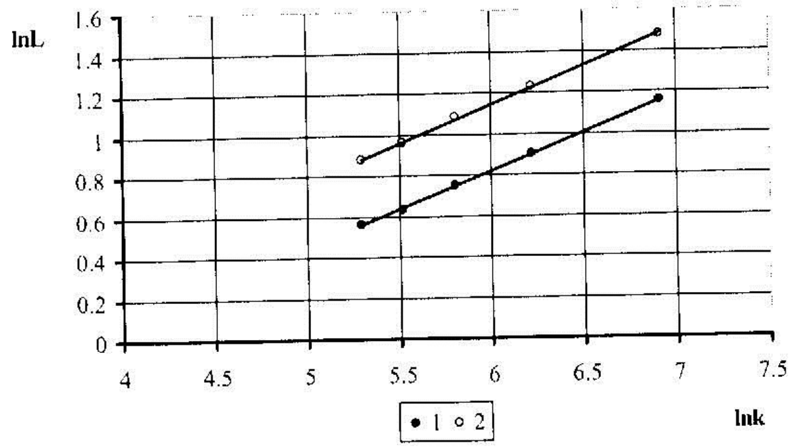

Figure 1. Calculation of fractal dimension: $1 - b = 1.2$; $2 - b = 1.5$.

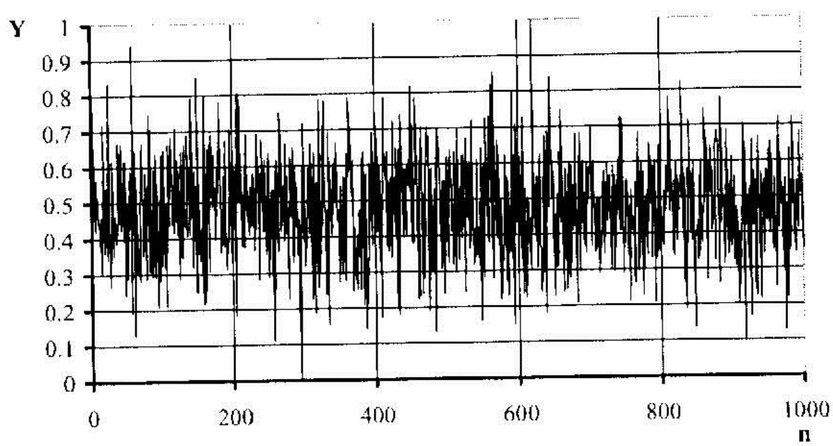

Figure 2. Realization of random numbers generator (normal distribution).

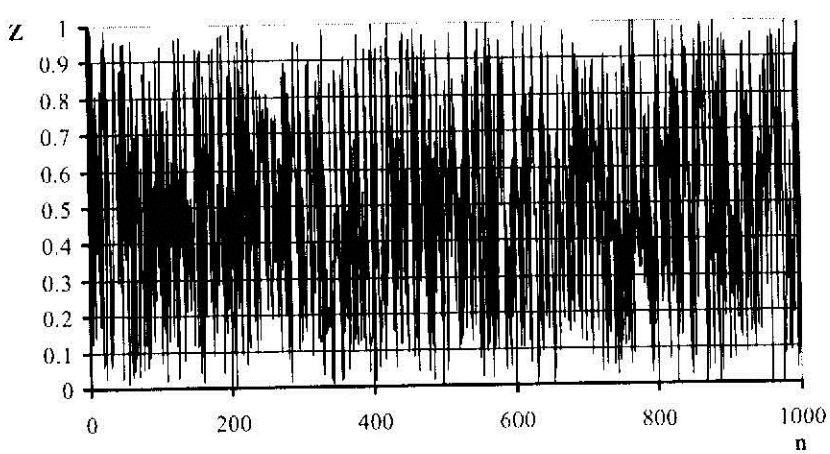

Figure 3. Realization of random number generator (uniform distribution).

The values of index I for given curves significantly differ from one another and are, respectively, 0.1557 and 0.3474. The I_1 (from 0.1624 to 0.3520) and I_2 (from 0.731 to 0.847) criteria values also changed. It can be seen from the results that the suggested criteria allow distinguishing the processes that are indistinguishable by fractal dimension values.

4. Diagnosis of Well Performance Based on Normal Production Data

The opportunity to obtain practically important conclusions and recommendations as a result of fractal theory application stimulates unceasing interest in conducting research in this area. Therefore, the fractal geometry methods have found their use during various studies of oil and gas production processes (Feder, 1988; Mirzajanzadeh and Sultanov, 1995). In addition, fractal characteristics of time series of measurements (Hausdorf dimension, Hurst exponent, etc.) are used during oil field production data analysis (Mirzajanzadeh and Shahverdiyev, 1997; Suleymanov, 1999).

Fractals can be observed in behavior of time processes of oil and gas production such as fluctuations in well rate, pressure, etc., when a decrease in measurement step discovers new characteristics of analyzed parameters. The character of their fluctuations depends on the external impact as well as on the nonequilibrium processes of multiphase systems flow and carries information about the condition and behavior of formation (Mirzajanzadeh et al., 1997, 2004). Determination of fractal characteristics' values of well production data allows carrying out early diagnosis of changes in the formation well system conditions and timely regulation of the well operating regime in order to optimize the production process.

Analysis of published scientific works with the use of fractal approach in petroleum engineering shows that the problems solved are related to the following:

- Determining physical properties of the formation on the basis of analysis of seismic data, logs, core data, outcrops at the surface, and hydrodynamic surveillance of the wells in order to understand the heterogeneity distribution and its further use during 3D geological and reservoir simulation modeling (Hardy and Beier, 1994).
- Research on fractal character of displacement efficiency ("viscous fingering") to forecast production during water injection (Feder, 1988).

It is notable that despite a large number of publications, the oil production diagnosis is rarely considered.

The applicability of fractal characteristics of time series as diagnostic criteria of different oil production processes has been reported in the literature (Hardy and Beier, 1994; Mirzajanzadeh et al., 1997; Abbasov et al., 2000; Suleymanov et al., 2009).

Let us consider the application of the suggested criteria to retrospective analysis of well performance of one of Azerbaijan's oil fields. Figure 4 shows measurements of wellhead pressure taken from well 1 in December 2004 and January 2005. The fractal dimension values estimated from the trend slopes are quite close: 1.831 and 1.849. In addition, the values of suggested index I for given data significantly differ and are, respectively, 0.021 and 0.031.

Further well production data analysis showed that the changing nature of fluctuations in this case was related to the start of water breakthrough in the well, which corresponds well to nonequilibrium condition of multiphase flow system. Analogous analysis of the water breakthrough process diagnosis was carried out for well 2.

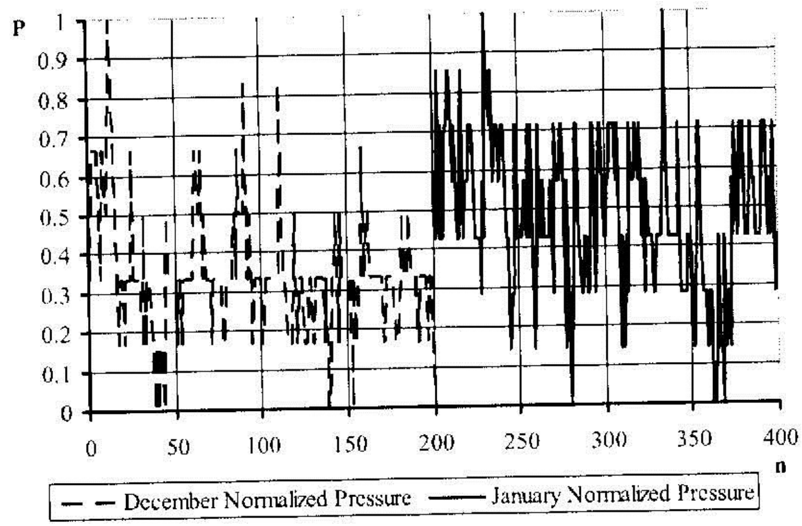

Figure 4. Dynamics of wellhead pressure (normalized) in well 1.

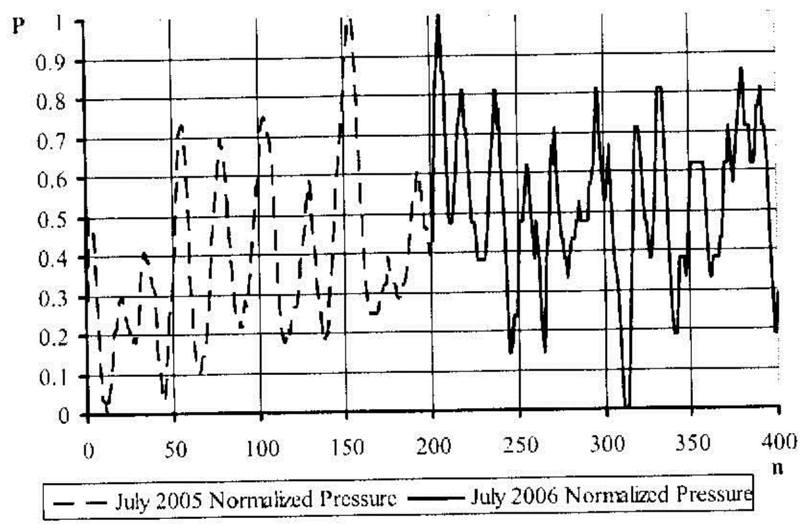

Figure 5. Dynamics of wellhead pressure (normalized) in well 2.

Figure 5 shows measurements of wellhead pressure taken from well 2 in July 2005 and July 2006. It can be seen from Figure 6 that the data in the fractal plane does not lie on a straight line, which does not permit using fractal dimension for its analysis.

Based on the change in the index I (respectively 0.043 and 0.059), diagnosis of the nature of the fluctuations is possible for given time intervals.

5. Conclusions

Given criteria are assigned for practical engineering calculations during analysis of multifractal, chaotic fluctuations and an algorithm for their calculation may be easily realized.

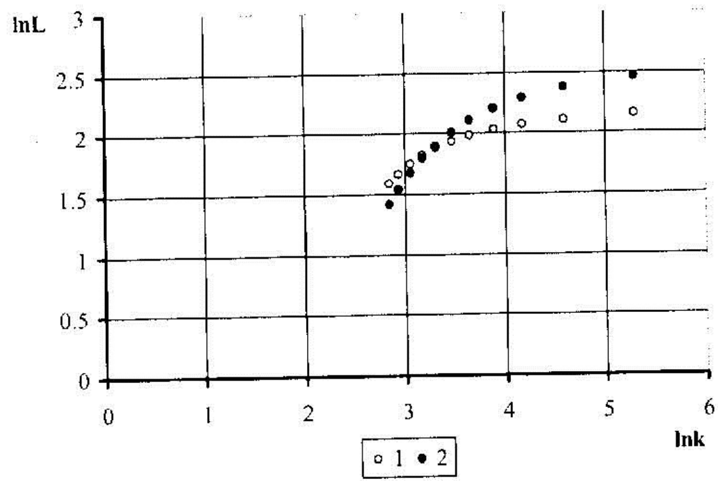

Figure 6. Calculation of fractal dimension (well 2): 1: July 2005; 2: July 2006.

The applicability of the suggested criteria of time series variations for early diagnosis of qualitative changes in behaviors of dynamic systems was proven using model examples as well as practical examples of oil and gas production.

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References

Abbasov, A. A., Suleymanov, A. A., and Ismaylov, A. J. (2000). *Determination of Fractal Dimension of Time Series*. Baku, Azerbaijan: Azerbaijan Oil Industry.

Feder, E. (1988). *Fractals*. New York: Plenum Press.

Hardy, H., and Beier, R. (1994). *Fractals in Reservoir Engineering*. River Edge, NJ: World Scientific Publishing Company.

Mandelbrot, B. B. (1967). Statistical self-similarity and fractional dimension. *Science* 156:636–638.

Mandelbrot, B. B. (1982). *The Fractal Geometry of Nature*. New York: W.H. Freeman.

Mandelbrot, B. B. (1997). *Fractals, Hasard et Finance*. Paris: Flammarion.

Mirzajanzadeh, A. Kh., Aliev, N. A., and Yusifzade, Kh. B. (1997). *Fragments on Development of Offshore Oil and Gas Fields*. Baku, Azerbaijan: Elm.

Mirzajanzadeh, A. Kh., Hasanov, M. M., and Bahtizin, R. N. (2004). *Modeling of Oil and Gas Production Processes*. Moscow: ICR.

Mirzajanzadeh, A. Kh., and Shahverdiyev, A. Kh. (1997). *Dynamic Processes in Oil and Gas Production: System Analysis, Diagnosis, Prognosis*. Moscow: Nauka.

Mirzajanzadeh, A. Kh., and Sultanov, Ch. A. (1995). *Reservoir Oil Recovery Process Diacoptics*. Baku, Azerbaijan: Azerbaijan Publishing Company.

Moon, F. C. (1987). *Chaotic Vibrations*. New York: John Wiley & Sons.

Peters, E. (1996). *Chaos and Order in the Capital Markets*. New York: John Wiley & Sons.

Peters, E. (2003). *Fractal Market Analysis*. New York: John Wiley & Sons.

Suleymanov, A. A. (1999). Analysis of technological data of the operation of oil and gas wells. *Petrol. Sci. Tech.* 17:663–669.

Suleymanov, A. A., Abbasov, A. A., and Ismaylov, A. J. (2009). Application of fractal analysis of time series in oil and gas production. *Petrol. Sci. Tech.* 27:915–922.