FRACTAL MODELING OF OIL AND GAS PRODUCTION PROCESSES: NON-LINEARITY, NON-UNIFORMITY, UNCERTAINTY

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ABSTRACT

Fractal representations simplify the analysis of the turbulent movement of a liquid or gas, as well as the flow process, which is important for the technology of field development. At the same time, in geological processes, nanoscale components and phenomena act as the main ones where the difference in the properties of three-dimensional and two-dimensional (surface) states of matter is important. Fundamentally new methods of complex analysis of oil and gas systems, currently being developed on the basis of modern achievements in fractal physics of nanotechnology, geophysics and mathematical physics, make it possible to concretize information about their dynamics, taking into account the complexity of the topology of oil and gas reservoirs, the porous structure of stressed oil and gas layers, changes in the state of deposits under the influence of technogenic processes. Fractal and nanostructural modeling helps to determine the current level of self-organization and manage balanced field development, and, ultimately, significantly increase the final coefficient of oil and gas extraction.

Keywords: fractal modeling, fractal structures, oil and gas saturation systems

INTRODUCTION

It is advisable to study natural and man-made systems (oil and gas deposits) with a rapidly changing state and manage the development of deposits on the basis of fluid dynamic monitoring, fractal and nanoscale modeling. Fractal and nanostructural characteristics are used as diagnostic criteria that determine the condition of development objects, as well as the need and time of rehabilitation cycles. Self-organization of natural systems provides for strictly dosed technogenic intervention.

Fractal modeling as a tool for studying the hidden order in the dynamics of disordered systems, such as oil and gas fields, has become a technological need. Fractal models simplify the analysis of the turbulent motion of a liquid or gas, as well as the flow process, which is important for industrial technologies of oil and gas field development technology [1-5].

In this paper, the possibilities of a significant increase in the informativeness of seismic-acoustic location tools used for geological exploration and monitoring of the geophysical situation of oil and gas deposits, based on fractal modeling of the scattering of seismic and acoustic fields, are considered. It is shown, in particular, that the use of these methods makes it possible to carry out detailed diagnostics of geodynamics of oil and gas reservoirs with superimposed technogenic processes. The relationship between the fractal structure of an unordered oil and gas saturated elastic medium and the fractonic features of seismic and acoustic waves propagating and scattered in it is investigated.

Thus, fractal clusters formed by sandstones have values of Hausdorff dimension D, located in the range D = 2.57 2.87, (see, for example, [1]). In the absence of significant pressure drops, the transfer of oil or gas in a terrigenous reservoir is due to diffusion on a fractal corresponding to this medium. The dimension of the fractal depends on the grade of sandstone. Fractal properties of the collector are manifested in a wide range of sizes of sand particles - from 0.1 to 100 microns. The Hausdorff dimension D of this continuum two - phase cluster is determined by the relation

D = d - b / n

where d is the dimension of the space; b,n are the critical thermodynamic parameters of the system corresponding to the so-called two-indicator scaling. In the extreme case of fine-grained layers, when their thickness h significantly exceeds the characteristic size of sand particles L, we have d = 3 , b = 0.4 , n = 0.88. At the same time, D = 2.55, which coincides with the data for cluster systems composed of voids of porous matter. If the particle sizes are comparable to the thickness of the sand film, then we can assume that d = 2, and b = 5/36, n = 4.3. Such an intermediate case corresponds to variations in the fractal dimension of the cluster in the range of 1.9 < D < 2.55.

Oil transfer in such a fractal structure is characterized by the probability density f (r,t) to find a particle placed at time t = 0 at point 0, at point r at time t = 0. Since the function f (r, t) is non-analytical and has features on all scales, the reservoir oil and gas content can be described under these conditions by the diffusion equation on a fractal, which in spherical coordinates has the form

$$\frac{\partial F}{\partial} = \frac{1}{r^{D-1}} \frac{\partial}{\partial'} \left[K r^{D-1-\zeta} \frac{\partial F(r,t)}{\partial} \right],$$

where F (r, t is the smooth envelope of the function f (r, t) , K is the generalized diffusion coefficient, x is the indicator of anomalous diffusion.

From the solution of this equation follows the expression for the mean square of the distance <r2 > by which the particle moves in time t :< r2 > = [K (2 + x)2 t] 2 / (2 + x) G (z + 2 (2 + x) -1) G (z) .

The Euler gamma function is denoted by G (z) in (2) , (3); z = D(2 + x)-1.

When studying wave processes in materials with a fractal structure, the spectra of natural vibrations of fractals are of the greatest interest, determined on the basis of an analogy between the equations of elastic vibrations of fractals and the equation of random walks on a fractal [6,7]. Localized vibrational states on fractals that replace ordinary phonon states at frequencies exceeding a certain transition frequency (crossover) are called fractons. The frequency distribution of fractons, due to scale invariance, has a power-law form, and the exponent is determined by the so-called fractonic (spectral) dimension

df = 2D/(2 + x), (4) expressed in terms of the anomalous diffusion index x > 0. The fractonic dimension characterizes the dimension of space in the low-frequency asymptotics of the density of vibrational states.

It is extremely important in oil and gas geological studies to be able to estimate the fractal dimension of the inhomogeneities of the Earth's crust by the frequency dependences of the scattering coefficients of seismic waves.

Thus, the problem of studying and assessing the oil and gas potential of Paleozoic formations representing the lower formation-tectonic plate complex has long been relevant for Western Siberia. The matter is complicated by the fact that due to the special structure and condition of this layer of the Earth's crust, it is impossible to obtain extended reflecting seismic horizons suitable for reliable structural constructions. There are many such reference horizons in the Mesozoic cover [8]. The consequence of this was an ambiguous assessment of the prospects of Paleozoic deposits, uncertain mapping and development of objects.

We have attempted to process seismic information on a profile crossing a number of deposits in the south of Western Siberia. In the time section, the sites representing a complex picture of acoustic reflections in the Paleozoic are selected. There is a chaotic distribution of reflecting areas with a fractal structure [8].

Fractal dimension is a quantity that has many definitions and methods of calculation. Its important property is that it is included in the relations of the form a (e) = CeD,(5) where a is a certain value depending on the value e, which usually characterizes the linear size; C is a constant coefficient of proportionality, and the exponent D is a fractal dimension. If we prologarithm, then on a logarithmic scale in e we get a linear dependence with a proportionality coefficient C: ln a (e) = lnC + Dlne . (6)

This property was used in the calculations. According to the seismic profile, a fragment of which is shown in [8], the numbers of reflecting sites of different sizes were calculated within the selected Paleozoic blocks. The logarithms of the obtained numbers are presented in the form of graphs. Four or more points corresponding to different sizes of platforms lie on one straight line, the slope of which in each case gives the value D.

When analyzing the obtained values, it turned out that from site to site, if there is a tectonic fault, the value of D changes dramatically. In addition, between two blocks with close values of D there is a third one in the middle, but with a different D. Here we can assume the presence of a structural complication combining the first two blocks. Thus, the fractal value D can be used as one of the criteria for similarity and difference of sections (blocks). It should be noted that the theory of flow was developed on gas-liquid models (water filling a grid of cells from which air is pumped out; air displacing glycerin; water displacing non-wettable liquid, such as oil, etc.), as well as on computer models. Moreover, all of these processes have revealed an amazing similarity of their fractal properties. At the same time, this theory can also be transferred to processes in solids, if we take geological time scales, since solids are plastic under certain conditions and "flow" like liquids. As for spatial scales, both micro and macro levels are available for fractal research, which is evident from the very essence of the fractal mathematics apparatus used.

The fractal cluster of radius r contains ~ r D cluster nodes. When wandering on a fractal, as follows from (3), the offset from the initial node will be r μ t 1/(2 + x) , (7)
where x 0 . In the situation of the absence of fractality x = 0, and the usual diffusion ratio r μ t 1/2 takes place .

The probabilities of finding a particle at any node at a distance r from the initial one will become the same after a sufficiently long time t for any r. Therefore, the probability of being at the initial node i after time t can be represented as w_i μ r - D μ r - D/(2+x). (8)

In the case of fractal oscillations, the density of the distribution of its vibrational states r(w) over the frequencies w is determined based on the analogy between the equation of elastic vibrations of fractals and the equation of random walks on fractals: $\rho(\omega) \in \omega^{d_{f-1}}$. (9)

Fractal dimension df = d for the density of ordinary phonon states on a d-dimensional regular lattice.

The area of fractal behavior of real fractal structures is limited to a certain maximum scale l . At the same time, at scales exceeding l, and, consequently, at low frequencies not exceeding a certain frequency of the wc(l) crossover, the situation of the usual phonon spectrum is realized. At higher frequencies, there is a transition (crossover) to the fracton spectrum, which can characterize the degree of oil and gas saturation of the studied media.

The tension of an elastic porous medium is related to its saturation with oil or gas. Therefore, variations in time of the fractonic part of the spectrum will reflect the geodynamics of oil and gas saturated systems caused by technogenic processes. At the same time, it becomes possible to judge the saturation of an elastic medium with oil and (or) gas by spatial changes in fractonic characteristics, and by the transition of fractons to the phonon spectrum in a number of real situations, it is possible to register the boundary of an oil and gas field.

Since the number of particles that make up the real material must correspond to the number of oscillation modes, the density of the states of the phonon (rp) and fracton (rf) spectra per unit volume is expressed as follows: $\rho_p = Nd\frac{\omega^{d-1}}{\omega_c^d}$, (10)

$\rho_p = Nd\frac{\omega^{d-1}}{\omega_c^d} = Nd_f\frac{\omega^{d_f-1}}{\omega_c^{d_f}}$, (11) where $N = l^{-d}$- the number of fractal fragments per unit volume forming the phonon part of the spectrum; $n = (l/l_0)^{D/d_f}$- number of size particles l 0 in a fractal fragment of size l ; $\omega_d = (l/l_0)^{D/d_f}\omega_c$ (12)- fractonic Debye frequency, defined through the crossover frequency ω_c. The fractional Debye frequency, like the usual Debye frequency for the phonon spectrum, provides normalization of the number of oscillations by the number of particles as the integration limit. Integrating the densities r p (w) and rf (w) at intervals (0, wc) and (wc, wd), respectively, we obtain that the total number of phonon states is Np = N, whereas for fractons the total number of vibrational modes is Nf = N(n - 1). The total number of particles is equal to the number of all vibrational states: $N = N_p + N_f = N_n$.(13)

From (10), (11) it follows that at the crossover frequency, the density of phonon states exceeds the density of factor states: $r_p = N_d > r_f = N_f\ d_f$, (14) $d > d_f$. The presence of this feature can be used to register the boundaries of an oil-saturated structure.

Fundamentally methods of complex analysis of oil and gas systems, currently being developed on the basis of modern achievements in fractal physics, geophysics and mathematical physics, make it possible to concretize information about their dynamics, taking into account the complexity of the topology of oil and gas reservoirs, the porous structure of stressed oil and gas layers, changes in the state of deposits under the influence of technogenic processes.

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