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非饱和岩石中的纵波频散与衰减: 双重孔隙介质波传播方程

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Velocity dispersion and attenuation of P waves in partially-saturated rocks: Wave propagation equations in double-porosity medium

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摘要 本文采用Rayleigh理论描述纵波激励下非饱和岩石中气泡的局域流体流动,从经典力学的哈密顿原理导出了双重孔隙介质中的波传播方程,即Biot-Rayleigh方程.方程的格式简洁,参数少,所有相关参数物理可测,因此,方程具有较好的物理可实现性.基于相同的岩石与前人理论对比,初步验证了本理论的有效性.对三个地区的砂岩储层进行了分析,结果显示:地震频段内纵波对储层是否含气非常敏感,但对含气饱和度指示性不佳,且随着孔隙度降低,纵波频散与衰减在中低频段更为显著;含甲烷与含二氧化碳的砂岩储层均呈第三类AVO响应特征,很难从叠前分析技术中鉴别;理论预测的纵波频散随饱和度与频率变化的趋势与特征,与多频段实验观测结果一致.

关键词 非饱和, 地震波频散, 衰减, AVO分析, 双重孔隙介质, 砂岩

Abstract: The dynamic process of P-wave-induced local fluid flow in partially-saturated rocks is described by introducing Rayleigh's theory into poroelastic equations. The wave propagation equations in double-porosity medium (Biot-Rayleigh Equations) are derived from Hamilton's principle of classic mechanics. This thoery benefits from concise mathematical expressions and fewer coefficients. All relevant coefficients in expressions can be determined by measuring rock fundamental properties, so that the Biot-Rayleigh equations are physically realizable. Comparisons with the former theories in literature have preliminarily proved the validity of this theory. An analysis on the sandstone reservoirs of the three districts shows: seismic-band P waves are sensitive to gas in reservoir, but are not so efficient to quantitatively indicate gas saturation, and P-wave dispersion and attenuation are more significant in seismic band for lower porosity sandstones; the CH_4-saturated and CO_2-saturated reservoirs share the same 3rd type of AVO characteristics and can hardly be discriminated based on the traditional pre-stack analysis; the theory successfully predicts the trends and the multi-frequency-band experimental observed characteristics of P wave velocity variation in relation to water saturation and frequency.

Keywords Partially-saturated, Seismic wave velocity dispersion, Attenuation, AVO analysis, Double-porosity medium, Sandstone

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