Frequency dependent attenuation and dispersion in patchy-saturated porous rocks

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SUMMARY

From seismic wave equations in modified patchy-saturated model established on the basis of White model, we derived the formulas of reciprocal quality factors and velocities of the two kinds of P-waves and analyzed the seismic attenuation and velocity dispersion of the two kinds of P-waves in patchy-saturated rocks within the seismic band. Through comparison of seismic attenuation in modified patchy-saturated, Biot and BISQ models, we find that seismic attenuation in modified patchy-saturated model is much higher than that in the other two models---about 1000 times higher. Therefore, the modified patchy-saturated model can describe seismic propagation more accurately in the seismic band and can be used in seismic exploration. Owing to the importance of porosity, permeability and fluid saturation, we also studied and analyzed the effects of the three factors on seismic attenuation and velocity dispersion of P-waves in patchy-saturated rocks within the seismic band.

THEORY

The dilatational wave equations in the modified patchy-saturated model are

$$\rho\frac{\partial^2\theta}{\partial t^2}+\rho_{f_2}\frac{\partial^2\varepsilon}{\partial t^2}=H\nabla^2\theta+2\gamma D\nabla^2\varepsilon,$$

$$\rho_{f_2}\frac{\partial^2\theta}{\partial t^2}+m\frac{\partial^2\varepsilon}{\partial t^2}=2\gamma D\nabla^2\theta+2D\nabla^2\varepsilon-\frac{\eta_2}{\kappa}\frac{\partial\varepsilon}{\partial t},$$

Solving the above equations, we obtain

$$\left(4\gamma^2D^2-2DH\right)k'^4+\left(2D\rho\omega^2-4\gamma D\rho_{f_2}\omega^2+m\omega^2H+i\frac{\eta_2}{\kappa}\omega H\right)k'^2$$
$$+\rho_{f_2}^2\omega^4-m\rho\omega^4-i\frac{\eta_2}{\kappa}\rho\omega^3=0$$

Then we have

$$k_{1,2}'^{\,2}=\frac{-B\pm\sqrt{B^2-4AC}}{2A}\qquad k_{1,2}=\mathrm{Re}(\sqrt{k_{1,2}'})$$

$$\alpha_{1,2}=\mathrm{Im}(\sqrt{k_{1,2}'})\qquad v_{1,2}=\frac{\omega}{k_{1,2}}=\frac{\omega}{\mathrm{Re}(\sqrt{k_{1,2}'})},$$

$$Q_{1,2}^{-1}=\frac{v_{1,2}\alpha_{1,2}}{\pi f}=\frac{2\alpha_{1,2}}{k_{1,2}}=\frac{2\,\mathrm{Im}(\sqrt{k_{1,2}'})}{\mathrm{Re}(\sqrt{k_{1,2}'})},$$

with

$$A=4\gamma^2D^2-2DH$$

$$B=2D\rho\omega^2-4\gamma D\rho_{f_2}\omega^2+m\omega^2H+i\frac{\eta_2}{\kappa}\omega H$$

$$C=\rho_{f_2}^2\omega^4-m\rho\omega^4-i\frac{\eta_2}{\kappa}\rho\omega^3$$

In the Biot and BISQ models, we have the same expressions about the velocity and reciprocal quality factor of P-waves, but with different A,B and C.

The Biot model:

$$A=4\gamma^2D^2-2DH$$

$$B=2D\rho\omega^2-4\gamma D\rho_f\omega^2+m\omega^2H+i\frac{\eta}{\kappa}\omega H$$

$$C=\rho_f^2\omega^4-m\rho\omega^4-i\frac{\eta}{\kappa}\rho\omega^3$$

The BISQ model: please refer to the paper of Dvorkin et al. in 1994.

CONCLUSIONS

Through comparing with the Biot and BISQ models, we find that seismic attenuation of the fast P-wave in the modified patchy-saturated model is much higher than that in the Biot and BISQ models---about 1000 times higher, within the seismic band. Therefore, the modified patchy-saturated model can describe the seismic waves in real rocks more accurately and can be used in seismic exploration. Through research the effects of porosity, permeability and fluid saturation on seismic attenuation and velocity dispersion, we obtained: First, for the fast P-wave, seismic attenuation increases with increasing porosity and frequency and decreasing gas saturation or increasing water saturation within the seismic band. Attenuation peaks move to high frequencies as rock permeability increases. When the porosity is low, velocity dispersion is not obvious, and it is obvious only at low frequencies when the rock permeability is small. Velocity dispersion becomes severe as the gas saturation goes down. Second, for the slow P-wave, seismic attenuation and velocity dispersion are all apparent no matter what the rock permeability and porosity are low and high. Seismic attenuation goes up with increasing porosity and gas saturation and decreasing frequency within the seismic band.

FUTURE WORK

We will derive the S-wave equation in the modified patchy-saturated porous rocks and study the effects of porosity, permeability and gas saturation on seismic attenuation and velocity dispersion of S-wave.

ACKNOWLEDGEMENTS

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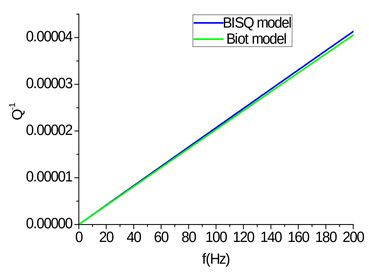
Comparison of inverse quality factors in three models



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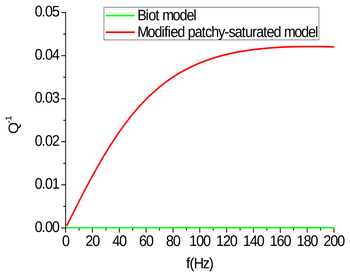

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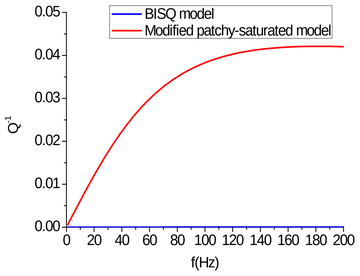
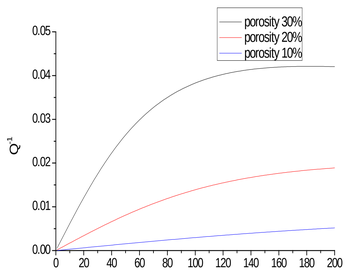
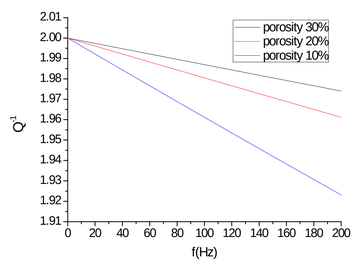


(c)

Attenuation and dispersion of the two kinds of P-waves with different porosity



(a) Reciprocal quality factor of the fast P-wave



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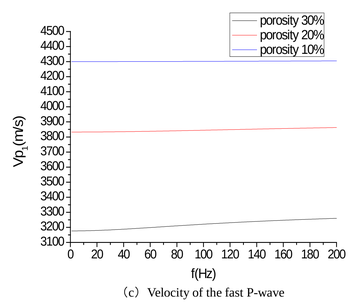

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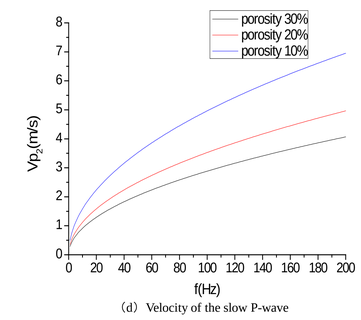
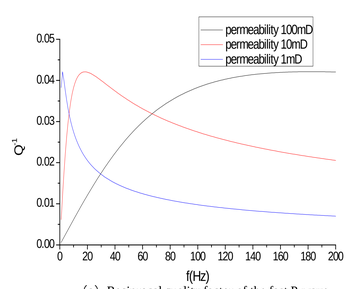


(d) Velocity of the slow P-wave

Attenuation and dispersion of the two kinds of P-waves with different permeability



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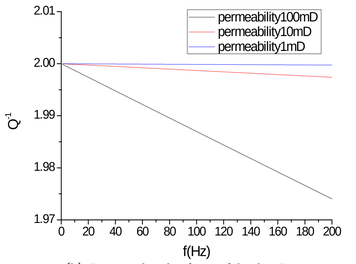

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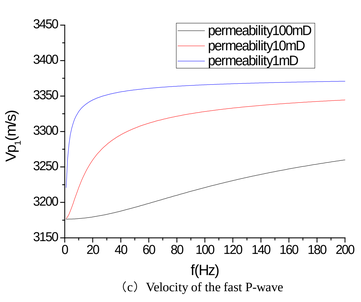

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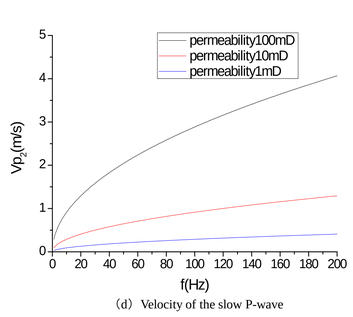
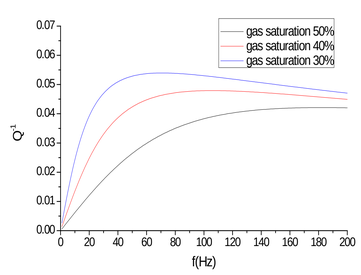
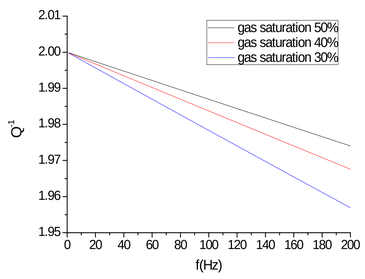


(d) Velocity of the slow P-wave

Attenuation and dispersion of the two kinds of P-waves with different gas saturation



(a) Reciprocal quality factor of the fast P-wave



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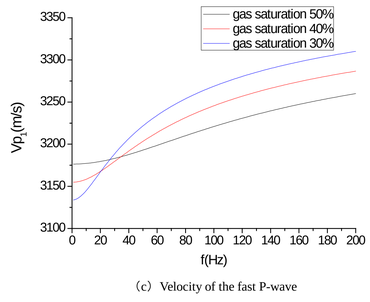
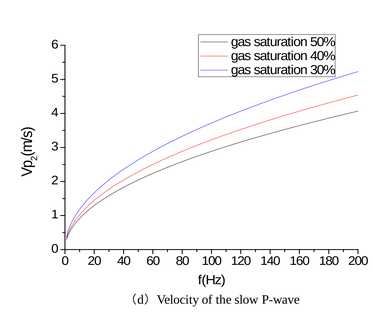


(c) Velocity of the fast P-wave



(d) Velocity of the slow P-wave