Drainage Flow of a viscous compressible fluid (gas) through a tortuous narrow conduit

Jackson Abankwa Opoku, Mechanical Engineering
Mentor: Kangping Chen, Associate Professor
SEMTE

Background

- Natural gas comes from rock formation that, once drilled allows the gas to flow freely.
- Currently, supplies are declining. The remaining vast gas resources lie trapped tightly in dense rocks, inside pores about 20,000 times narrower than human hair called tight/shale gas.
- A better understanding is required to construct optimal gas production schemes to extract most of the trapped gas during recovery

Modeling Approach

- The damped wave equation is simulated through a tortuous micro-conduit connected to a reservoir using COMSOL 2D Pressure Acoustic Transient Module.
- The total acoustic pressure variable, $\boldsymbol{\rho_t}$ is set as the density perturbation $\boldsymbol{\rho'}$,.
- Simulation parameters are;

(a) Fluid density term, $\boldsymbol{\rho}$ is set as one.

(b) Dynamic viscosity, $\boldsymbol{\mu}$ and bulk viscosity, $\boldsymbol{\mu_b}$ are set as $^{3D_\rho}/_4$ and zero respectively in the damping term

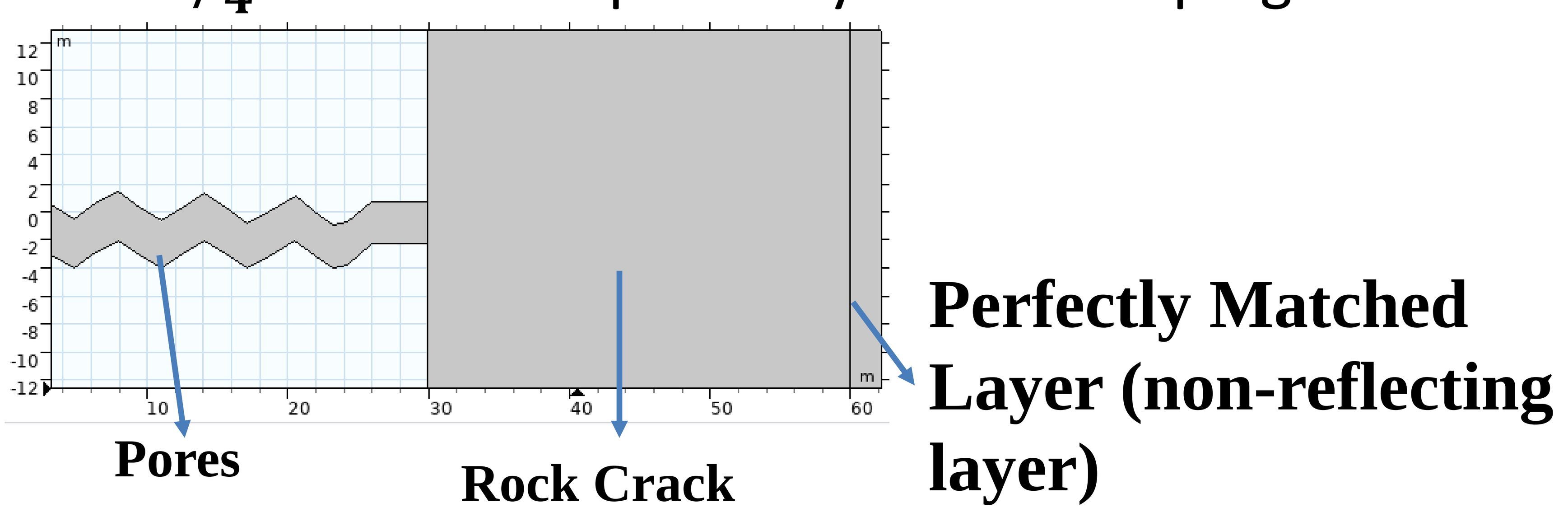


Fig 1. Computational Domain

(c) The two Domain sources are set as zero.

(d) Free triangular mesh was used in the conduit and reservoir with finer distribution at the interfaces.

(e) Mapped mesh was used in the PML

(f) Time step of 0.1 was used to run the simulation for 10 s.

Results and Discussion

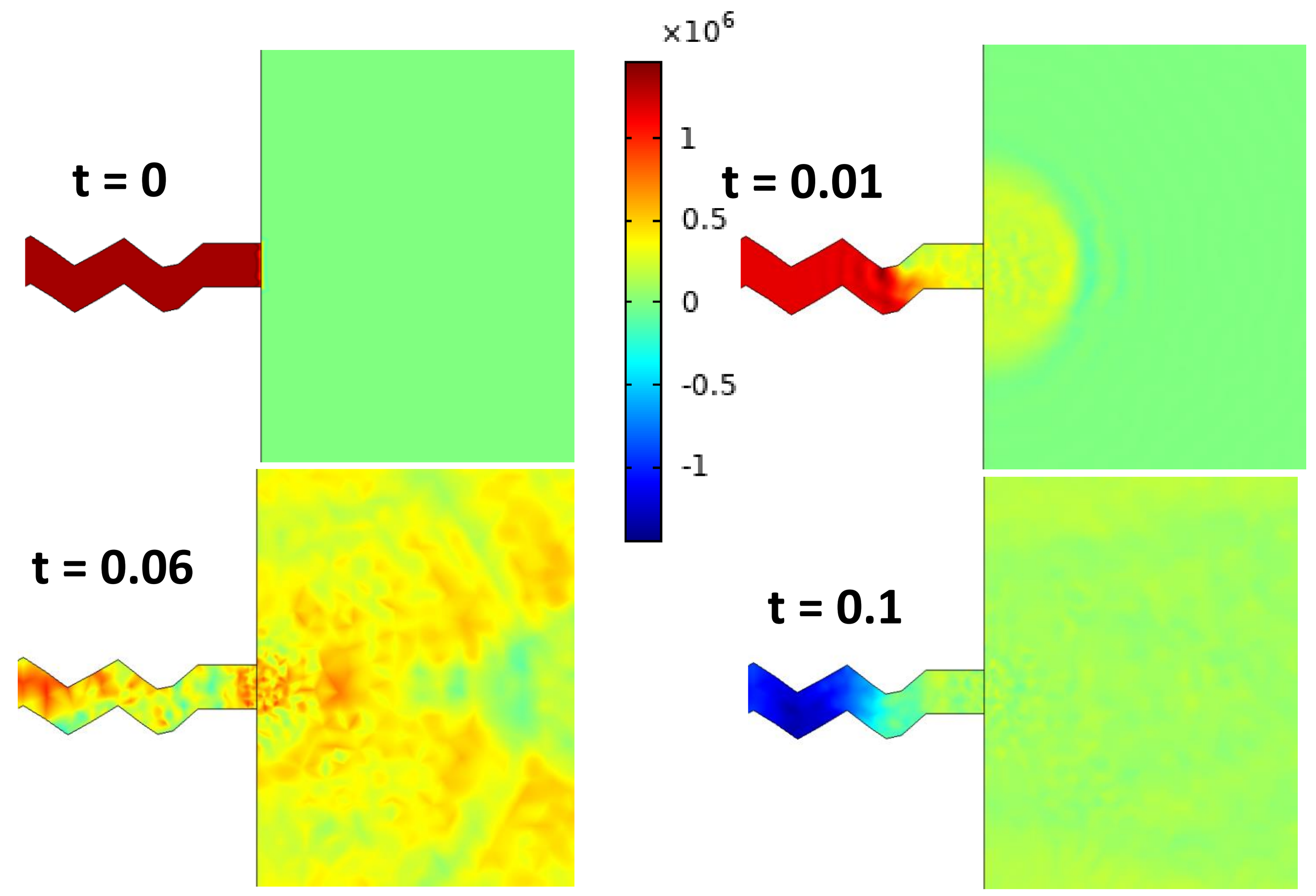
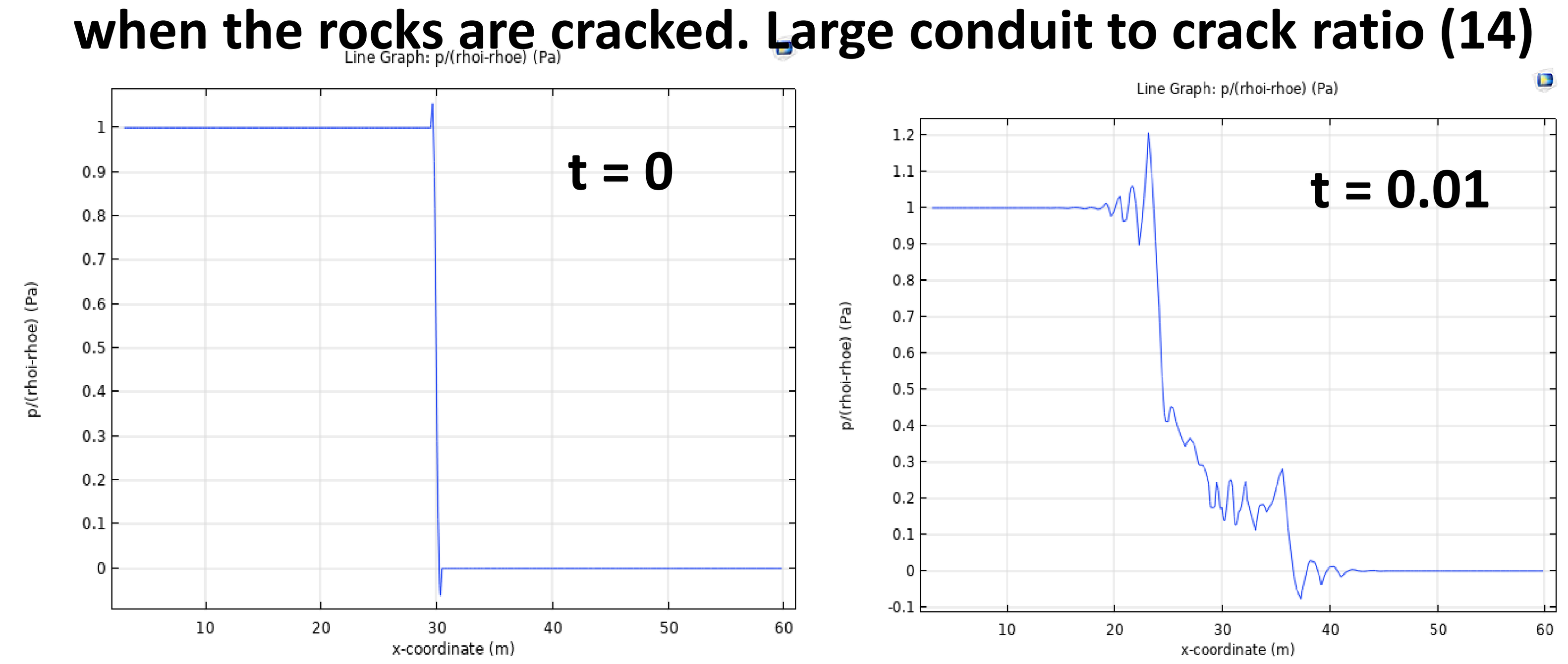


Fig. 2. Surface plot of the different acoustic wave regimes when the rocks are cracked. Large conduit to crack ratio (14)



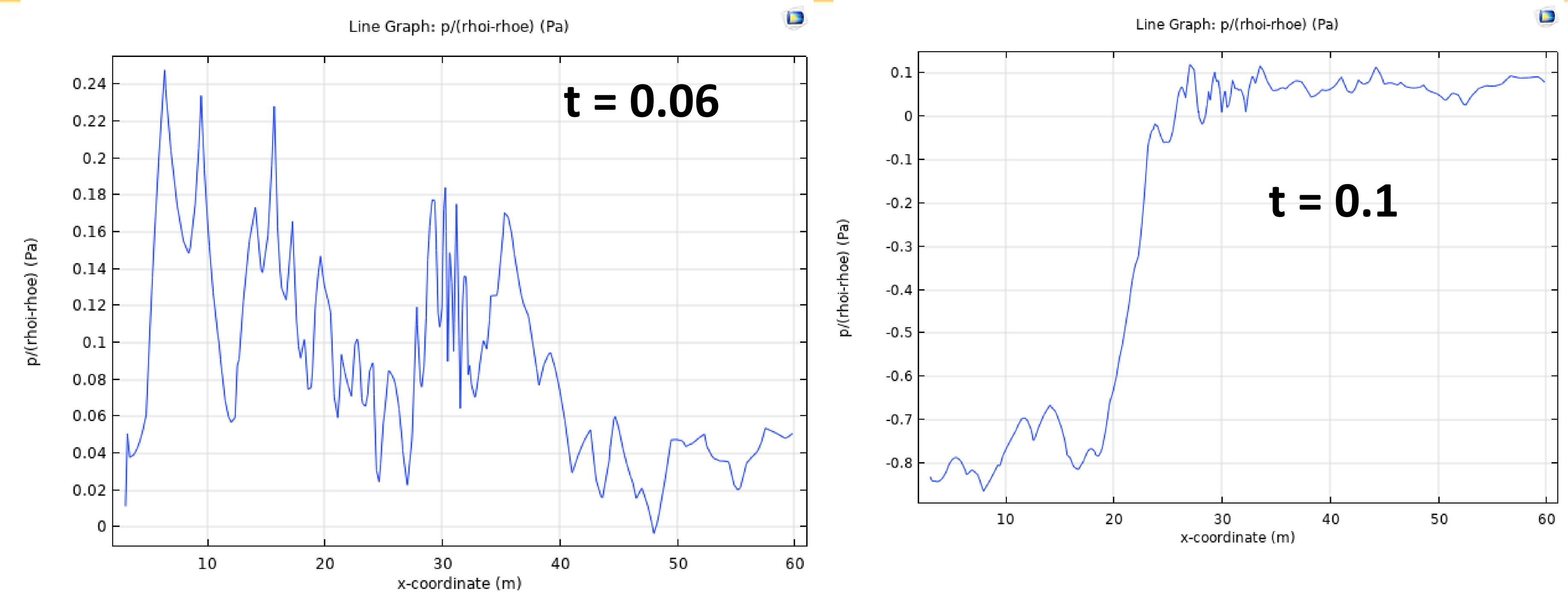


Fig. 3. Comparison of density wave oscillation inside the tube and reservoir (crack) at different time instances.

Plane decompression wavefront moves in the opposite direction as the wave exits the conduit, it reflects after hitting the sound hard(No flow) wall. The wave front is rarefracted back as it approaches the exit due to higher impedance difference in the reservoir with $\dot{m} = 10^{-10} kgs^{-1}$

Conclusion

- Conventional pressure driven theory can be applied in the crack void but not in the conduit due to its size.
- Drainage flow is controlled by the slow decay of the standing acoustic wave inside the capillary.

References

[1].Chen, K. P. and Shen, D., "Drainage flow of a viscous compressible fluid from a small capillary with a sealed end," J. Fluid Mech. 839, 621–643 (2018a). [2].Chen, K. P. and Shen, D., "Mechanism of fluid production from the nanopores of shale," Mech. Res. Commun. 88, 34–39 (2018b) [3].Jin, Y. and Chen, K. P., "Fundamental equations for primary fluid recovery from porous media," J. Fluid Mech. 860, 300–317 (2019). [4].Muskat, M., Physical Principles of Oil Production (McGraw-Hill, New York, 1949 [5] COMSOL Multiphysics® Modeling Software, Burlington, MA, USA

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