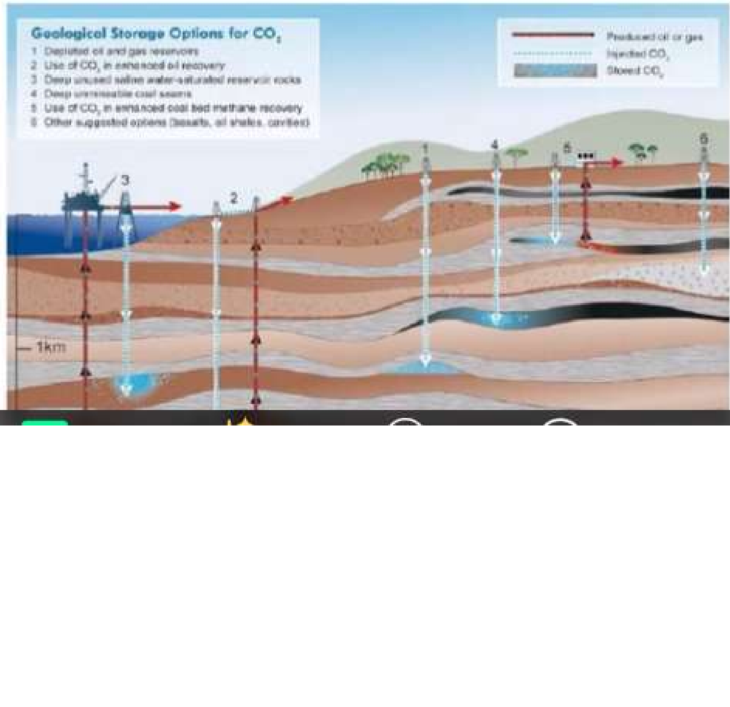
Introduction

- Gravity currents emerge from the interaction between buoyancy forces and the pull of gravity. When a denser fluid displaces a less dense fluid, it sets in motion a flow primarily oriented horizontally. This flow is initiated due to the disparity in density between the fluids.

- Density differences in natural fluid systems arise through temperature variations, salinity gradients and the presence of suspended particles.



- Important application of gravity currents is in Carbon Sequestration and the injection of lubricants from an oil-well drill into the

- A porous medium is a solid structure with small pores passages in the medium in which fluid flow.
- Flow in porous media has active research area last 4 to 5 decades in the field of science and engineering, such as the flow of water in the soil, the flow of contamination in porous media, and some in biomedical studies.
- Multi-phase flows in the porous medium have many applications, such as oil/gas reservoir simulation, carbon dioxide sequestration, and water soil infiltration.
- Layered porous medium which has isotropic in nature but has different permeability and porosity.

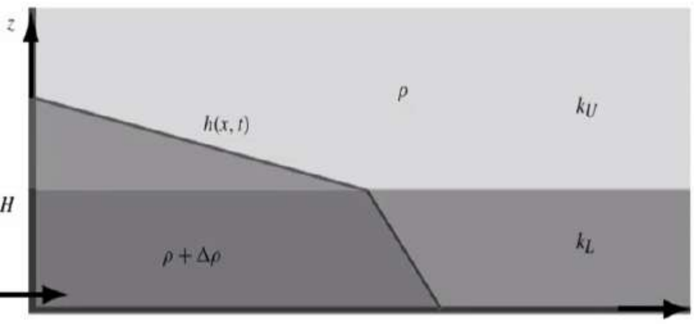
Today researchers are more interested in computational analysis rather than experiment. It discuss the relevance of this work to the geological sequestration of carbon di oxide and other industrial and natural flows in porous media.

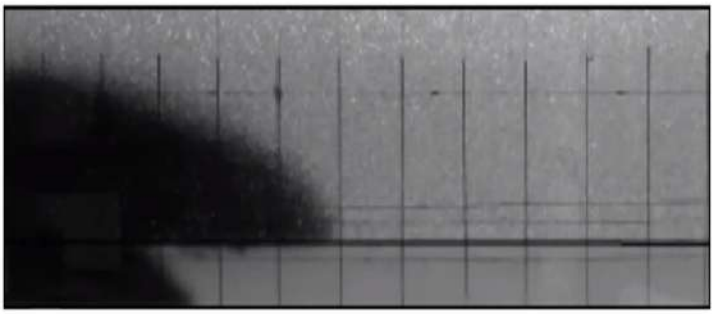
- ANDREW W. WOODS and ROBERT MASON, 2000 , The dynamic of the two-layer gravity-driven flow in permeable rock [1]
- Experimental insights into gravity-driven flows and mixing in layered porous media by Chunendra K. Sahu and Jerome A. Neufeld [2]
- JEROME A. NEUFELD and HERBERT E. HUPPERT, 2009 , Modelling carbon dioxide sequestration in layered strata [3]

- HERBERT E. HUPPERT, JEROME A. NEUFELD AND CHARLOTTE STRANDKVIST, 2013 , The competition between gravity and flow focusing in two porous media [4]

- The experimental setup is used to investigate gravity currents propagating through two-layered porous media.
- The gravity current profile of experiment in two layer porous media in which permeability of upper layer is more than lower layer.

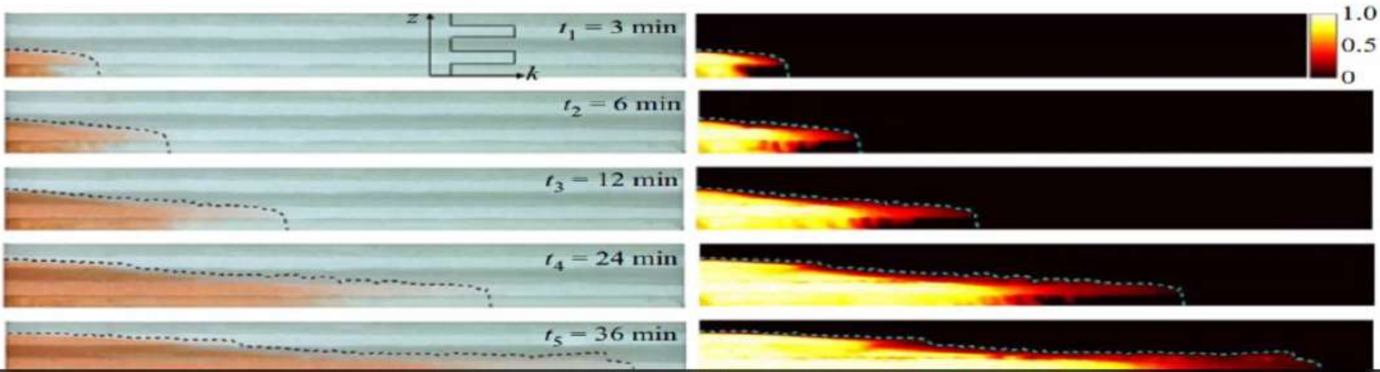
Gravity and flow focusing in two-layered porous media





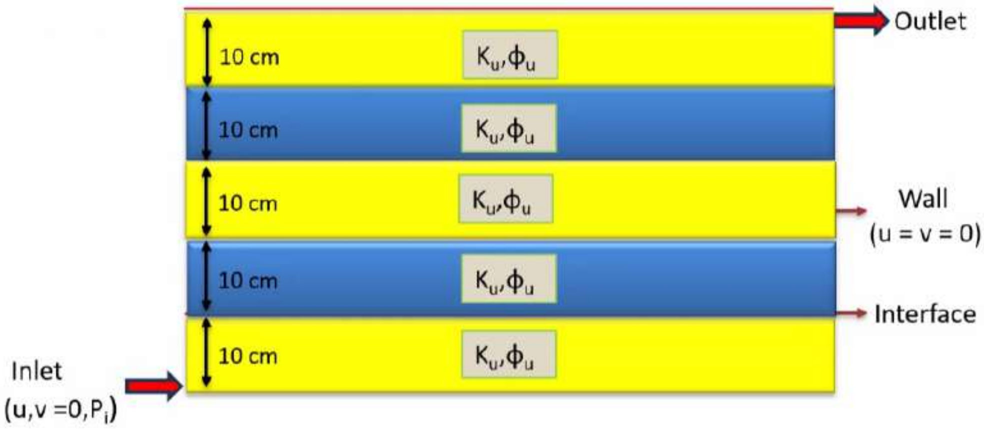
Experimental insights into gravity-driven flows and mixing in layered porous media by Chunendra K. Sahu and Jerome A. Neufeld

- This paper explores the process of dispersive entrainment in gravity currents within multi-layered porous media, a phenomenon where the current mixes with the surrounding fluid due to dispersion.
- Recognizing the influence of permeability heterogeneity on flow and mixing dynamics in porous media, this study presents findings from laboratory experiments designed to characterize the behavior of gravity currents in multi-layered porous media.



Problem Definition

•In this, we will study the velocity front location of injected fluid in permeable layer in a porous medium at different time intervals and observe the mixing of multi layered fluid, we will use commercial CFD software ANSYS fluent.



Multi-Layered Porous Media Structure

Problem Definition

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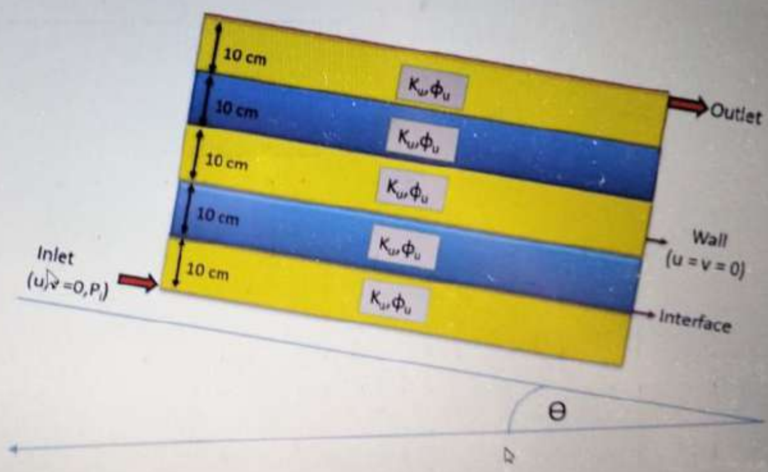


Multi-Layered Porous Media Structure with inclined base

Governing Equation

- Porous media are modeled by the addition of a momentum source term to the standard fluid flow equations. The source term is composed of two parts: a viscous loss and an inertial loss term

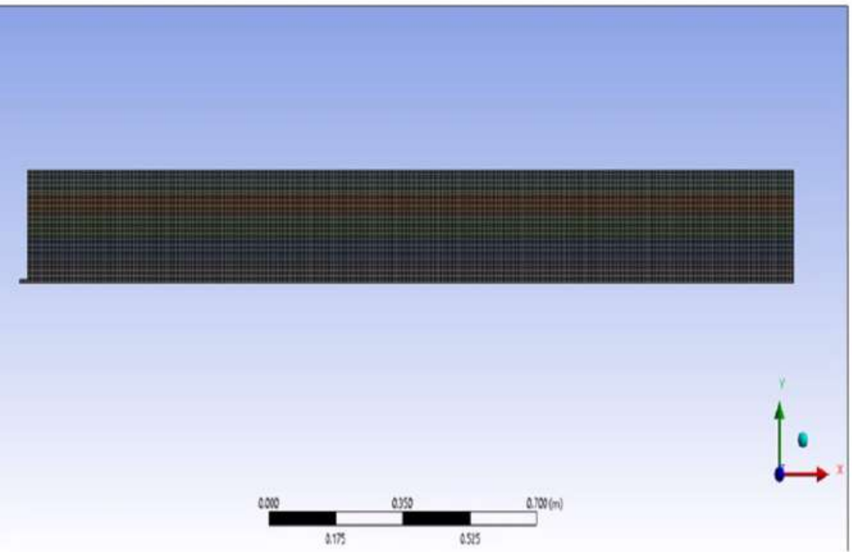
$$s_i = \left(\frac{u}{a}v_i + c_2\frac{1}{2}\rho_{|v|v_i}\right)$$

where α is the permeability and c_2 is the inertial resistance factor, simply specify D and C as diagonal matrices with 1/α and c_2

Darcy's Law in Porous Media

- In laminar flow through porous media, the pressure drop is typically proportional to velocity and the constant c_2 can be considered to be zero.
- Ignoring convective acceleration and diffusion, the porous media model then reduces to Darcy's Law:

Geometry and Meshing



Regular Cavity	Statistics
Physics pref.	CFD
Solver pref.	Fluent
Element order	Linear
Transition	slow
Nodes	75493
Elements	74840

Methods

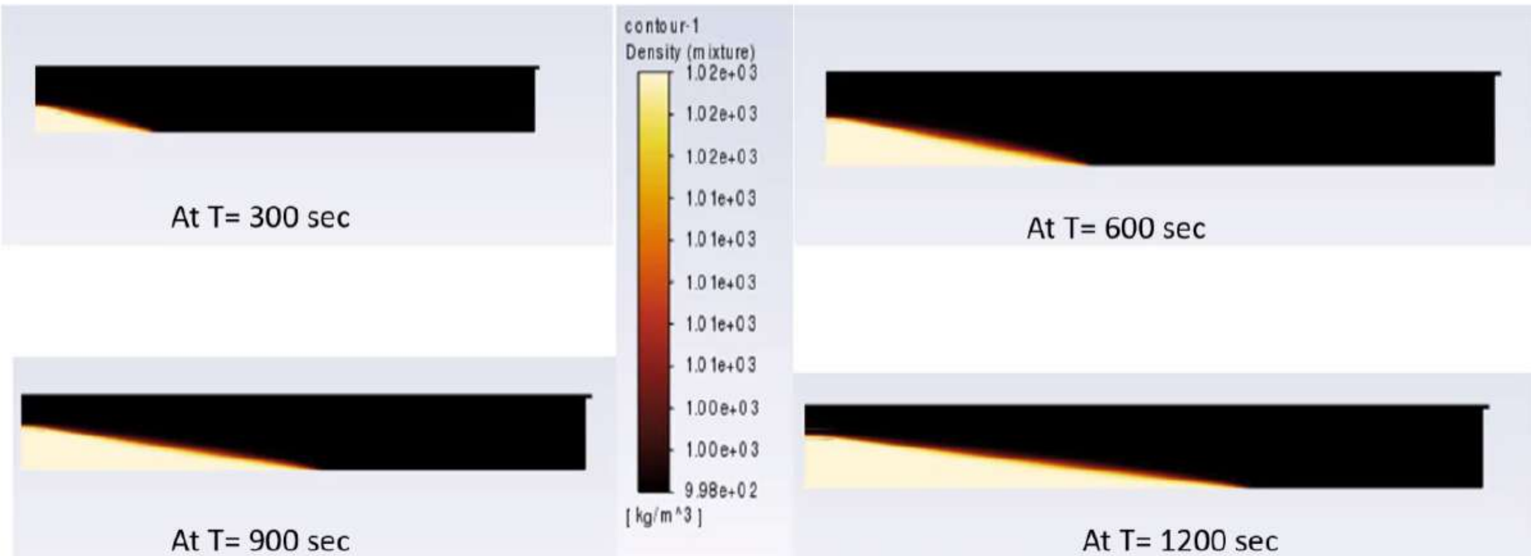
Solver type	Pressure based
Time	Transient
Pressure-velocity scheme	Coupled
Viscous model	Laminar
Multiphase model	VoF
Interface modelling	Sharp
Primary phase	Water(ambient fluid)
Secondary phase	Salt water(Injecting fluid)

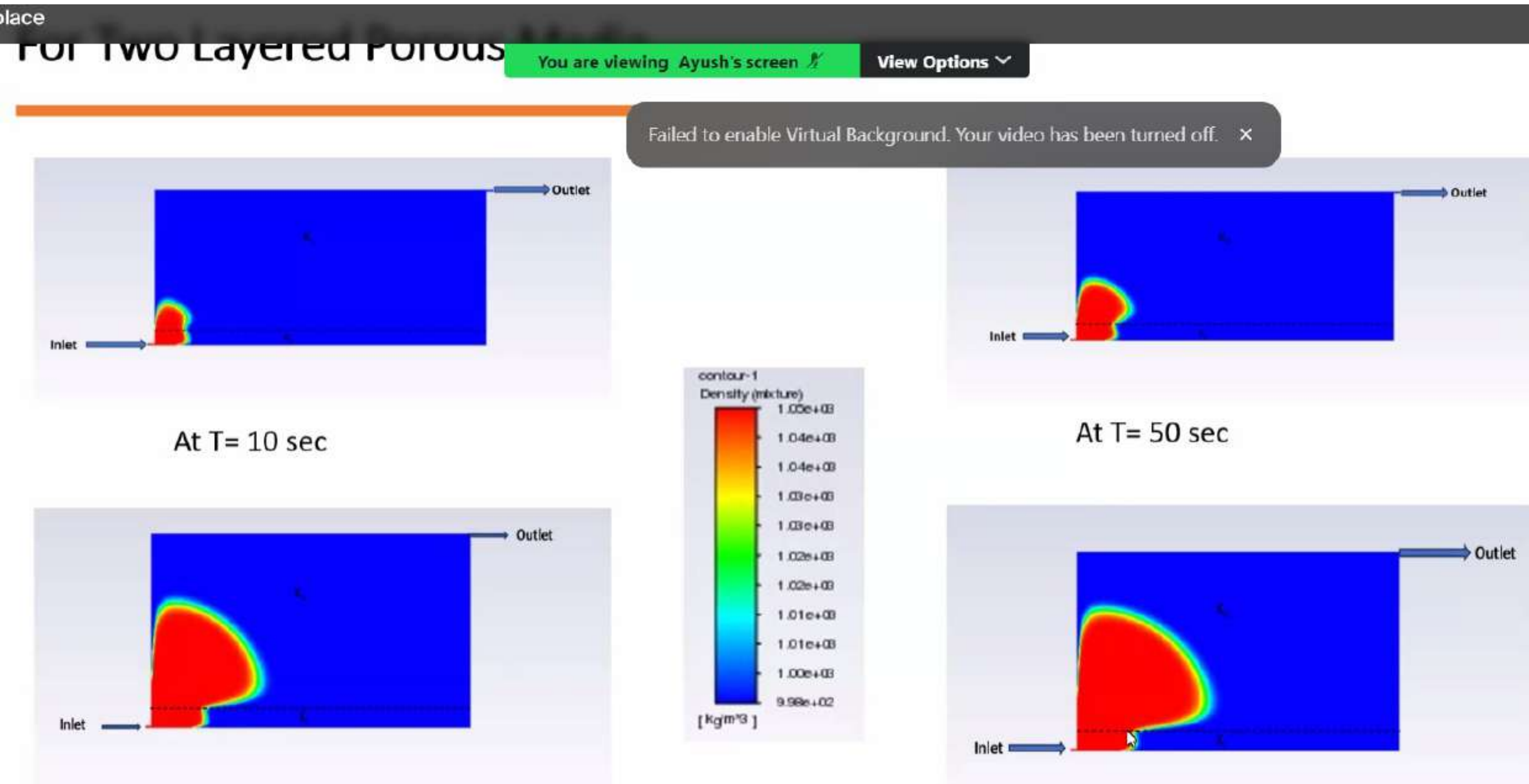
Simulation settings

Material	**water**	Density = 1000 kg/m3 and Viscosity = 0.001 kg/ m. sec
	salt water	Density = 1045 kg/m3 and Viscosity = 0.001kg/ m. sec
Cell zone condition	**upper layer porous media**	Ku = 1.2e-4 and Porosity = 0.41
	lower layer porous media	Kl= 9e-6 and Porosity = 0.38
Boundary condition	**pressure inlet**	Pressure gauge = 2000 Pa
	outlet pressure	pressure gauge = 0 Pa
	wall	No-slip condition
Run calculation	**Time advancement**	Fixed
	No. of time step	10000
	Time step size	0.01
	Max Iteration/time step	20

Results

- We are conducting simulation for Dispersive entrainment into gravity currents in porous media for homogeneous medium.
- The simulated results obtained from ANSYS exhibit a 95% accuracy when compared with experimental data, as documented in the paper on dispersive entrainment into gravity current.

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1.02e+03
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1.01e+03
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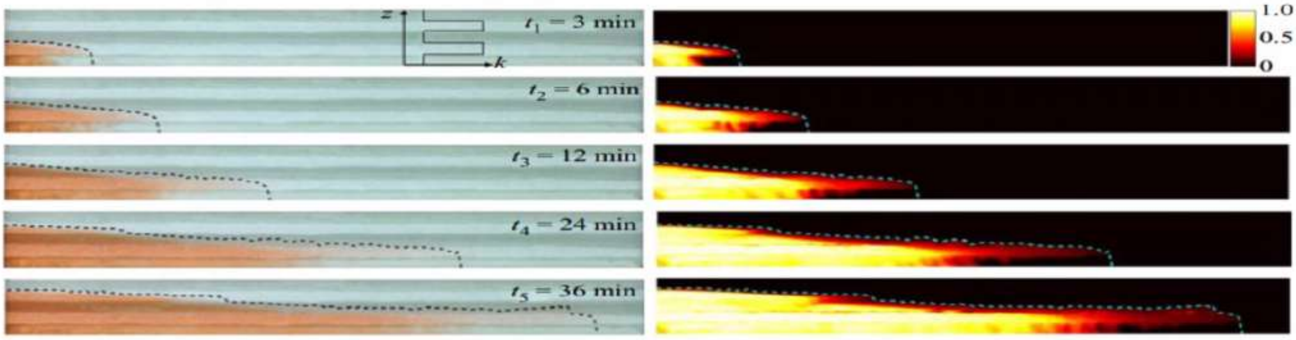
Validation Of Result W

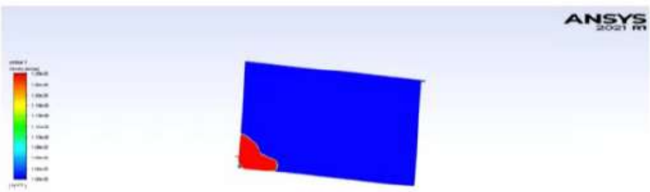
Experimental insights into gravity-driven flows and mixing in layered porous media by Chunendra K. Sahu and Jerome A. Neufeld



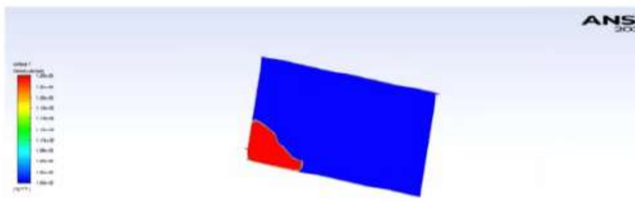
- Gravity currents predominantly flow in layers with higher permeability and porosity.
- The third layer exhibits significantly higher flow compared to other layers.
- Fluid mixing and the formation of fringes are observed.
- Notable dispersion phenomena occur in multi-layered porous media.
- In heterogeneous media, dispersion and entrainment are higher than in homogeneous media.
- Our model results align closely with these experimental findings. The third layer in our simulation demonstrated a similar flow pattern.

For Two Layered Poro … osition

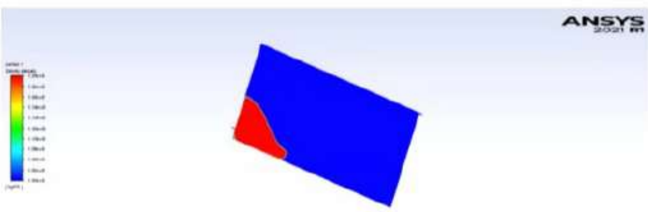
At Angle = 5 degree



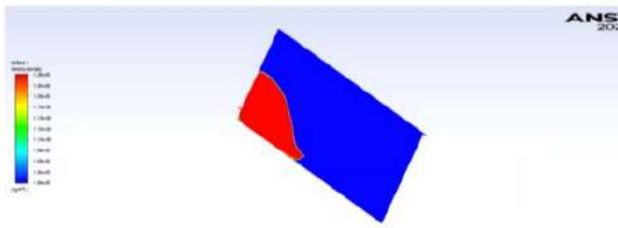
At Angle = 10 degree



At Angle = 20 degree



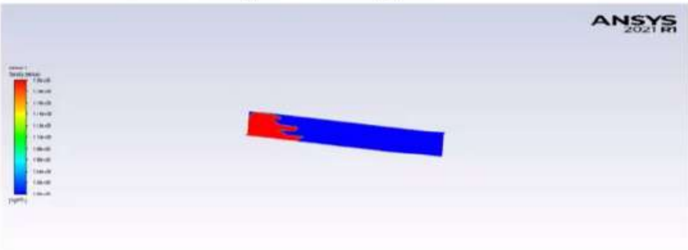
At Angle = 30 degree



- Simulations analysed gravity current behaviour in a double-layer porous medium at various angles.
- Inclination causes the component of gravity (g sin θ) to act along the horizontal flow direction.
- Increased inclination angle leads to faster gravity current flow.
- Higher angles enhance the gravitational force component, increasing the flow rate.
- Original non-inclined position showed a specific flow pattern and speed.
- Incremental angle increases resulted in faster and more extensive horizontal movement of the gravity current.
- Consistent trend observed across all angles, showing a clear relationship between inclination angle and gravity current speed.
- These findings emphasize the critical role of the porous medium's orientation in determining the flow dynamics of gravity currents.

For Multi-Layered Porous Media With Angular Position

At Angle = 5 degree



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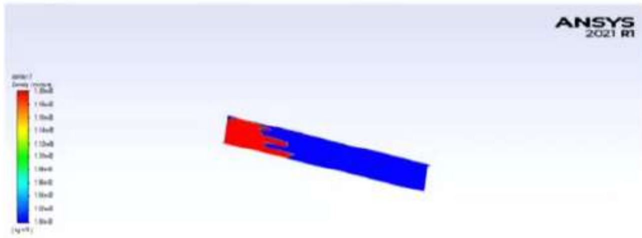

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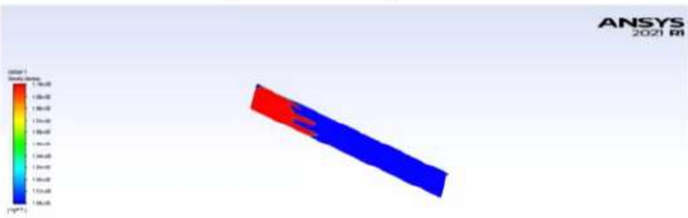

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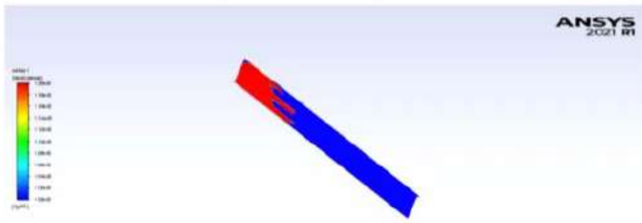

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- Analysed gravity current behaviour in a multi-layer porous medium at various angles.
- Inclined configurations enhance horizontal flow, increasing gravity current speed.
- Greater inclination angle correlates with faster flow.
- Minimal differences observed between 5° and 10° due to significant mixing in multi-layered media.
- In non-inclined position, gravity currents exhibited specific flow patterns and speeds.
- Higher angles led to faster and more extensive horizontal flow.
- Trend of increasing speed with angle was consistent across all studied angles.
- Clear relationship between inclination angle and gravity current speed, highlighting the impact of medium orientation on flow dynamics.
- These findings emphasize the crucial role of the porous medium's orientation in determining the flow dynamics of gravity currents. Understanding this relationship is essential for applications involving fluid flow in porous media

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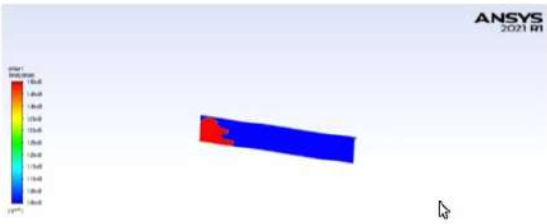
For Multi-Layered Porous Media With Angular Position at Higher Density than Original Case

At Angle = 5 degree



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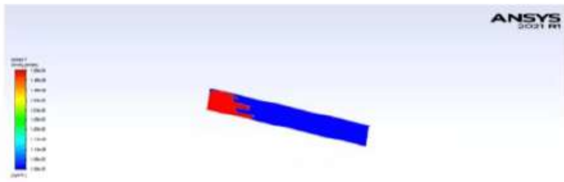

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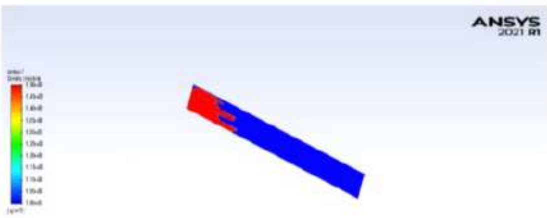

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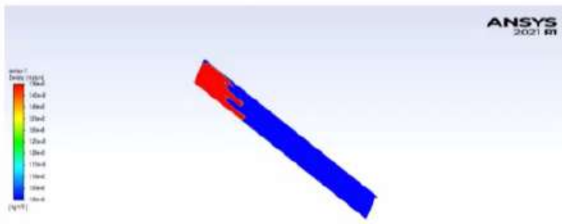
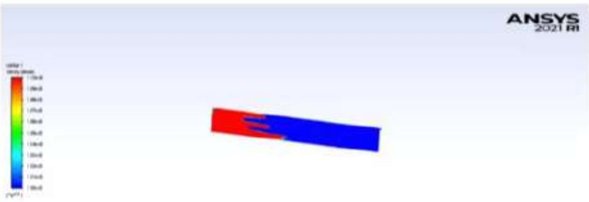


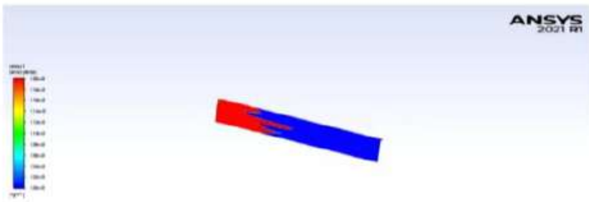
- Simulations studied gravity current behaviour in a multi-layer porous medium at various angles.
- Inclined configurations increase gravity current speed due to the component of gravity ($g \sin \theta$) along the flow direction.
- Greater inclination angle generally leads to faster flow, with minimal differences between 5° and 10° due to significant mixing over time.
- Increased injected fluid density from 1045 g/cm^3 to 1500 g/cm^3 further accelerated the gravity current.
- Higher density fluid resulted in faster and more extensive horizontal flow.
- With higher density fluid, the vertical stretch of the gravity current was reduced.
- At smaller angles (5° and 10°), the gravity current sometimes did not reach the upper boundary.
- These findings underscore the importance of both inclination angle and fluid density in understanding and predicting gravity current behaviour in the porous media.

For Multi-Layered Porous Media With Angular Position at Higher Inlet rate than Original Case

At Angle = 5 degree



At Angle = 10 degree



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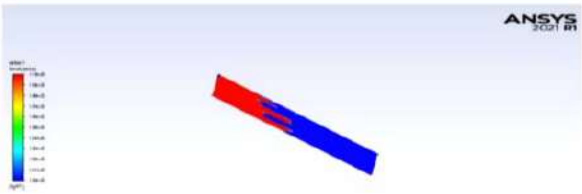

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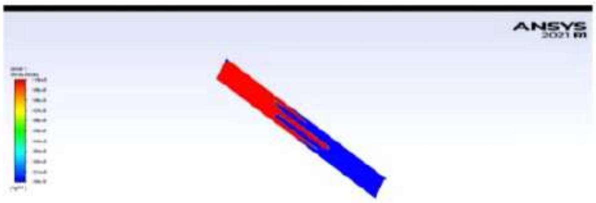

- Analysed gravity current beh m at various angles.
- Inclined setups showed increased gravity current speed due to the horizontal component of gravity (g sin θ).
- Minor distinctions in flow speed were observed between angles of 5° and 10° due to mixing effects.
- Increased inlet velocity from 5 mm/sec to 10 mm/sec, altering boundary conditions for combined effect with inclination.
- Higher inlet velocity and increased inclination led to faster and more extensive gravity current flow.
- Enhanced fluid mixing accelerated the flow rate, allowing the gravity current to traverse greater distances in the same timeframe.
- The heterogeneous medium facilitated quicker dispersive entrainment, highlighting the complex relationship between inlet velocity and inclination in flow behaviours.
- These observations underscore the critical role of both inclination angle and inlet velocity in comprehending and predicting gravity current dynamics in porous media.

- The simulations demonstrated that heterogeneous porous media significantly alter the dynamics of gravity currents compared to homogeneous media. Variations in permeability and porosity distribution led to distinct flow patterns and dispersion characteristics.

- It was observed that dispersive entrainment processes are intricately linked to the heterogeneity of the porous media. The presence of preferential flow paths and varying hydraulic conductivity influenced the extent and rate of mixing between the gravity current and ambient fluid.

- The presence of distinct layers with varying hydraulic properties profoundly influences gravity current behaviour. Simulations revealed that stratigraphic heterogeneity leads to non-uniform flow patterns, localized mixing zones, and enhanced dispersion compared to homogeneous media.

- The validity of the ANSYS Fluent models was confirmed through comparison with experimental data and theoretical predictions where applicable. This validation enhances the confidence in using 54 computational modelling to simulate complex flow phenomena in porous media.

- As we observed a change in pressure difference the front location changed, which means that as the pressure difference increases, the front location of the injected salt phase for a particular time increases.

- The model from the current work can be used to predict the behavior of gravity current flow and mixing in a heterogeneous medium of a much larger length scale by appropriately defining the depth-averaged parameters.

- The use of ANSYS Fluent allowed for detailed exploration of gravity currents in layered porous media with precision and efficiency. Unlike traditional experimental setups, computational modelling offers significant time and cost savings while providing detailed insights into complex flow behaviors and dispersion mechanisms.

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- Integration of advanced computational techniques such as machine learning algorithms and optimization methods can significantly enhance the predictive accuracy and efficiency of simulations in the study of fluid dynamics in layered porous media.

- These computational approaches can be instrumental in exploring complex interactions and non-linear behaviors within heterogeneous geological formations, providing deeper insights into the underlying mechanisms.

- Expanding the existing frameworks to include transient and dynamic simulations will allow researchers to study temporal variations and the long-term evolution of flow dynamics in these media, offering a more comprehensive understanding of these processes.

- Further research into multi-physics interactions, including the effects of thermal processes, chemical reactions, and mechanical deformations, is crucial. Such studies will enable the development of models that more accurately reflect the coupled processes influencing subsurface environments.

- Investigating scale-dependent heterogeneities, from pore-scale to basin-scale, will help elucidate how spatial variability influences flow patterns and dispersion phenomena, providing a more nuanced understanding of the behavior of fluids in complex geological settings.

- Simulations revealed that stratigraphic variability significantly influences flow patterns, mixing dynamics, and transport phenomena within porous media. This understanding is crucial for applications ranging from groundwater management to hydrocarbon recovery and environmental remediation.

- Computational models offer unparalleled flexibility in exploring various scenarios and modifying parameters. Unlike experimental setups, which are often constrained by logistical challenges and high costs associated with modifications, ANSYS Fluent allows researchers to adjust model parameters and boundary conditions swiftly and efficiently. This capability enhances the adaptability of the study to different geological settings and varying flow conditions.