CFD Simulation of Flow Through a Porous Medium

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Abstract

This project presents a CFD simulation of fluid flow and heat transfer through a porous medium using ANSYS Fluent. The study demonstrates the setup, solution, and analysis of key flow variables such as pressure, velocity, temperature, and turbulence quantities for an introductory CFD analysis.

1 Introduction

Computational Fluid Dynamics (CFD) uses numerical methods to solve fluid motion equations across a discretized domain. In this project, we simulate flow through a porous medium, a material with many small voids, and examine how fluid behavior, temperature distribution, and turbulence quantities vary within the domain.

2 Governing Concepts

In CFD, the motion of a fluid is governed by conservation equations for mass, momentum, and energy. These equations are solved across a mesh of small control volumes.

2.1 Pressure

Pressure is the force per unit area that the fluid exerts on its surroundings or on itself. Regions of high pressure often correspond to areas where the flow slows down.

2.2 Velocity Components

Velocity describes the speed and direction of fluid movement.

- u: x–direction component of velocity (horizontal movement)
- v: y–direction component of velocity (vertical movement)

These are obtained from solving the momentum equations in Fluent.

2.3 Temperature

Temperature indicates the thermal state of the fluid. It shows how energy is carried by the fluid and exchanged with the porous medium.

2.4 Turbulence Quantities

Turbulent flow involves chaotic fluctuations. The simulation tracks these using:

- **Eddy Viscosity** – an effective viscosity representing how turbulence mixes momentum.
- **Turbulent Kinetic Energy (k)** – measures energy in the fluctuating component of turbulent flow.
- **Turbulent Eddy Dissipation (ε)** – rate at which turbulent kinetic energy is converted to heat through viscous action.

3 Simulation Setup

The geometry, mesh, boundary conditions, solver settings, and turbulence model are defined to represent flow through the porous medium. Include a snapshot of the mesh:

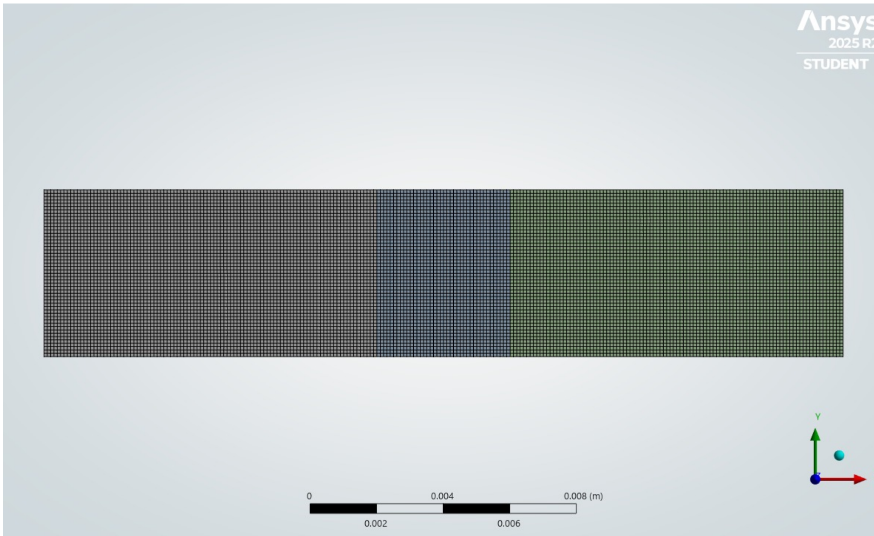


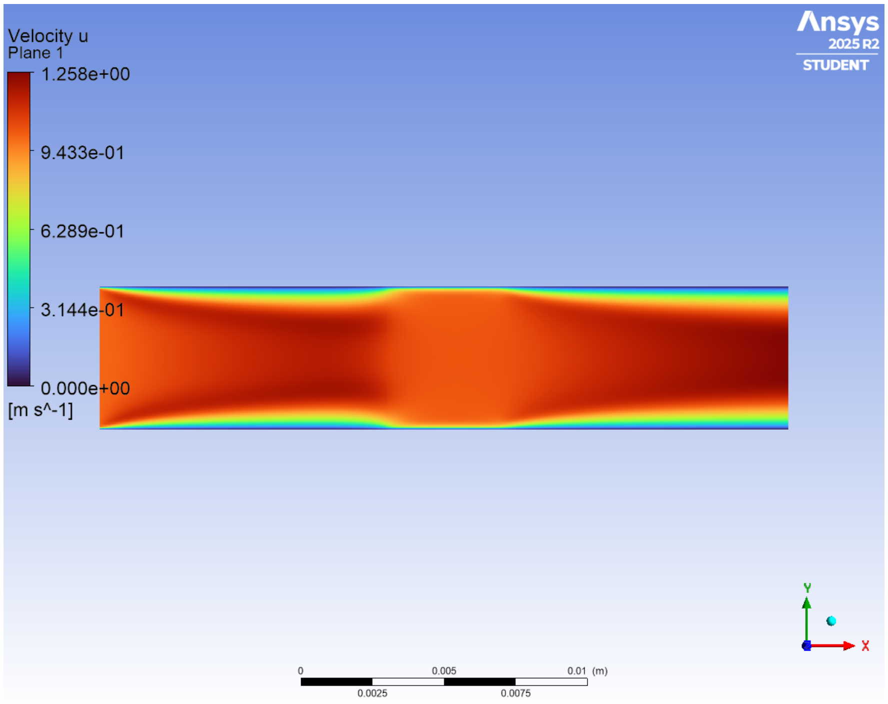
Figure 1: Mesh used in the simulation.

4 Results

4.1 Velocity Distribution

The velocity distribution shows how fluid flows through the porous medium. The components u (horizontal) and v (vertical) are obtained from the momentum equations. The **velocity magnitude** is calculated as:

$$|\vec{V}| = \sqrt{u^2 + v^2}$$


Velocity u
Plane 1
1.258e+00
9.433e-01
6.289e-01
3.144e-01
0.000e+00
[m s^-1]
Ansys
2025 R2
STUDENT
0
0.005
0.01
(m)
0.0025
0.0075

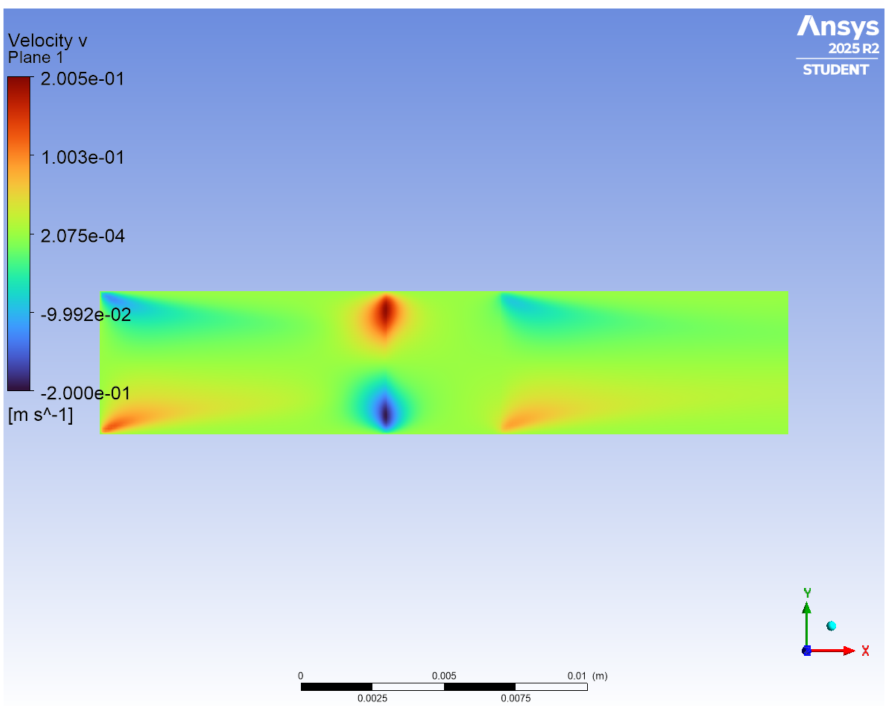

Velocity v
Plane 1
2.005e-01
1.003e-01
2.075e-04
-9.992e-02
-2.000e-01
[m s^-1]
Ansys
2025 R2
STUDENT
0
0.005
0.01
(m)
0.0025
0.0075

Figure 2: Velocity components u and v across the domain.

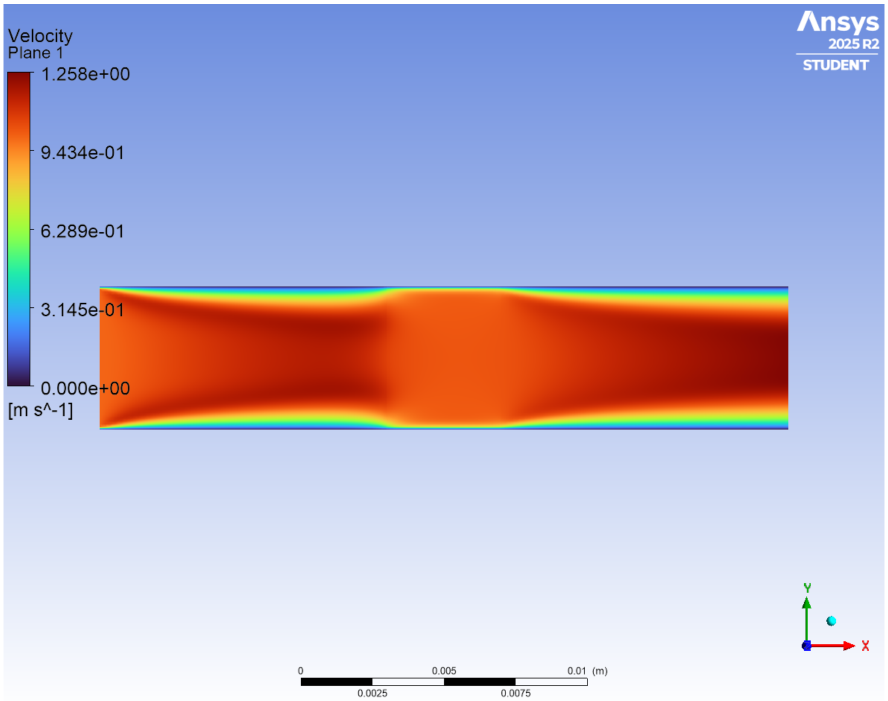


Figure 3: Velocity magnitude distribution, $|\vec{V}|$.

4.2 Pressure Distribution

The pressure distribution indicates regions of high and low fluid force. The **pressure drop** across the porous medium can be calculated as:

$$\Delta P = P_{\text{inlet}} - P_{\text{outlet}}$$

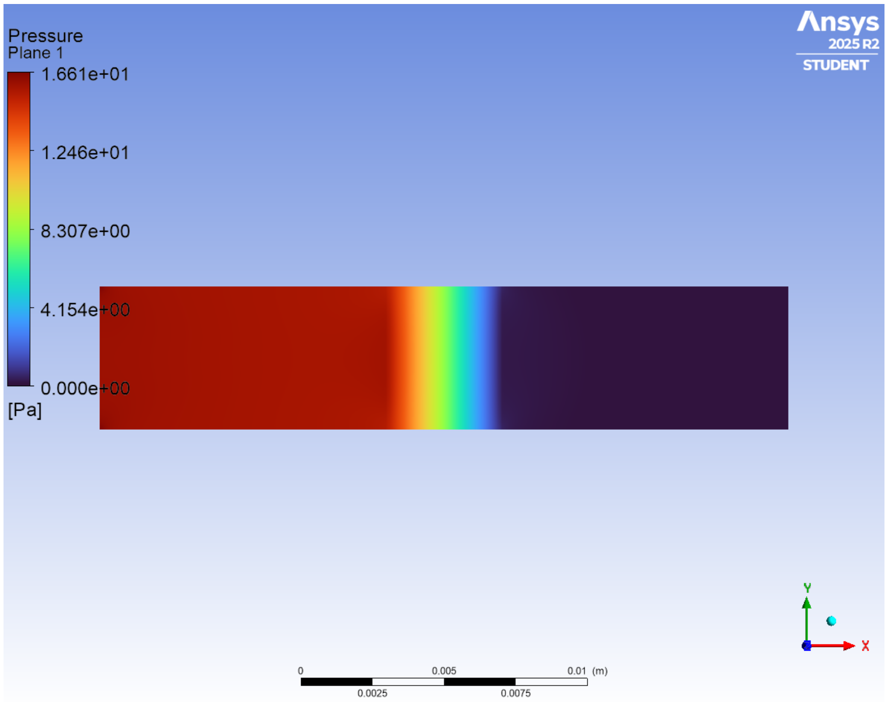


Figure 4: Pressure distribution and regions of high/low pressure.

4.3 Temperature Distribution

Temperature contours show how energy is transported and how the porous medium affects heat transfer. Key observations can include **temperature gradients and average outlet temperature.**

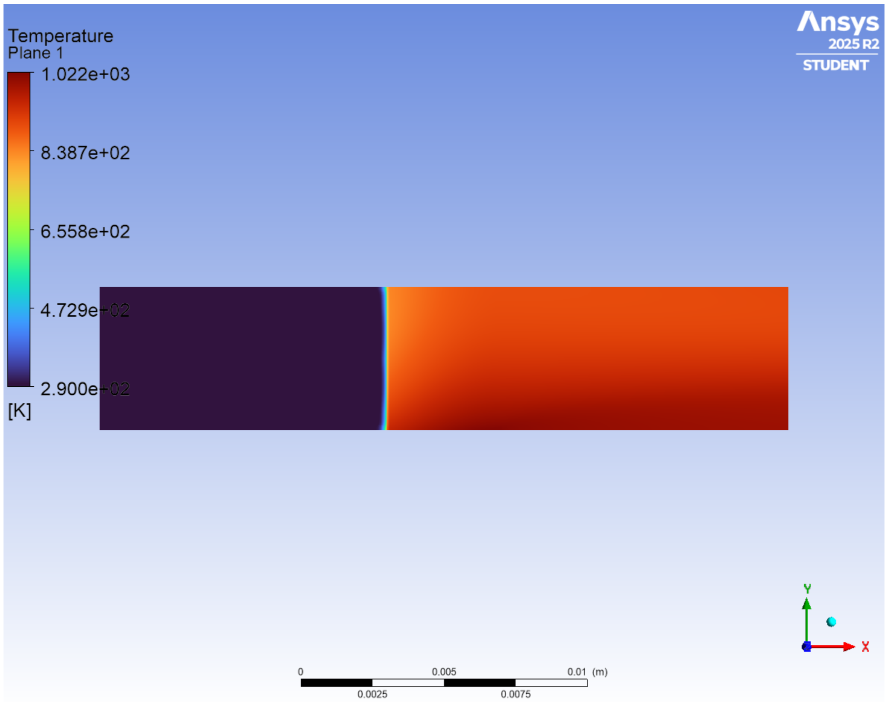
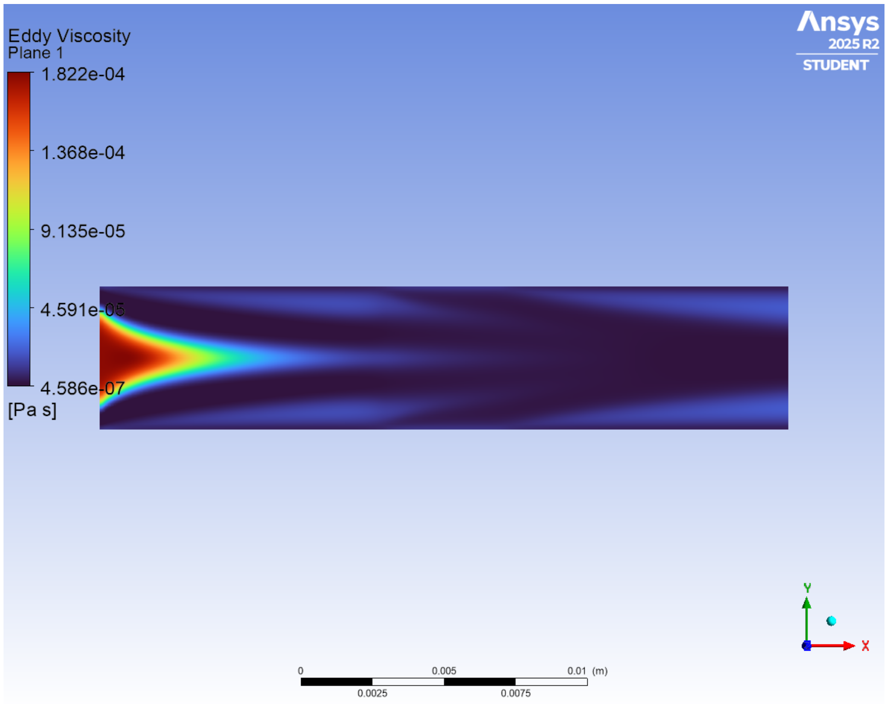


Figure 5: Temperature distribution in the porous medium.

4.4 Turbulence Effects

Turbulence is represented using the k–ε model. The key quantities are:

- **Eddy viscosity** – indicates where turbulent mixing is strongest.
- **Turbulent kinetic energy** (k) – energy contained in fluctuating motion.
- **Turbulent eddy dissipation** (ε) – rate at which turbulence energy dissipates.


Eddy Viscosity
Plane 1
1.822e-04
1.368e-04
9.135e-05
4.591e-05
4.586e-07
[Pa s]
Ansys
2025 R2
STUDENT
0
0.005
0.01 (m)
0.0025
0.0075

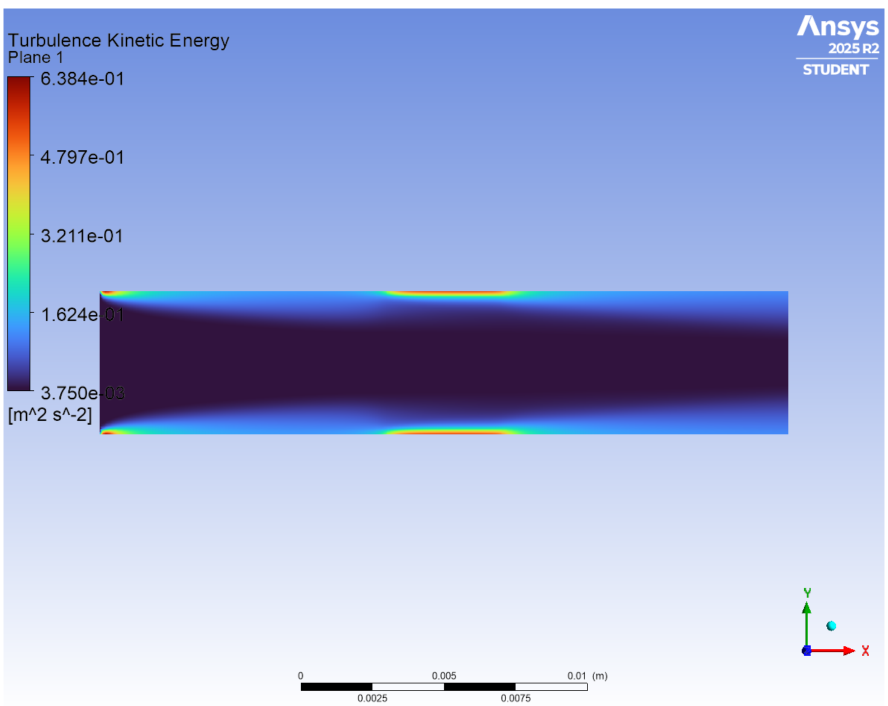

Turbulence Kinetic Energy
Plane 1
6.384e-01
4.797e-01
3.211e-01
1.624e-01
3.750e-03
[m^2 s^-2]
Ansys
2025 R2
STUDENT
0
0.005
0.01 (m)
0.0025
0.0075

Figure 6: Eddy viscosity and turbulent kinetic energy distributions.

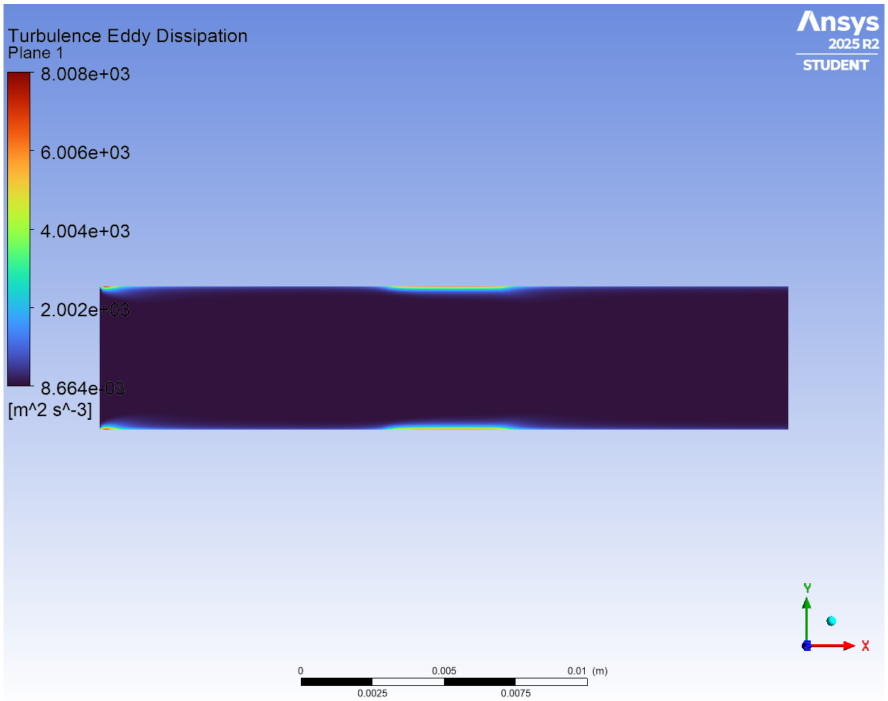


Figure 7: Turbulent eddy dissipation (ε) distribution.

5 Discussion

Pressure gradients drive the flow through the porous medium. Velocity fields indicate how the fluid navigates the geometry. Temperature distribution shows energy transport. Turbulence quantities highlight regions of intense mixing and dissipation. These results provide insight into fluid behavior in porous materials and can guide design considerations.

6 Conclusion

This CFD simulation demonstrates fundamental flow, heat transfer, and turbulence analysis for flow through a porous medium. Future work can extend to different geometries, flow rates, or more advanced turbulence models.