Course Project Presentation on

Study of fluid flow in porous metal foams using openFoam

ME 412 CFD and Heat transfer lab

Presented By:-

Ketan Yogi (174100005)

With the guidance of:-

Prof. Janani Sree Murallidharan

Mr. Divyesh Variys

Mr. C. S. Sanjid

Department of Mechanical Engineering
Indian Institute of Technology Bombay

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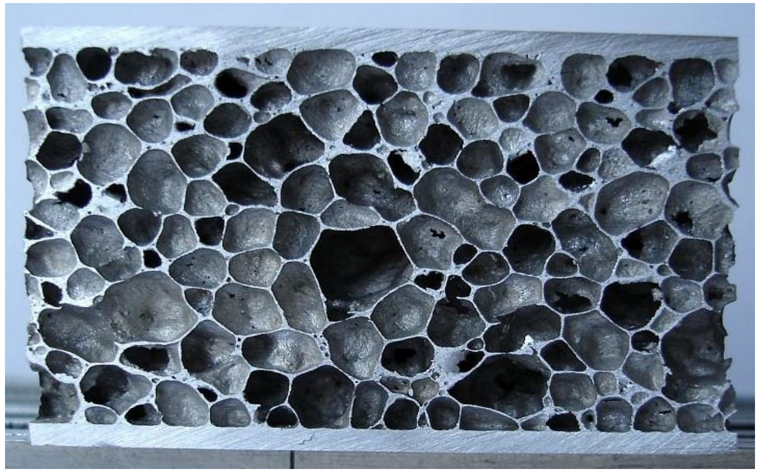
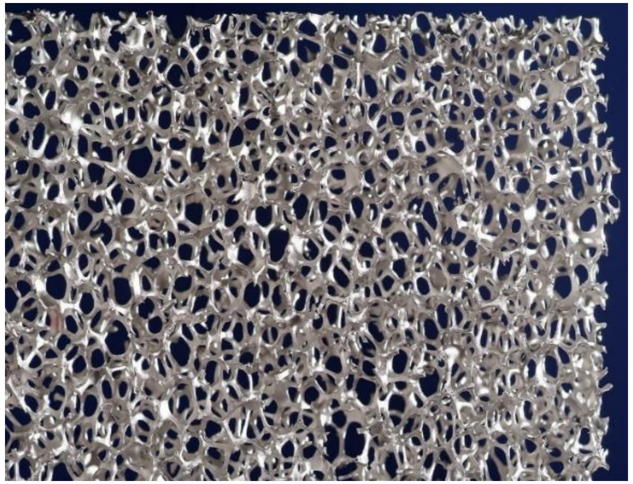
Outline of the presentation

- Introduction
  - Metal foam
  - Literature (Boomsma *et al*.(2002))
- Objectives of present work
- Progress of work
  - Geometry
  - Meshing (Grid Independence study)
  - Solving the case
  - Results
- Conclusions

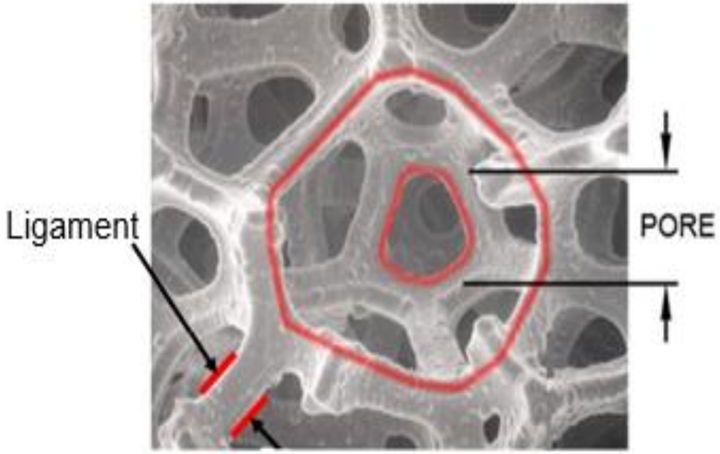
Metal Foam



Closed cell metal foam[a]



Open cell metal foam[b]



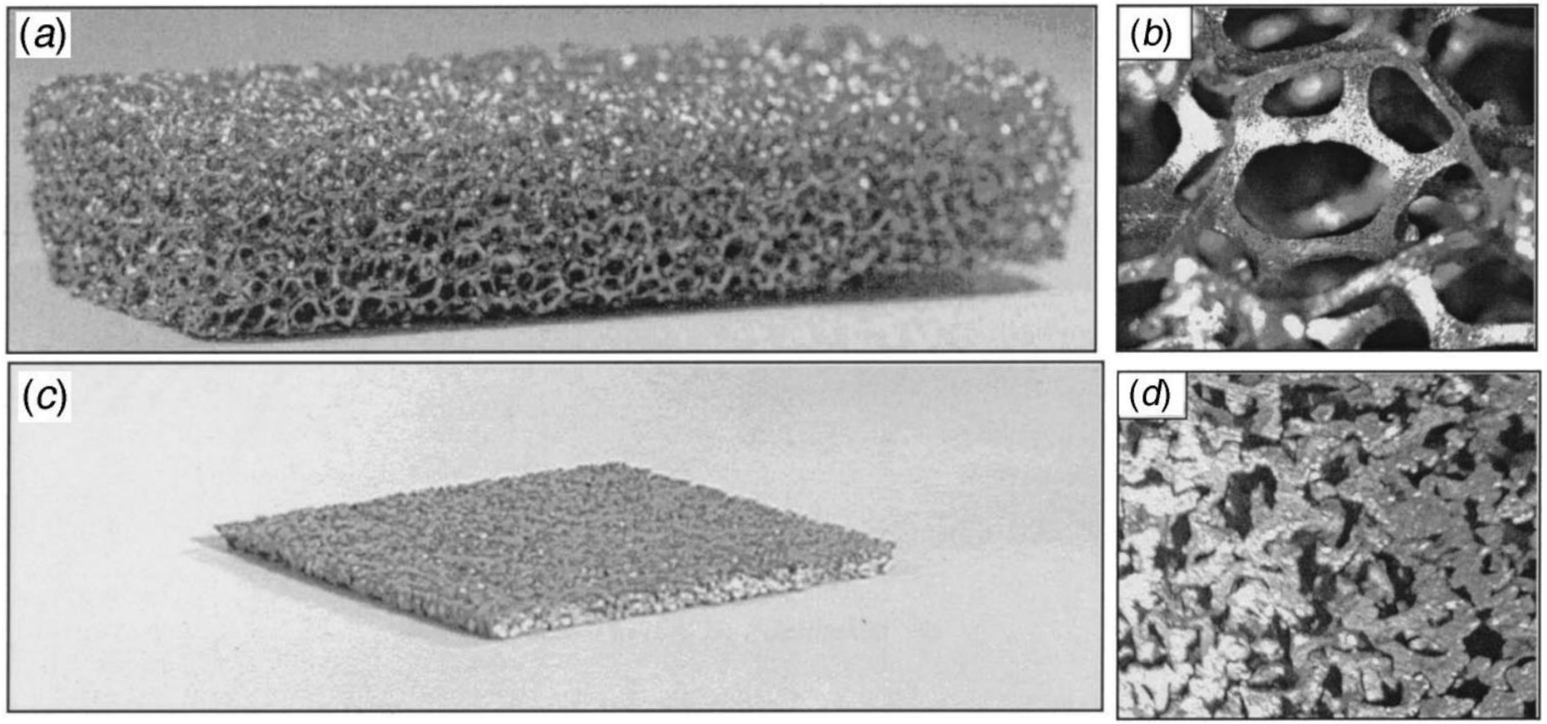
Micro structure of metal foam[c]

- Porosity $(\varepsilon) = \dfrac{Pore\ Volume}{Total\ Volume}$
- Pore density :- Pores per inch (*PPI*)
- Permeability (*K*)
- Ligaments or strut thickness

[a] https://www.ifam.fraunhofer.de/content/dam/ifam/en/documents/dd/Infobl%C3%A4tter/open_cell_metal_foams_fraunhofer_ifam_dresden.pdf
[b] http://www.wikiwand.com/en/Aluminium_foam_sandwich
[c] http://jsetceramics.blogspot.com/2014/09/applications-of-alumina-ceramic-foam.html

Literature (Boomsma *et al.* 2002)

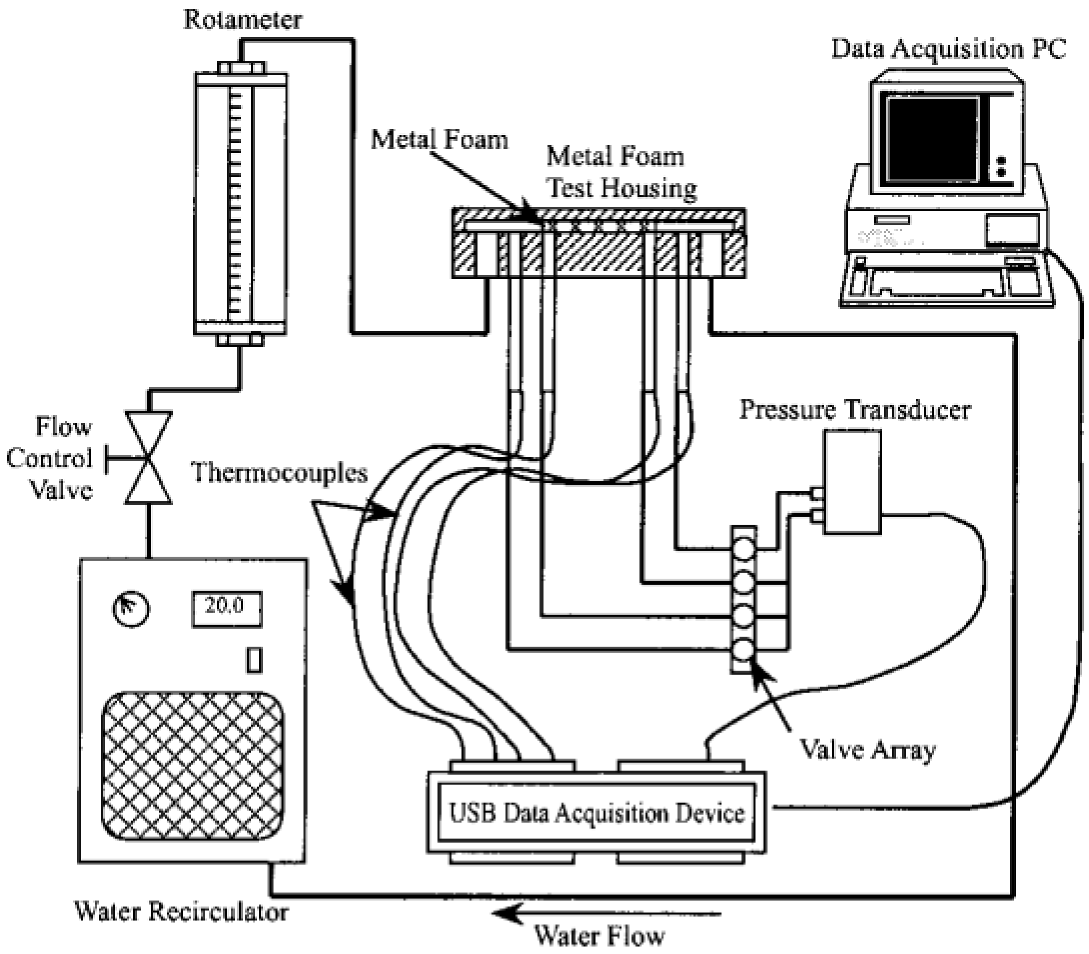
- **Effects of Compression and Pore Size Variations on Permeability and inertia coefficient**



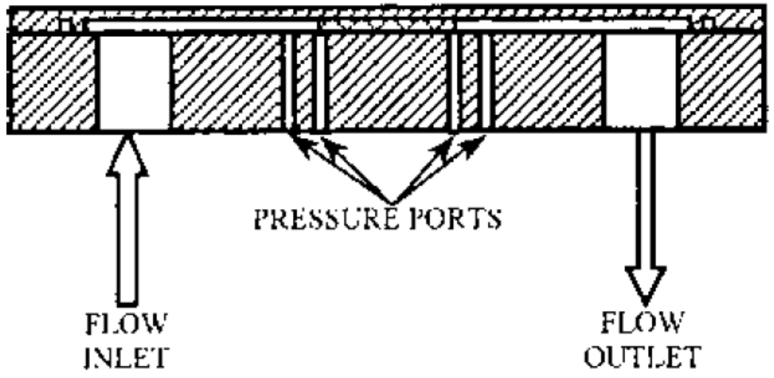
(a) Aluminum foam block (92% porous, 10 PPI, 6.9 mm pore diameter) (b) magnified view of a uncompressed Al foam (c) Compressed by a factor of four (76.1% porosity) (d) magnified view of compressed foam

K. Boomsma, D. Poulikakos, "The Effects of Compression and Pore Size Variations on the Liquid Flow Characteristics in Metal Foams", ASME, Journal of Fluids Engineering, Vol. 124, March 2002.

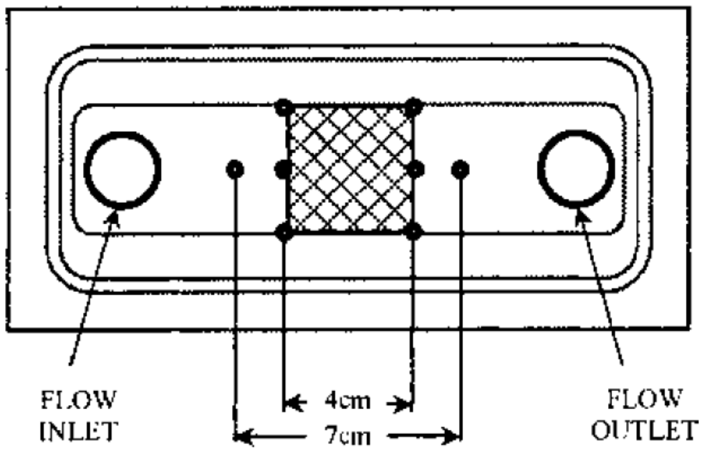
Literature Boomsma *et al.* 2002



Experimental apparatus used to measure the pressure drop of metal foam



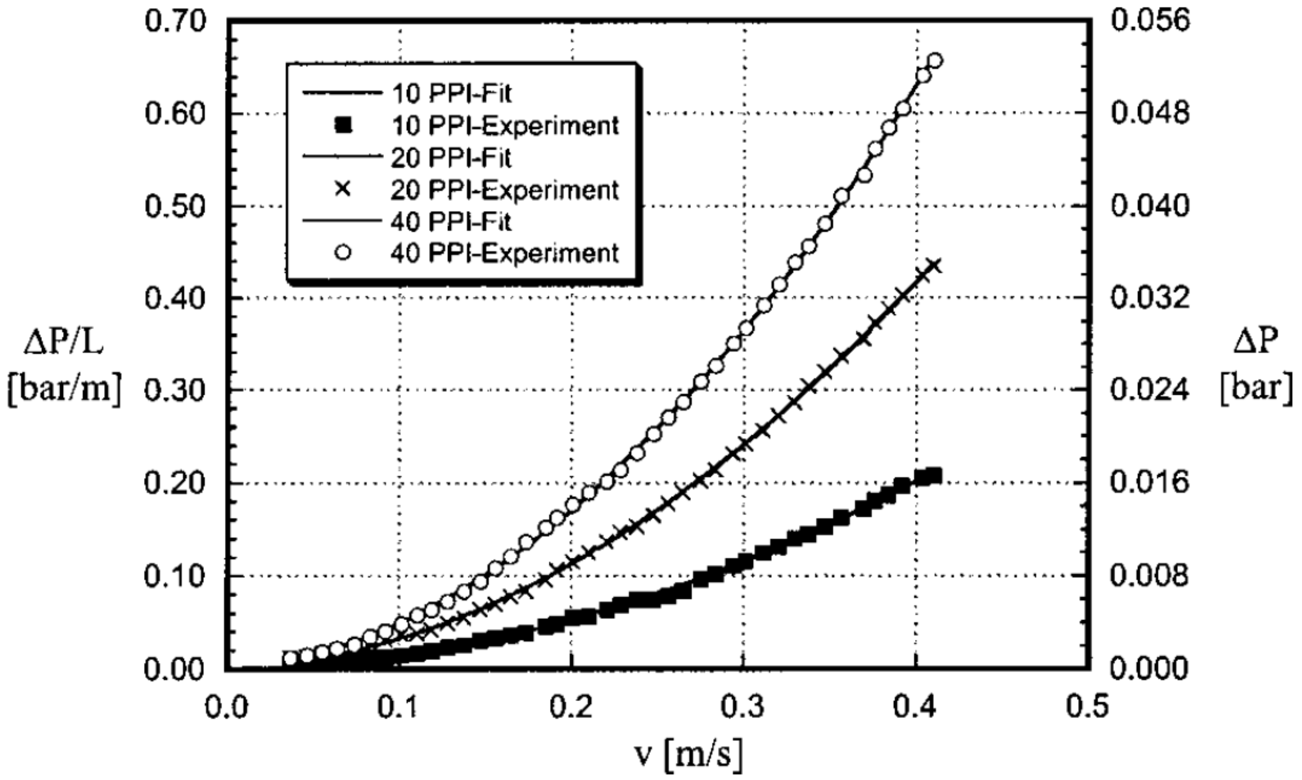
Metal foam test housing cross-sectional view of the inlet, outlet, and foam positioning



Top view of the metal foam test housing

Literature Boomsma *et al.* 2002

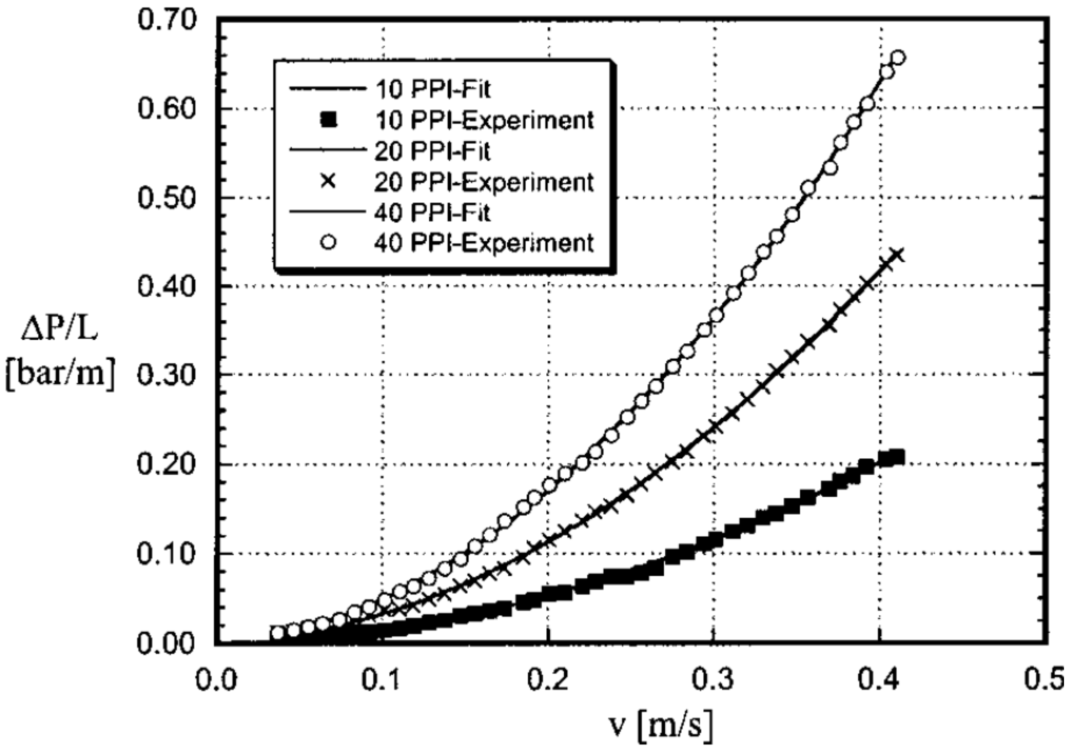
Foam	Pore dia. (d_p) (mm)	Porosity	Permiability ($K \times 10^{-10}$) (m^2)	Inertia coefficient (C) (m^{-1})
10 PPI	6.9	92.1	3529	120
20 PPI	3.6	92.0	1089	239
40 PPI	2.3	92.8	712	362



Pressure-drop versus fluid flow velocity for the three uncompressed metal foams.

Objectives of present work

- Replicate the results of the pressure drop in the channel filled with porous metal foam reported by Boomsam *et al.* using opneFoam tool.

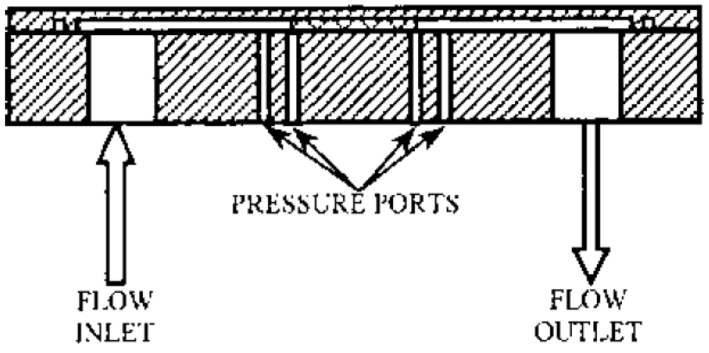


Pressure-drop versus fluid flow velocity for the three uncompressed metal foams.

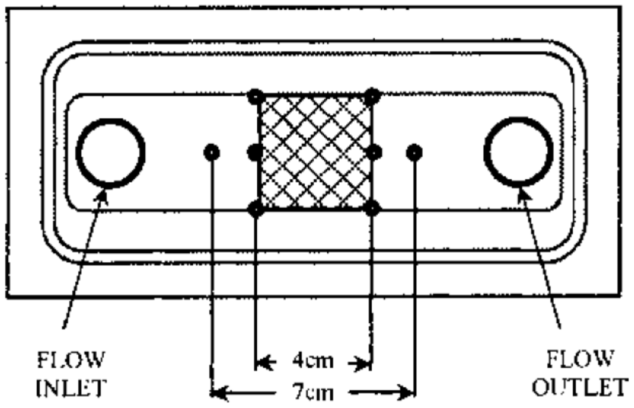
- Parameters of the study
  - **Foam geometry** :- Uncompressed Al foam (10, 20 and 40 PPI)
  - **Range of the velocity** :- 0.01 to 0.40 m/s (Re_{dh} = 668 to 7456)
  - **Working fluid** :- Water (@ 20 ℃)

Geometry and boundary conditions

(a)

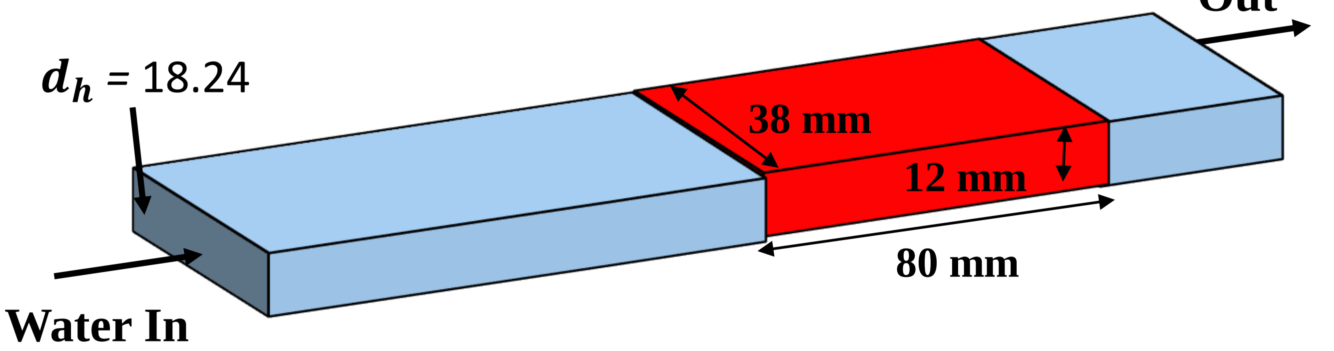


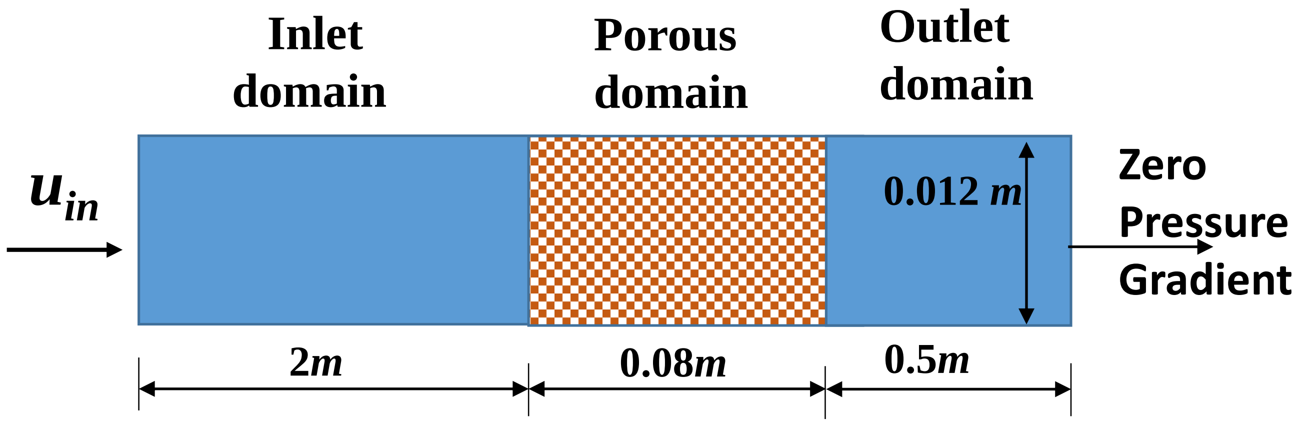
(b)



Metal foam test housing (a) cross-sectional view (b) top view

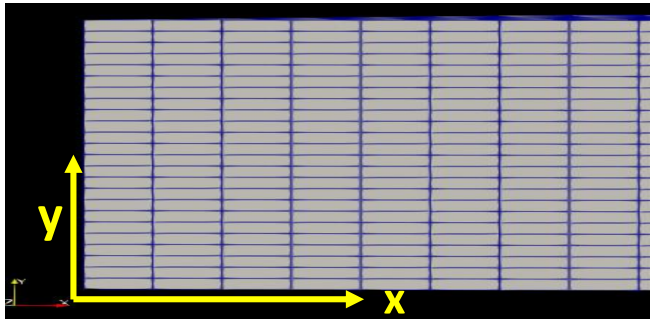
- Entrance length $\frac{L_e}{d_h} = 0.06 \times Re_{dh}$

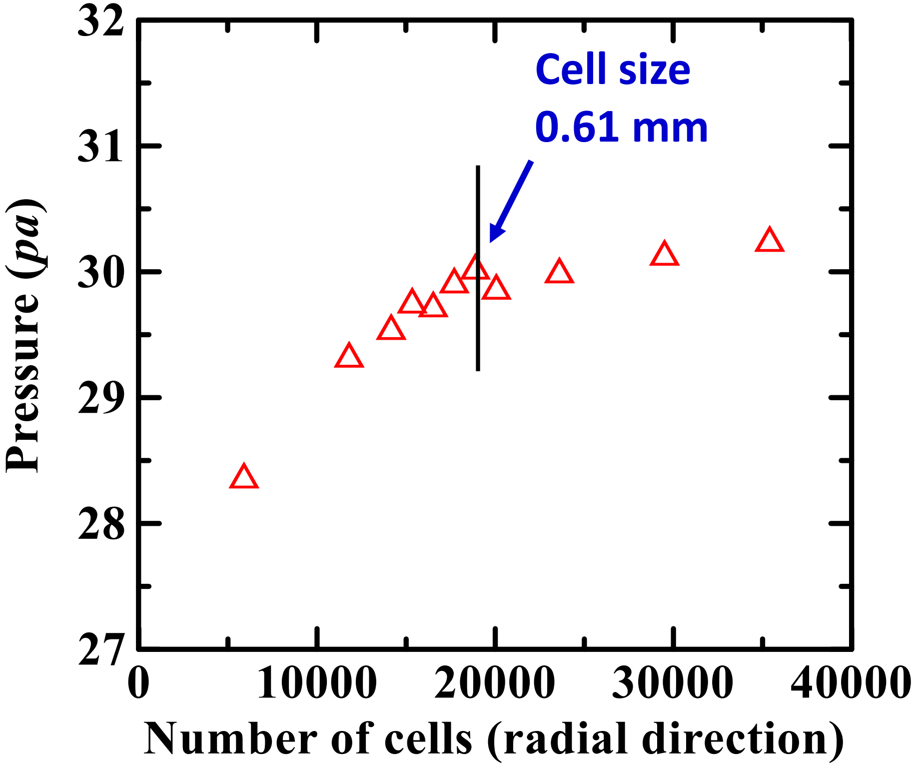


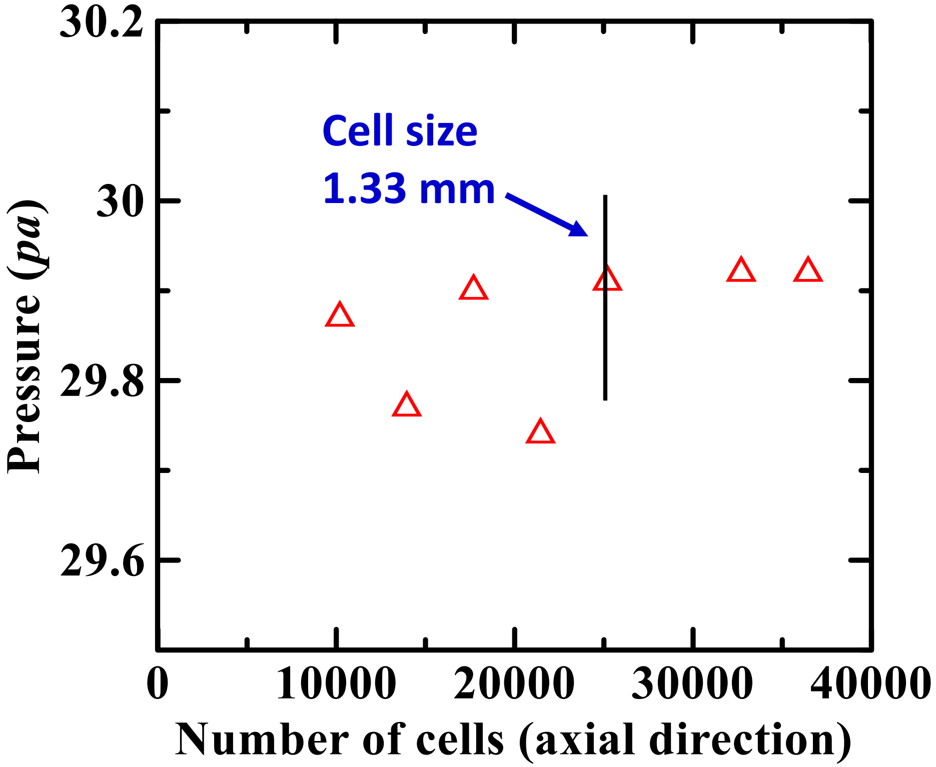


2D geometry for Simulation

Meshing (Grid independence study)



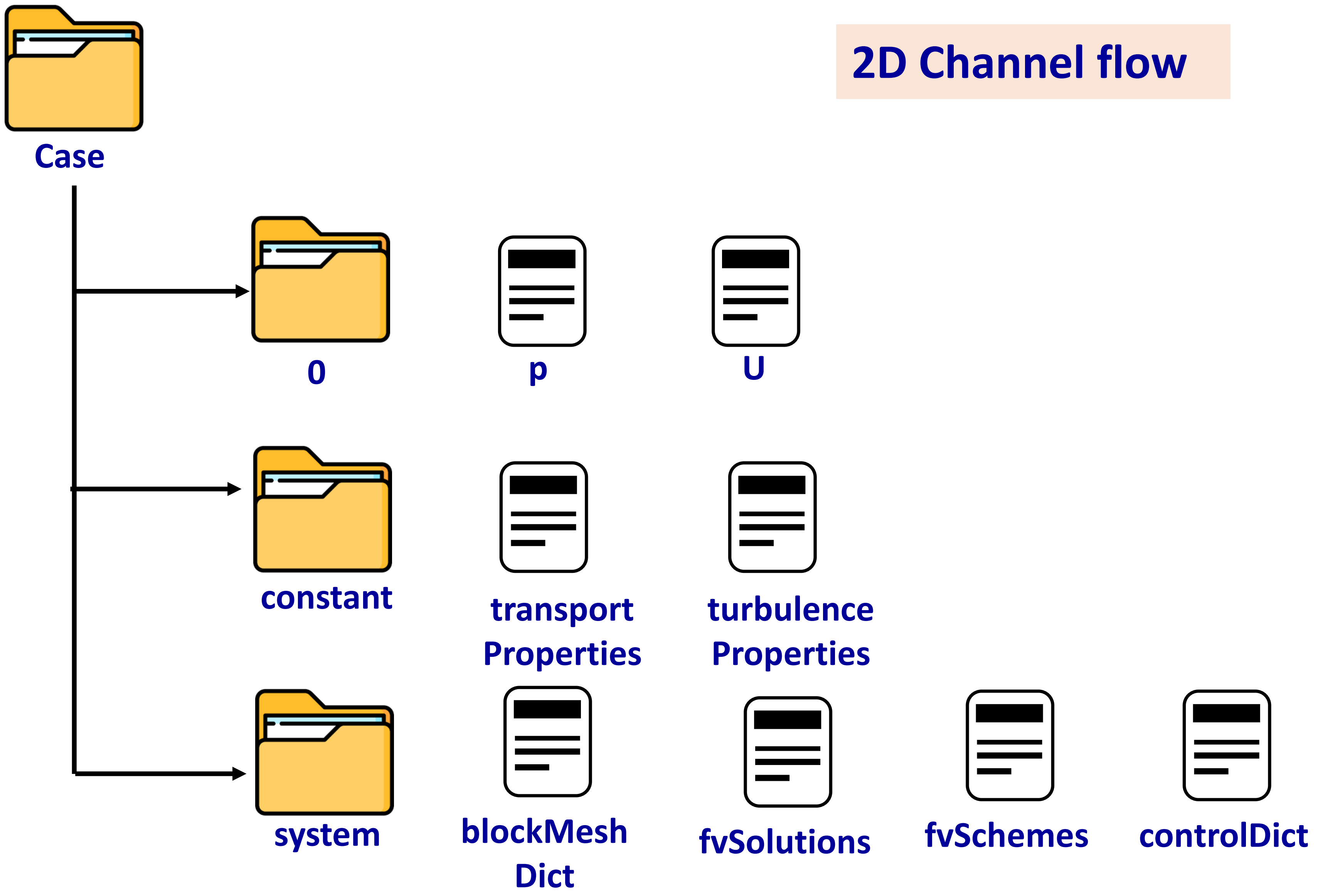




Variation of Total pressure with change in the total number of cells in radial and axial direction

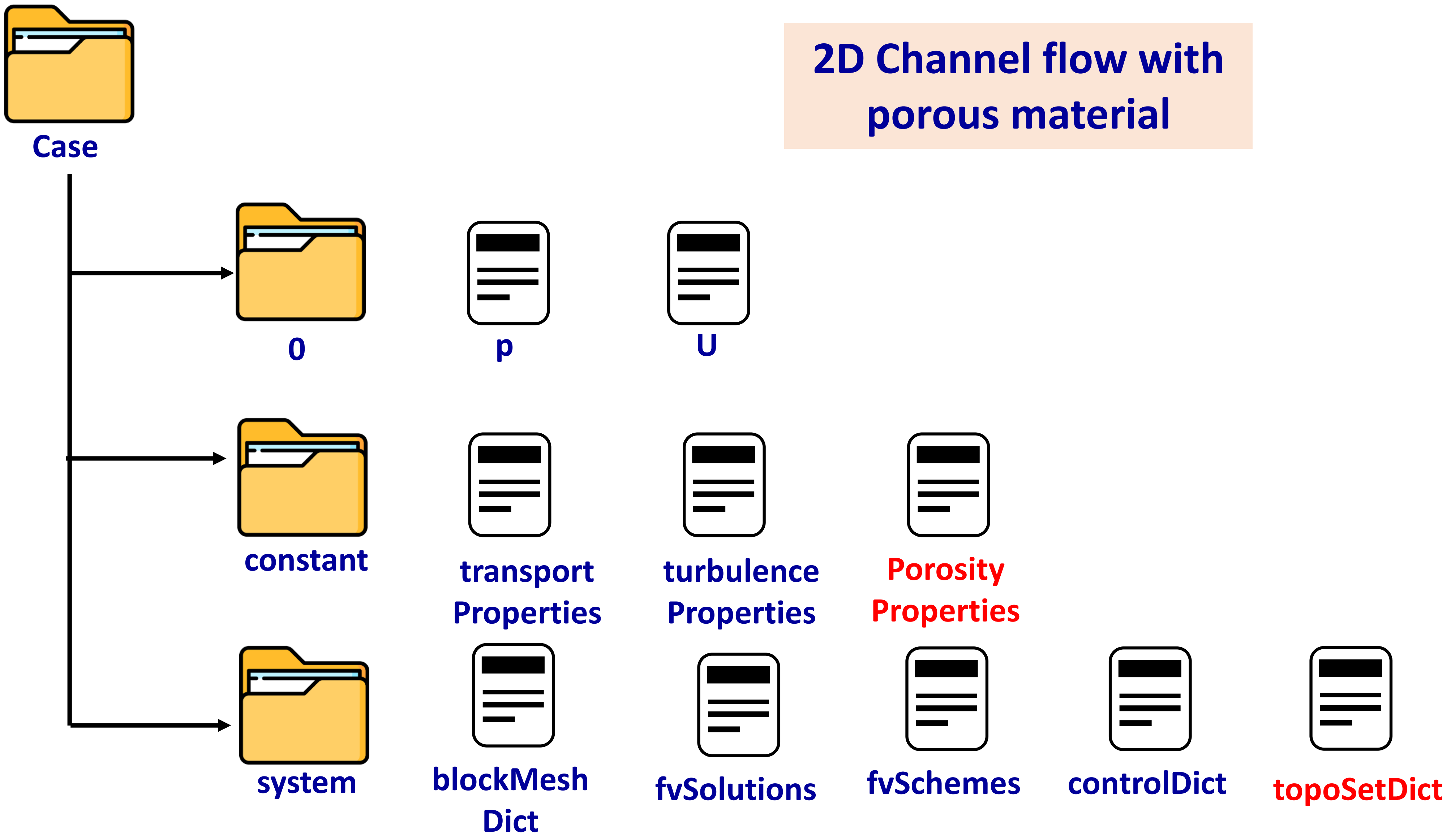
File structure for Porous material in openFoam

2D Channel flow



File structure for Porous material in openFoam

2D Channel flow with porous material



“porosityProperties” file

```
porosity1
{
    type            DarcyForchheimer;

    cellZone        porouszone;

    d   (1.405e7 -1000 -1000);
    f   (724 0 0);

    coordinateSystem
    {
        origin  (0 0 0);
        e1      (1 0 0);
        e2      (1 0 0);
    }
}
```

$$\frac{\partial}{\partial t}(\gamma\rho u_i) + u_j\frac{\partial}{\partial x_j}(\rho u_i) = -\frac{\partial p}{\partial x_i} + \mu\frac{\partial \tau_{ij}}{\partial x_j} + S_i$$

$$S_i = -\left(\mu D_{ij} + \frac{1}{2}\rho\,|u_{kk}|F_{ij}\right)u_i$$

$$S_i = -\left(\mu D + \frac{1}{2}\rho\,|u_{jj}|\,F\right)u_i$$

“porosityProperties”file

❑ Pressure drop in porous material

Darcy equation $$\frac{\Delta P}{L} = \frac{\mu}{K} u$$

Darcy-Forchheimer equation $$\frac{\Delta P}{L} = \frac{\mu}{K} u + \rho C u^2$$

$$S_i = -\left(\mu D + \frac{1}{2} \rho \left|u_{jj}\right| F\right) u_i$$

$$\boxed{D = \frac{1}{K}}$$

$$\boxed{F = 2C}$$

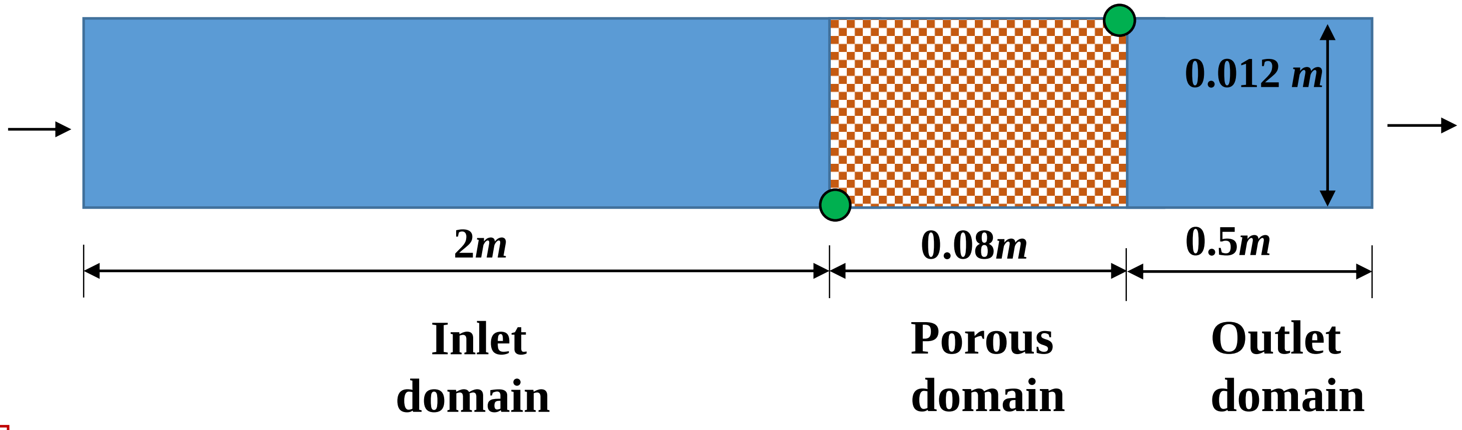
Boomsma *et al.*		
Foam	K*10-10 (m^2)	C (m^{-1})
10 PPI	3529	120
20 PPI	1089	239
40 PPI	712	362

"toposetDict" file

```
actions
(

    {
        name    porouszone;
        type    cellSet;
        action  new;
        source  boxToCell;
        sourceInfo
        {
            box (2 0 0) (2.08 0.012 0.038);
        }
    }

  {
        name    porouszone;
        type    cellZoneSet;
        action  new;
        source  setToCellZone;
        sourceInfo
        {
            set porouszone;
        }
    }
```



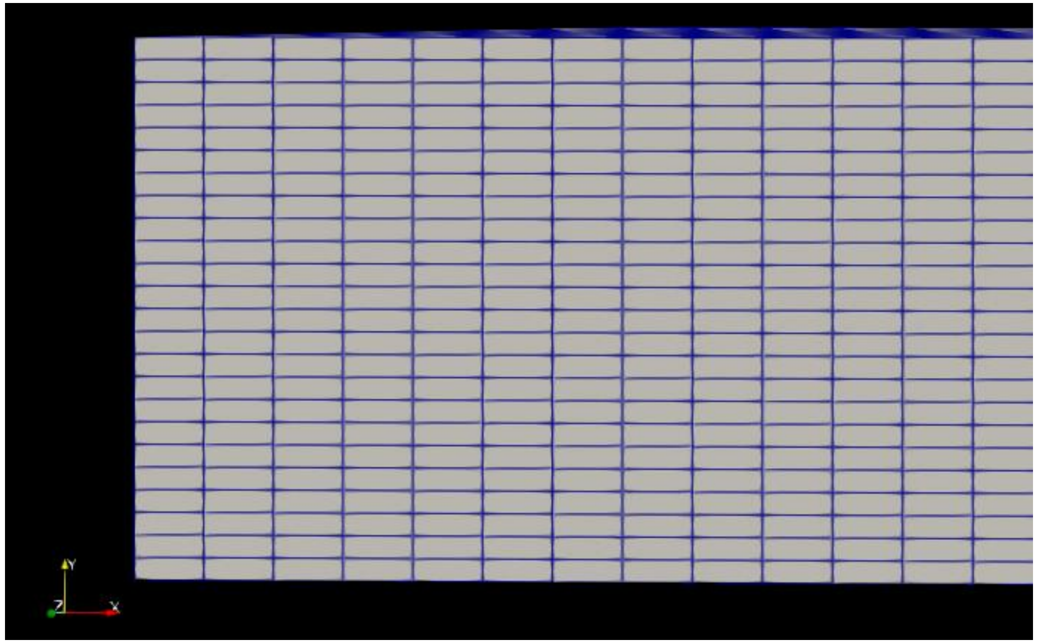
Box (minx miny minz)
(maxx maxy maxz)

Solving the case

- **blockMesh**

- **topoSet**

- **porousSimpleFoam solver**



Mesh Domain

```
----------------
Mesh Information
----------------
  boundingBox: (0 0 0) (2.58 0.012 0.038)
  nPoints: 174006
  nCells: 82840
  nFaces: 335522
  nInternalFaces: 161518
----------------
```

Meshing details

Solving the case

- **blockMesh**

- **topoSet**

```
Created cellSet porouszone
    Applying source boxToCell
    Adding cells with centre within boxes 1((2 0 0) (2.08 0.012 0.038))
    cellSet porouszone now size 1200
Created cellZoneSet porouszone
    Applying source setToCellZone
    Adding all cells from cellSet porouszone ...
    cellZoneSet porouszone now size 1200
```

- **porousSimpleFoam solver**

Solving the case

- blockMesh

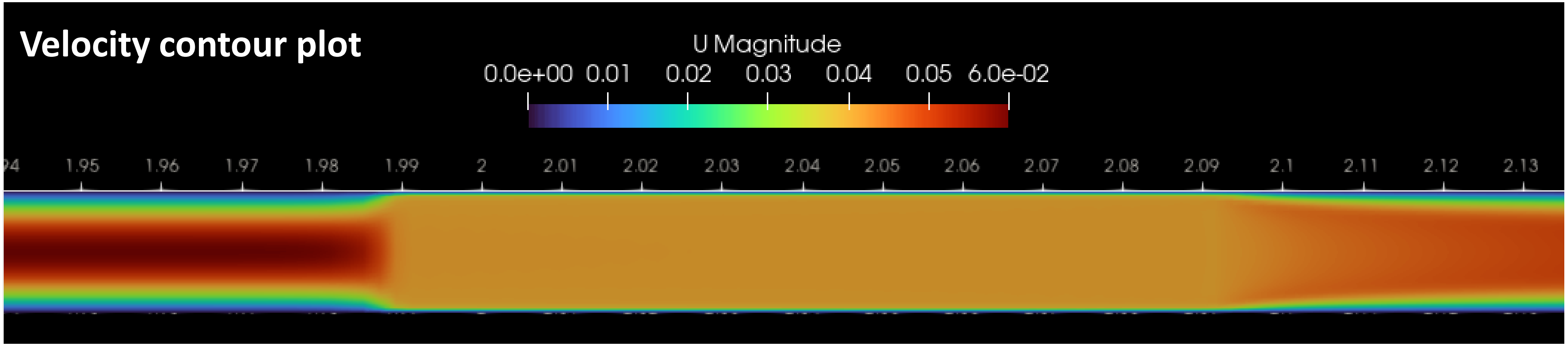
- topoSet

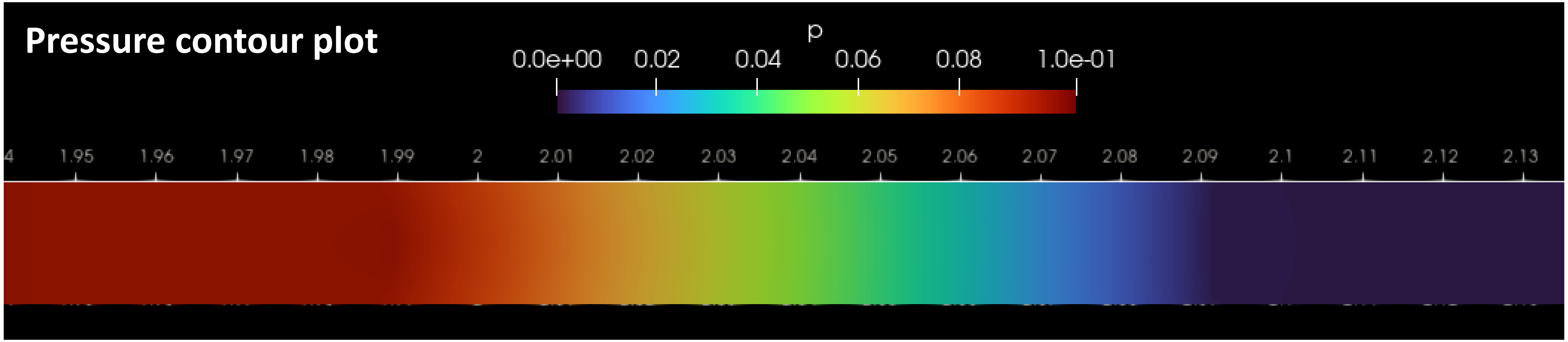
- porousSimpleFoam solver

Steady-state solver for incompressible, turbulent flow

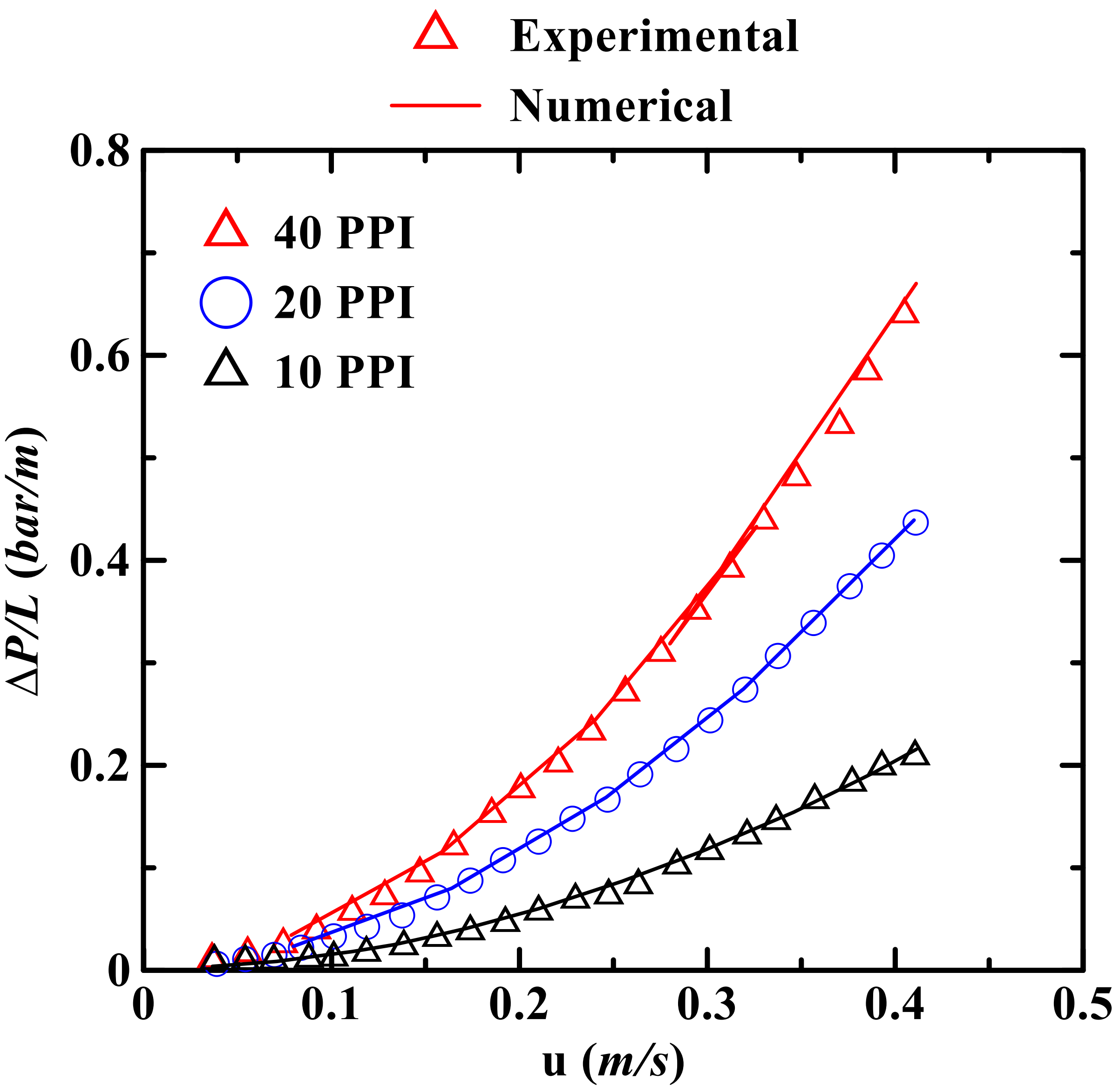
Results and Discussion

40 PPI AL foam (u = 0.04 m/s)





Validation



Pressure-drop versus fluid flow velocity for the three uncompressed metal foams.

Conclusion

- **The simulated results match well with the experimental results**

Thank You

porousSimpleFoam solver

- **Steady-state solver for incompressible, turbulent flow**
- **applications/solvers/incompressible/simpleFoam/porousSimpleFoam**

```
porousSimpleFoam
├── createZone.H
├── Make
│       files
│       options
├── pEqn.H
├── porousSimpleFoam.C
├── porousSimpleFoam.dep
└── UEqn.H
```

porousSimpleFoam solver

- **Steady-state solver for incompressible, turbulent flow**
- **applications/solvers/incompressible/simpleFoam/porousSimpleFoam**

- createZone.H
- Make
  - files
  - options
- pEqn.H
- porousSimpleFoam.C
- porousSimpleFoam.dep
- UEqn.H

uEqn.H

```
tmp<fvVectorMatrix> UEqn
  (
      fvm::div(phi, U)
    + turbulence->divDevReff(U)
    ==
      fvOptions(U)
  );

  mrfZones.addCoriolis(UEqn());

  UEqn().relax();


 tmp<volScalarField> trAU;
 tmp<volTensorField> trTU;

 if (pressureImplicitPorosity)
 {
     tmp<volTensorField> tTU = tensor(I)*UEqn().A
     pZones.addResistance(UEqn(), tTU());
     trTU = inv(tTU());
     trTU().rename("rAU");
```

```
fvOptions.constrain(UEqn());

volVectorField gradp(fvc::grad(p));

for (int UCorr=0; UCorr<nUCorr; UCorr++)
{
    U = trTU() & (UEqn().H() - gradp);
}
U.correctBoundaryConditions();

fvOptions.correct(U);

}
{
    pZones.addResistance(UEqn());

    fvOptions.constrain(UEqn());

    solve(UEqn() == -fvc::grad(p));

    fvOptions.correct(U);

    trAU = 1.0/UEqn().A();
    trAU().rename("rAU");
}
```

Porous media model

- **src/finiteVolume/cfdtools/general/porosityModels**

DarcyForchheimer.C

DarcyForchheimer.dep

DarcyForchheimer.H

DarcyForchheimerTemplates.C

```
forAll(cellZoneIds_, zoneI)
    {
        const labelList& cells =
mesh_.cellZones()[cellZoneIds_[zoneI]];

        forAll(cells, i)
        {
            const label cellI = cells[i];

            const tensor Cd = mu[cellI]*D +
(rho[cellI]*mag(U[cellI]))*F;

            const scalar isoCd = tr(Cd);

            Udiag[cellI] += V[cellI]*isoCd;
            Usource[cellI] -= V[cellI]*((Cd - I*isoCd) & U[cellI]);
        }
    }
```

Porous media model

- **src/finiteVolume/cfdtools/general/porosityModels**

DarcyForchheimer.C

DarcyForchheimer.dep

DarcyForchheimer.H

DarcyForchheimerTemplates.C

```
adjustNegativeResistance(d);

    D_.value().xx() = d.value().x();
    D_.value().yy() = d.value().y();
    D_.value().zz() = d.value().z();
    D_.value() = (E & D_ & E.T()).value();



adjustNegativeResistance(f);

// leading 0.5 is from 1/2*rho
F_.value().xx() = 0.5*f.value().x();
F_.value().yy() = 0.5*f.value().y();
F_.value().zz() = 0.5*f.value().z();
F_.value() = (E & F_ & E.T()).value();
```