CFD using OpenFOAM
Lecture 3: Essential Governing Laws & OpenFOAM Implementation

Part I : Computational Heat Conduction

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Outline

Governing Laws

Energy Conservation

FVM Numerical Methodology

OpenFOAM Implementation

OpenFOAM Illustration

- Assuming Incompressible fluid : (CV $\rightarrow$ Control Volume)

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Governing Laws in CFD & HT

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  " Increase in energy within CV = Net amount of energy entering into CV + amount energy generated within CV "

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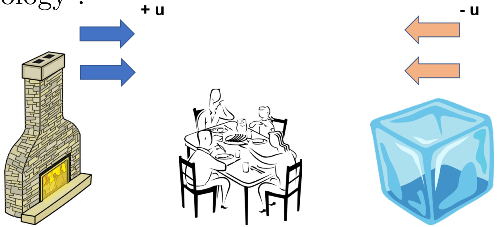

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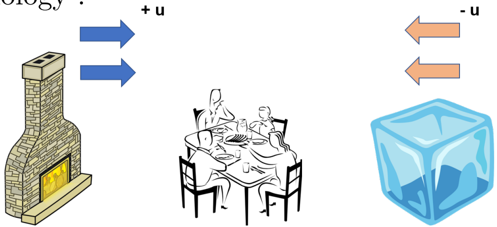

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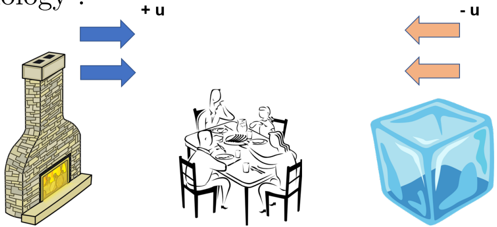

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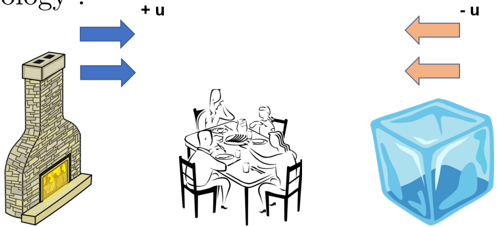

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- Convection : Conduction + Advection

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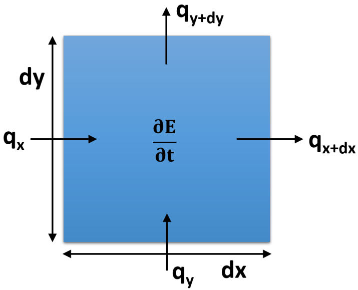

$$\frac{\partial E}{\partial t} = \frac{q_x - q_{x+dx}}{dx} + \frac{q_y - q_{y+dy}}{dy} \quad (1)$$

$$\implies \frac{\partial E}{\partial t} = -\frac{\partial q_x}{\partial x} - \frac{\partial q_y}{\partial y} \quad (2)$$

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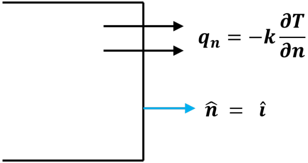

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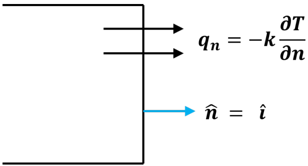

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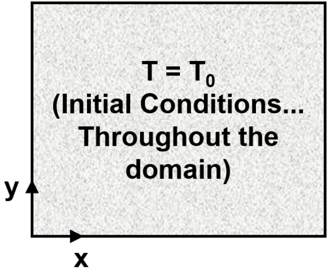
where k → Thermal Conductivity, n → normal direction

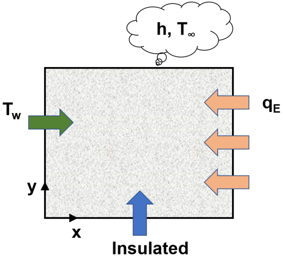
- Also, Assuming total energy E = $\rho C_p T$ (for incompressible solids/fluids)

$$\frac{\partial(\rho C_p T)}{\partial t} = k\left[\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}\right] \tag{4}$$



- Initial Conditions (IC) $\rightarrow$ The variable values at t= 0 (starting of simulations) for whole domain.

Initial and Boundary Conditions



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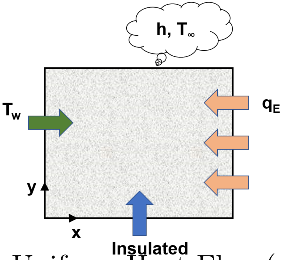
- Boundary Conditions (BC) → condition of variables all over boundary at all time-steps.



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1. Uniform Heat Flux (q_n) :

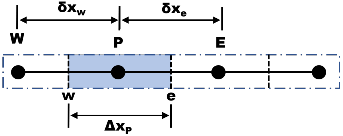
$$\frac{\partial T}{\partial n} = 0 \tag{5}$$

2. Insulated $q_n = 0$
3. Convective Boundary :

$$-k\frac{\partial T}{\partial n} = h(T - T_\infty) \tag{6}$$

- Consider a 1D domain as shown. It is required to obtain algebraic equation for steady state energy conservation at CV - 'P'.

$$k\frac{\partial^2 T}{\partial x^2} + \dot{Q}_{gen,vol} = 0$$



$$\implies \int_V k\frac{\partial^2 T}{\partial x^2}dV + \int_V \dot{Q}_{gen,vol}dV = 0$$

Using Gauss-divergence theorem i.e, $\int_V \frac{\partial \phi}{\partial n}dV = \int_S \phi\hat{n}.dS$

$$\implies \int_w^e k\frac{\partial T}{\partial x}dy.dz + \dot{Q}_{gen,vol}\Delta x.1.1 = 0$$

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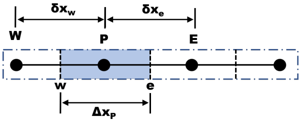

$$k\left[\left(\frac{\partial T}{\partial x}\right)_e - \left(\frac{\partial T}{\partial x}\right)_w\right] + \dot{Q}_{gen,vol}\Delta x = 0$$

$$\implies k\left[\frac{T_E - T_P}{\delta x_e} - \frac{T_P - T_W}{\delta x_w}\right] + \dot{Q}_{gen,vol}\Delta x = 0$$

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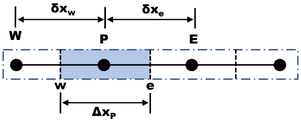

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- Using the above formulation, Linear Algebraic Equation can be obtained as follows :

$$a_P T_P + a_W T_W + a_E T_E + b = 0 \tag{7}$$

OpenFOAM Format of Equations

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```
while (simple.correctNonOrthogonal())
{
    fvScalarMatrix TEqn
    (
        fvm::ddt(T) - fvm::laplacian(DT, T)
    ==
        fvOptions(T)
    );

    fvOptions.constrain(TEqn);
    TEqn.solve();
    fvOptions.correct(T);
}
```

- ‘**fvm**’ option is used create matrix of co-efficients i.e, a_P, a_W, a_E .... through FV discretisation technique discussed earlier

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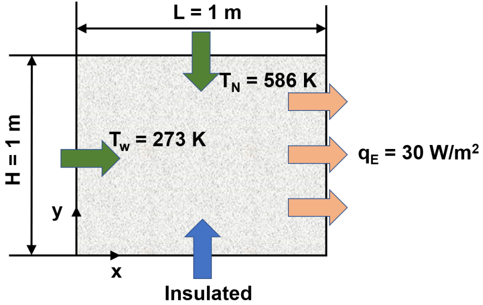
```
solvers
{
    T
    {
        solver          PCG;
        preconditioner  DIC;
        tolerance       1e-06;
        relTol          0;
    }
}
```

```
ddtSchemes
{
    default         Euler;
}

gradSchemes
{
    default         Gauss linear;
    grad(T)         Gauss linear;
}
```

- Consider a 2D Unsteady state heat-conduction problem as shown :



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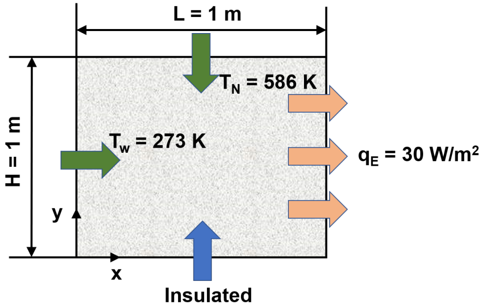

Parameter	Value
Thermal Conductivity (k)	16.2 W/mK
Density (ρ_s)	7750 kg/m^3
Heat capacity (Cp)	500 J/kg.K

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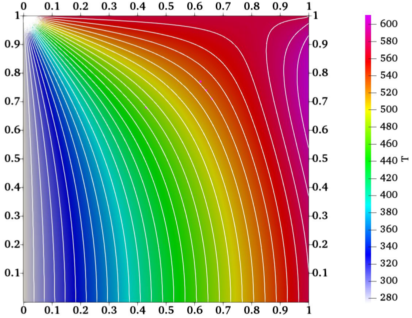
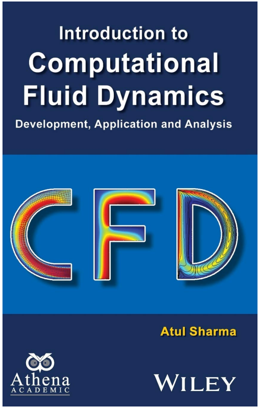


Figure: Steady State Temperature Contour

References

1. Sharma, A. (2016). Introduction to computational fluid dynamics: development, application and analysis. John Wiley & Sons.
2. https://www.openfoam.com/



Thank you for listening!

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