EN634 Nuclear Reactor Thermal Hydraulics

Introduction to two-phase flow

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TWO-PHASE FLOWS

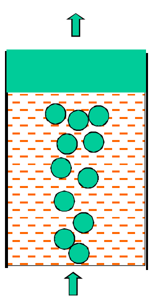
Has a large industrial relevance

- Chemical (Reactors, Distillation Columns ,etc.)
- Petroleum (Oil-Gas Lines, Refinery)
- Geothermal (Boiling)
- Power (Boilers, Fluidized Beds)
- Space (Fuel Tanks)

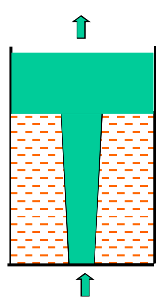
The subject matter is extremely complex

Classification

Dispersed

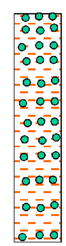


Separated

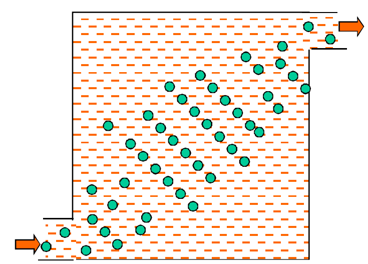


Dimensionality

One dimensional



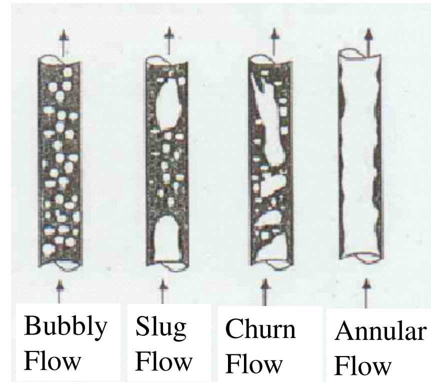
Multi-dimensional



Engineering Approach

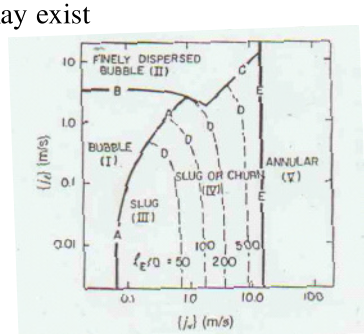
- This course will emphasize on one-dimensional area-averaged analysis
- The key issue in engineering is to compute the state of the system during steady and transient conditions
- Computation of pressure gradients and heat transfer coefficients play a central role
- In single-phase well established correlations have been developed for laminar and turbulent flows
- In two-phase flows, this becomes complicated as fluids can distribute themselves in a pipe in many patterns

Flow Patterns



Flow Pattern Maps

- The gradients of velocity and temperature at the wall will depend on flow pattern
- Maps have been generated to identify the type of flow that may exist

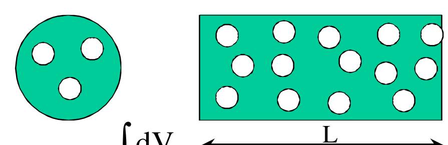


Definitions-I

Definitions

- Volume averaged void fraction or gas hold up

  These are defined after time averaging



$$\alpha_V = \frac{V_g}{V_g + V_l} = \frac{\int_g dV}{\int_{g+l} dV}$$

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Definitions (Cont'd-II)

- Area averaged void fraction or gas hold up

$$\alpha_A = \frac{A_g}{A_g + A_l} = \frac{\int_g dA}{\int_{g+l} dA}$$

- For a well distributed steady system

$$\alpha_A = \alpha_V$$

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Definitions (Cont'd-III)

- Superficial Velocity or Volume Flux

$$j_g = \frac{Q_g}{A_{pipe}}; \qquad j_l = \frac{Q_l}{A_{pipe}}$$

- Homogeneous Velocity

$$j = u_H = \frac{\text{Total Volume flowrate}}{A_{pipe}}$$

$$= \frac{Q_g + Q_l}{A_{pipe}} = j_g + j_l$$

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Definitions (Cont'd-IV)

- Phase Averaged Velocity

$$\bar{u}_g = \frac{Q_g}{A_g}; \qquad \bar{u}_l = \frac{Q_l}{A_l}$$

- From above definitions

$$j_g = \bar{u}_g \alpha \ ; \quad j_l = \bar{u}_l (1 - \alpha)$$

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Definitions (Cont'd-IV)

- Volume fraction

$$\beta = \frac{Q_g}{Q_g + Q_l}; \quad = \frac{j_g}{j_g + j_l}$$

- Relative Velocity

$$\bar{u}_r = \bar{u}_g - \bar{u}_l$$

- Slip

$$s = \frac{\bar{u}_g}{\bar{u}_l}$$

Definitions (Cont'd-IV)

- Relation between α, β and s

$$\beta = \frac{Q_g}{Q_g + Q_l} = \frac{A_g \bar{u}_g}{A_g \bar{u}_g + A_l \bar{u}_l} = \frac{\alpha s}{\alpha s + (1-\alpha)}$$

Definitions (Cont'd-VI)

- Static Quality

$$x_s = \frac{V_g \rho_g}{V_g \rho_g + V_l \rho_l} = \frac{\int_g dm}{\int_{g+l} dm}$$

- Flow Quality

$$x = \frac{\rho_g A_g \bar{u}_g}{\rho_g A_g \bar{u}_g + \rho_l A_l \bar{u}_l} = \frac{\int_g d\dot{m}}{\int_{g+l} d\dot{m}}$$

Definitions (Cont'd-VII)

- Thermodynamic equilibrium Quality

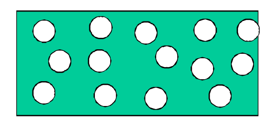
$$x_e = \frac{h - h_f}{h_{fg}}$$

When Thermodynamic equilibrium exists

$$x_e = x$$

Definitions (Cont'd-VIII)

- Static Density



$$\rho_s = \frac{\text{Mass of mixture}}{\text{Volume}} = \frac{V[\alpha \rho_g + (1-\alpha)\rho_l]}{V}$$

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Definitions (Cont'd-IX)

- Drift Velocity

$$u_d = u_g - j$$

- Drift Flux

Volume flux of gas relative a surface moving with a velocity j

$$j_{gl} = \alpha(u_g - j)$$

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Definitions (Cont'd-X)

Similarly

$$j_{lg} = (1-\alpha)(u_l - j)$$

We can see the following relationship

$$j_{gl} = \alpha(u_g - j) = \alpha u_g - \alpha j = j - j_l - \alpha j$$

$$= (1-\alpha) j - j_l = (1-\alpha) j - (1-\alpha) u_l$$

$$= (1-\alpha)(j - u_l)$$

$$= -j_{lg}$$

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Void, Quality, Slip Relations

$$x = \frac{\rho_g A_g \bar{u}_g}{\rho_g A_g \bar{u}_g + \rho_l A_l \bar{u}_l} = \frac{1}{1 + \frac{\rho_l}{\rho_g}\frac{(1-\alpha)}{\alpha}\frac{1}{s}}$$

By rearrangement

$$\alpha = \frac{1}{1 + \frac{\rho_g}{\rho_l}\frac{(1-x)}{x} s}$$

$$s = \frac{x}{(1-x)}\frac{1-\alpha}{\alpha}\frac{\rho_l}{\rho_g}$$