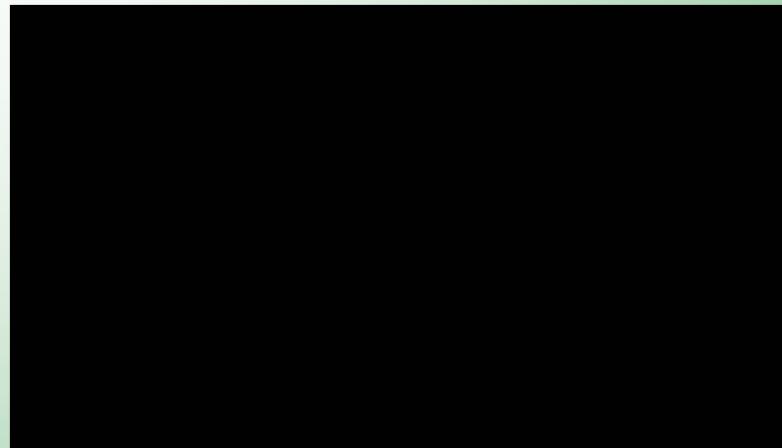


Case study #2: Gas-lift



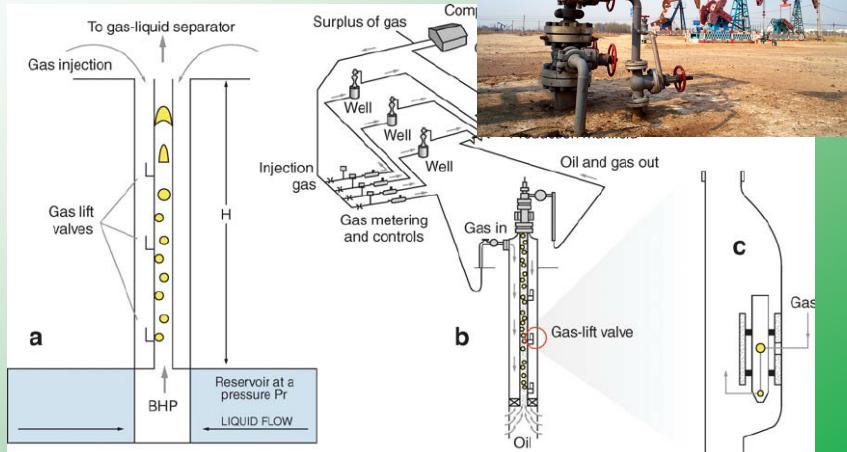
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Case study #2: Gas-lift

- Applications:

- Gas-lift in oil wells



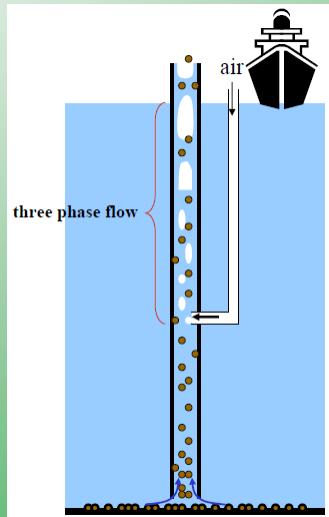
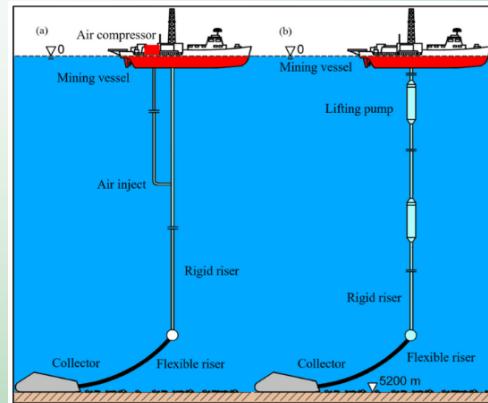
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Case study #2: Gas-lift

- Applications:

- Gas-lift in oil wells
 - Deep-sea mining



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Case study #2: Gas-lift

- Applications:

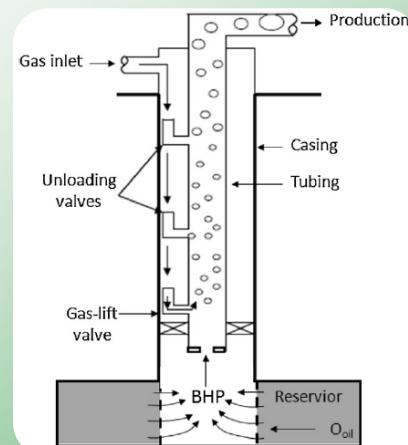
- Gas-lift in oil wells
- Deep-sea mining
- ...

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Case study #2: Gas-lift

- Gas-lift in oil wells (Amani 2012b):

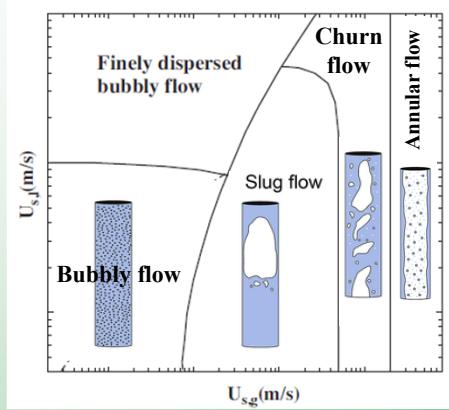


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Case study #2: Gas-lift

- Gas-lift in oil wells (Amani 2012b):

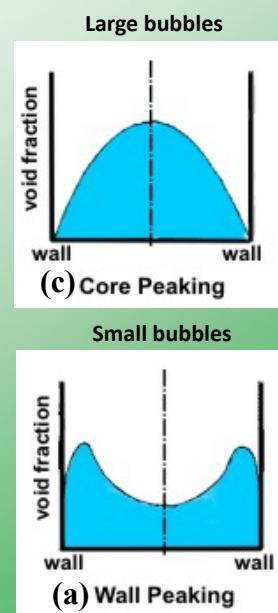
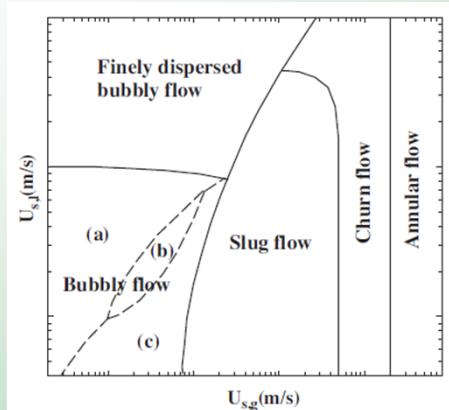


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Case study #2: Gas-lift

- Gas-lift in oil wells:



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Case study #2: Gas-lift

- **Gas-lift in oil wells (Amani 2012b):**
 - **Multi-fluid Modeling**
 1. Model closures
 2. Problem definition
 3. Solution using ANSYS Fluent

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Model closures

- **Interfacial transfer**
 - **Multi-fluid Modeling**
 1. **Mass transfer** $\dot{m}_{qk} = 0$
 2. **Interfacial forces** F_{ck}^{drag} F_{ck}^{lift} F_{ck}^{wall} F_{ck}^{vm} F_{ck}^{td}
 3. ...
- **Reynolds stress** $\bar{\rho}_k \widetilde{u''_{k,i} u''_{k,j}}$
 - **Turbulence closure**
 - **$k - \varepsilon$**
 - **$k - \omega$**
 - **SST $k - \omega$**
 - ...

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Model closures

- Drag force

- Assuming dispersed flow regime ($k=p$)

Drag force on a single bubble or particle

$$F_D = m_p \frac{\mathbf{u}_c - \mathbf{u}_p}{\tau_p}; \quad \tau_p = \tau_v = \frac{1}{f_D} \frac{\rho_p d_p^2}{18 \rho_c v_c}$$

(Chapter 9)

$k = p$ → Particle (bubble) phase
 c → Primary (continuous) phase

Friction factor $f_D = \frac{Re_p}{24} C_D$
 Drag coefficient C_D
 Particle Reynolds number $Re_p = \frac{|\mathbf{u}_c - \mathbf{u}_p| d_p}{v_c}$

➢ Assuming monodispersed bubbles

$$F_{ck}^{\text{drag}} = \frac{F_D}{A_p} a$$

Interfacial area $a = \delta_s = \delta(\varphi_k) |\nabla \varphi_k| = |\nabla \chi_k| \sim |\nabla C|$

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Model closures

- Drag force

- Assuming dispersed flow regime ($k=p$)

- Assuming monodispersed bubbles

$$F_{ck}^{\text{drag}} = \frac{F_D}{A_p} a = 3 \rho_c v_c \underbrace{\frac{f_D}{d_p} a}_{K_{cp}} (\mathbf{u}_c - \mathbf{u}_p) = K_{cp} (\mathbf{u}_c - \mathbf{u}_p)$$

$$K_{cp} = 3 \rho_c v_c \frac{f_D}{d_p} a = \frac{1}{8} C_D \rho_c |\mathbf{u}_c - \mathbf{u}_p| a$$

?

?

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Model closures

- **Drag force**

- **Assuming dispersed flow regime ($k=p$)**
- **Assuming monodispersed bubbles**
- **Assuming particle model for interfacial area concentration**

$$a = \frac{NA_p}{\Delta V} = \frac{NA_p}{NV_p/\alpha_p} = \frac{\pi d_p^2}{\frac{\pi}{6} d_p^3}$$

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Model closures

- **Drag force**

- **Assuming dispersed flow regime ($k=p$)**
- **Assuming monodispersed bubbles**
- **Drag coefficient:**

- ❖ **Schiller-Neumann (solid particles - drops)**

$$C_D = \begin{cases} \frac{24}{Re_p} (1 + 0.15 Re_p^{0.687}) & ; Re_p \leq 1000 \\ 0.44 & ; Re_p > 1000 \end{cases}$$

- ❖ **Tomiyama et al. (bubbles)**

$$C_D = \max \left[\min \left(\left(\frac{24}{Re_p} (1 + 0.15 Re_p^{0.687}) \right), \frac{72}{Re_p} \right), \frac{8}{3} \frac{Eo}{Eo + 4} \right]$$

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Model closures

- Lift force

- Assuming dispersed flow regime ($k=p$)
- Similarly, from lift force F_D on a single bubble or particle (Chapter 9)

$$\mathbf{F}_{ck}^{\text{lift}} = -C_L \alpha_p \rho_c (\mathbf{u}_p - \mathbf{u}_c) \times (\nabla \times \mathbf{u}_c)$$

Lift coefficient

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Model closures

- Lift force

- Tomiyama correlation (assuming larger-scale deformable bubbles in the ellipsoidal and spherical cap regimes): Modified Eotvos number

$$C_l = \begin{cases} \min[0.288 \tanh(0.121 \text{Re}_p), f(Eo')] & Eo' \leq 4 \\ f(Eo') & 4 < Eo' \leq 10 \\ -0.27 & 10 < Eo' \end{cases}$$

$$f(Eo') = 0.00105Eo'^3 - 0.0159Eo'^2 - 0.0204Eo' + 0.474$$

$$Eo' = \frac{g(\rho_q - \rho_p) d_h^2}{\sigma}$$

$$d_h = d_b (1 + 0.163 Eo^{0.757})^{1/3}$$

$$Eo = \frac{g(\rho_q - \rho_p) d_b^2}{\sigma}$$

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Model closures

- Lift force

- Tomiyama correlation (assuming larger-scale deformable bubbles in the ellipsoidal and spherical cap regimes)
- Shaver-Podowski Correction:

$$C_{CL} = \begin{cases} C_L & \frac{y_w}{d_b} \geq 1.0 \\ C_L \left(3 \left(\frac{2y_w}{d_b} - 1 \right)^2 - 2 \left(\frac{2y_w}{d_b} - 1 \right)^3 \right) & 0.5 \leq \frac{y_w}{d_b} < 1.0 \\ 0 & \frac{y_w}{d_b} < 0.5 \end{cases}$$

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Model closures

- Wall lubrication force

- Assuming dispersed flow regime ($k=p$)

$$F_{ck}^{\text{wall}} = C_{Wl} \alpha_p \rho_c \left| (\mathbf{u}_p - \mathbf{u}_c)_\parallel \right|^2 \mathbf{n}_w$$

Wall force coefficient Unit normal pointing away from the wall

- Frank correlation (bubbles):

$$C_{wl} = C_w \max \left(0, \frac{1}{C_{wd}} \cdot \frac{1 - \frac{y_w}{C_{wc} d_b}}{y_w \left(\frac{y_w}{C_{wc} d_b} \right)^{m-1}} \right)$$

$$C_w = \begin{cases} 0.47 & Eo < 1 \\ e^{-0.933Eo+0.179} & 1 \leq Eo \leq 5 \\ 0.00599Eo - 0.0187 & 5 < Eo \leq 33 \\ 0.179 & 33 \leq Eo \end{cases}$$

Model constants

By default, $C_{wd}=6.8$, $C_{wc}=10$, and $m=1.7$.

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Model closures

- Virtual mass force

- Assuming dispersed flow regime ($k=p$)
- Similarly, from lift force F_{vm} on a single bubble or particle (Chapter 9)

$$F_{ck}^{vm} = C'_{vm} \alpha_p \rho_c \left(\frac{D\mathbf{u}_c}{Dt} - \frac{d\mathbf{u}_p}{dt} \right); \quad C'_{vm} = 0.5$$

$$\frac{D}{Dt} = \frac{\partial}{\partial t} + \mathbf{u}_c \cdot \nabla$$

$$\frac{d}{dt} = \frac{\partial}{\partial t} + \mathbf{u}_p \cdot \nabla$$

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Model closures

- Turbulent dispersion force

- Assuming dispersed flow regime ($k=p$)

$$F_{ck}^{td} = -K_{cp} \mathbf{U}_{pm}$$

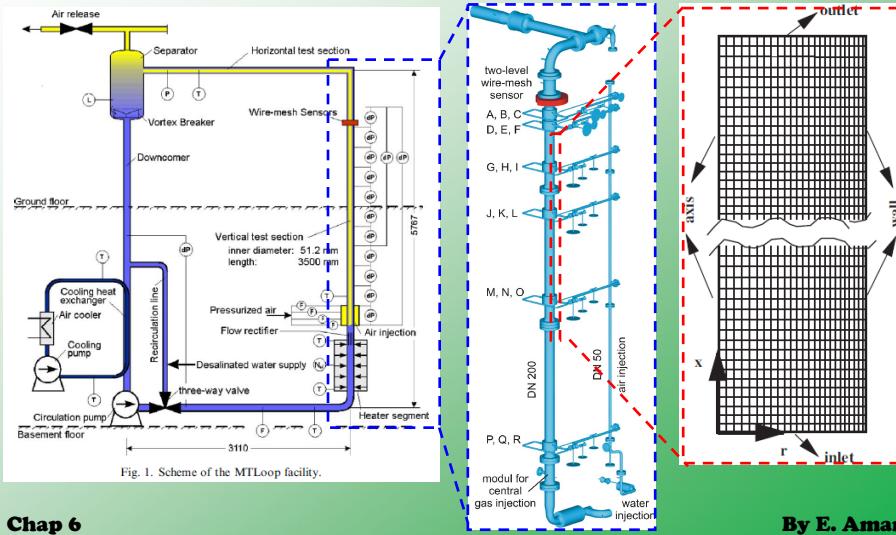
- Simonin's model for the drift velocity, \mathbf{U}_{pm} .

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Problem definition

- Validation case (Lucas et al. 2005):

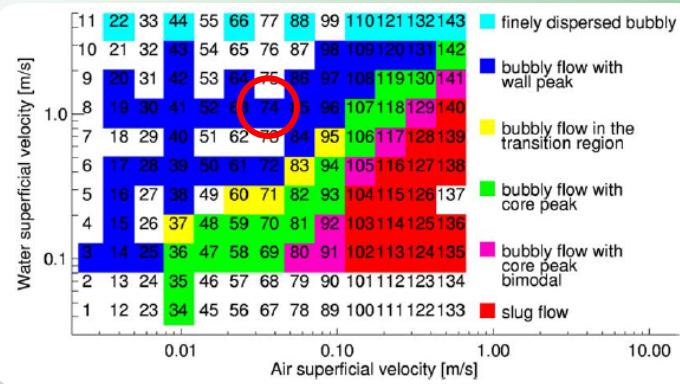


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Problem definition

- Validation case (Lucas et al. 2005):



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Problem definition

- Validation case (Lucas et al. 2005):

Table 2 – Experimental databases used for validation. Ranges are: (1) $2.65 < Eo_d < 6.06$, (2) $1.17 < Eo_d < 2.65$, (3) $Eo_d < 1.17$, (4) $6.06 < Eo_d < 9.5$, (5) $Eo_d > 9.5$.

Range	Test case	D (cm)	$U_{s,l}$ (m/s)	$U_{s,g}$ (m/s)	d_{ave} (mm)	Eo_d
(1) Wall-peak	F038 ^a	5.12	0.225	0.0096	4.3	2.99
	F039 ^a	5.12	0.405	0.0096	4.5	3.31
	F040 ^a	5.12	0.641	0.0096	4.6	3.48
	F074^a	5.12	1.017	0.0368	4.5	3.31
	F096 ^a	5.12	1.017	0.0898	4.82	3.88
(2) Wall-peak	F042 ^a	5.12	1.611	0.0096	3.6	2.01
	L1 ^b	3.8	0.753	0.23	3	1.35
	L2 ^c	5.72	1.0	0.1	2.81	1.175
	S1 ^d	6	1.03	0.0753	4	2.54
(3) Wall-peak	W1 ^e	5.715	0.43	0.4	3.2	1.56
	W2 ^e	5.715	0.73	0.1	2.8	1.166
	F107-1 ^a	5.12	1.017	0.14	2	0.57
(4) Core-peak	F118 ^a	5.12	1.017	0.219	6.74	8.46
	F094 ^a	5.12	0.405	0.0898	6.45	7.62
	F107-2 ^a	5.12	1.017	0.14	6.25	7.07
(5) Core-peak	L3 ^c	5.72	1.0	0.1	6.6	8.05
	F107-3 ^a	5.12	1.017	0.14	8.5	14.9
	F129 ^a	5.12	1.017	0.342	10.2	23.56

^a Prasser et al. (2003) and Lucas et al. (2005).

^b Liu and Bankoff (1993).

^c Liu (1998).

^d Serizawa et al. (1975).

^e Wang et al. (1987).

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Problem definition

- Validation case (Lucas et al. 2005):

- Case F074

$$D = 5.12 \text{ cm}$$

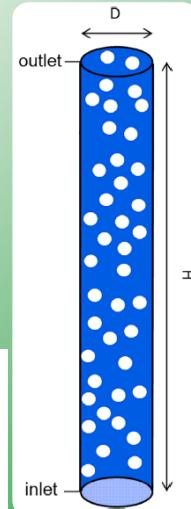
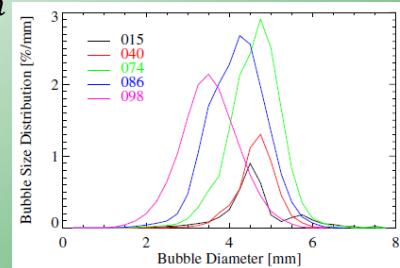
$$H = 3.5 \text{ m}$$

Water-air (bubbly regimes)

$$\sigma = 0.0728 \text{ N/m}$$

$\rho_l, \rho_g, \mu_l, \mu_g \rightarrow$ Fluent Database

$$d_p = 4.5 \text{ mm}$$



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Problem definition

- Validation case (Lucas et al. 2005):

- Case F074

$$D = 5.12 \text{ cm}$$

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Water-air (bubbly regimes)

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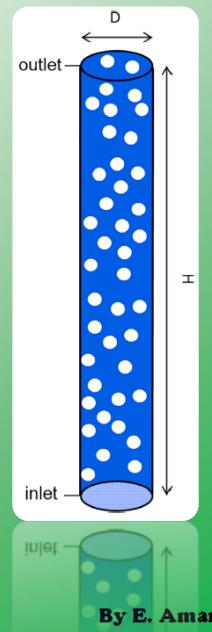
$$\langle U_{sl} \rangle_A = 1.017 \text{ m/s} \quad \langle U_{sg} \rangle_A = 0.0368 \text{ m/s}$$

Assuming Uniform inlet

$$\langle U_{sk} \rangle_A = U_{sk} = J_k = \alpha_k \tilde{U}_k \longrightarrow \tilde{U}_{k,in} = \frac{\langle U_{sk} \rangle_A}{\alpha_{k,in}}$$

Incompressible flow

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Problem definition

- Validation case (Lucas et al. 2005):

- Case F074

$$D = 5.12 \text{ cm}$$

Grid: 40×400

$$H = 3.5 \text{ m}$$

Water-air (bubbly regimes)

$$\sigma = 0.0728 \text{ N/m}$$

$\rho_l, \rho_g, \mu_l, \mu_g \rightarrow$ Fluent Database

$$d_p = 4.5 \text{ mm}$$

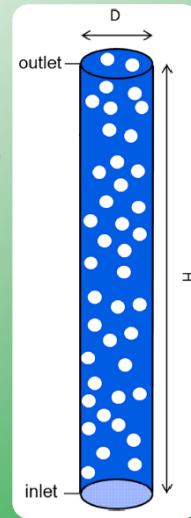
$$\langle U_{sl} \rangle_A = 1.017 \text{ m/s} \quad \langle U_{sg} \rangle_A = 0.0368 \text{ m/s}$$

Assuming Uniform inlet

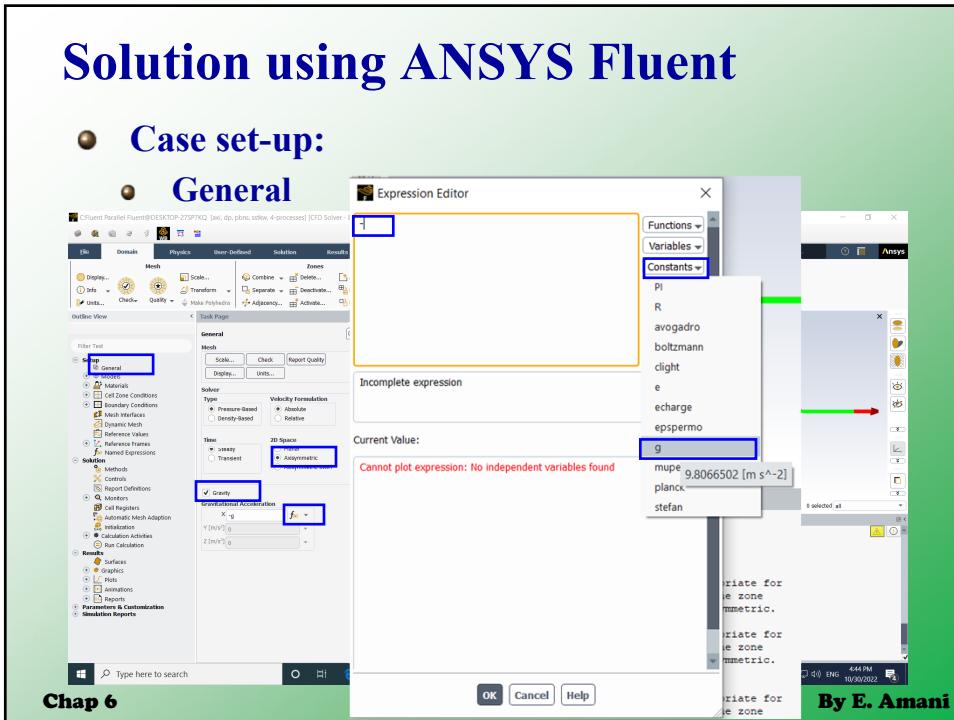
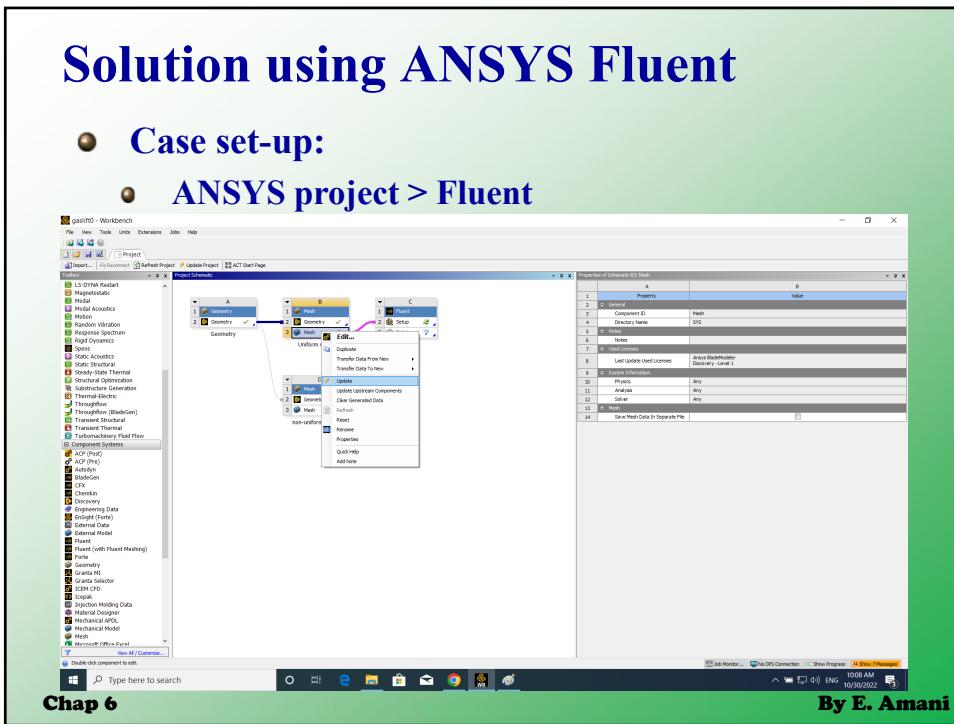
$$\alpha_{g,in} = 0.0404$$

$$\tilde{U}_{g,in} = \frac{0.0368}{0.0404} = 0.91089 \text{ m/s}$$

$$\text{Chap 6} \quad \tilde{U}_{l,in} = \frac{1.017}{1 - 0.0404} = 1.0598 \text{ m/s}$$



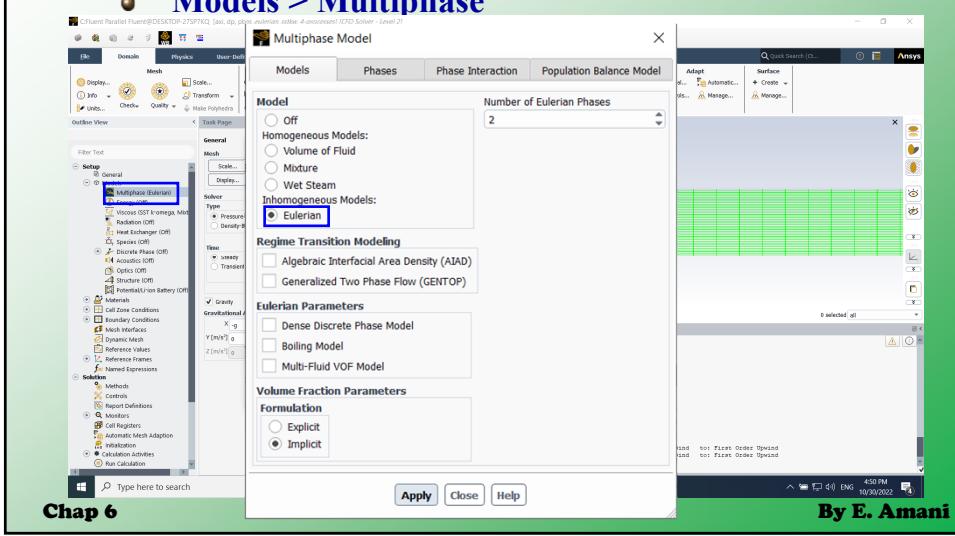
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Solution using ANSYS Fluent

Case set-up:

Models > Multiphase

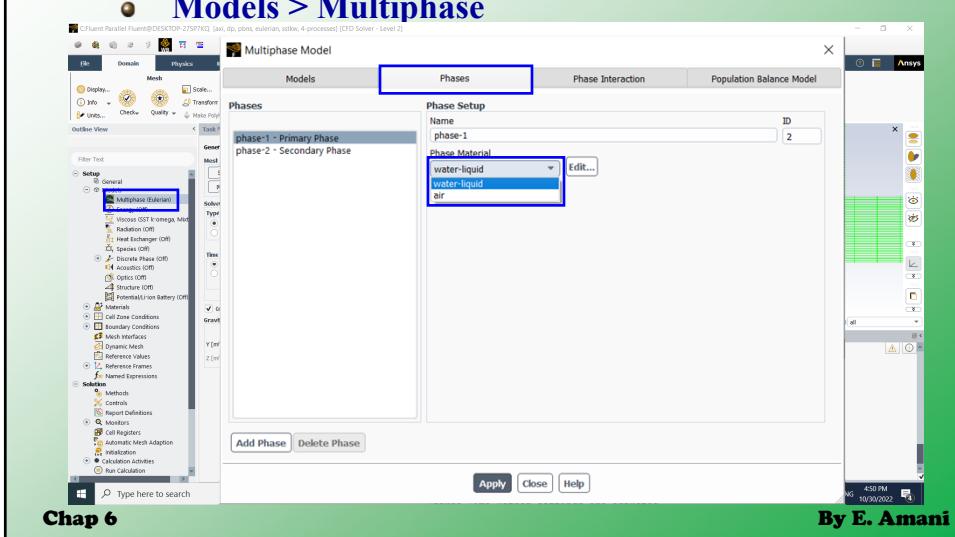


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Solution using ANSYS Fluent

Case set-up:

Models > Multiphase

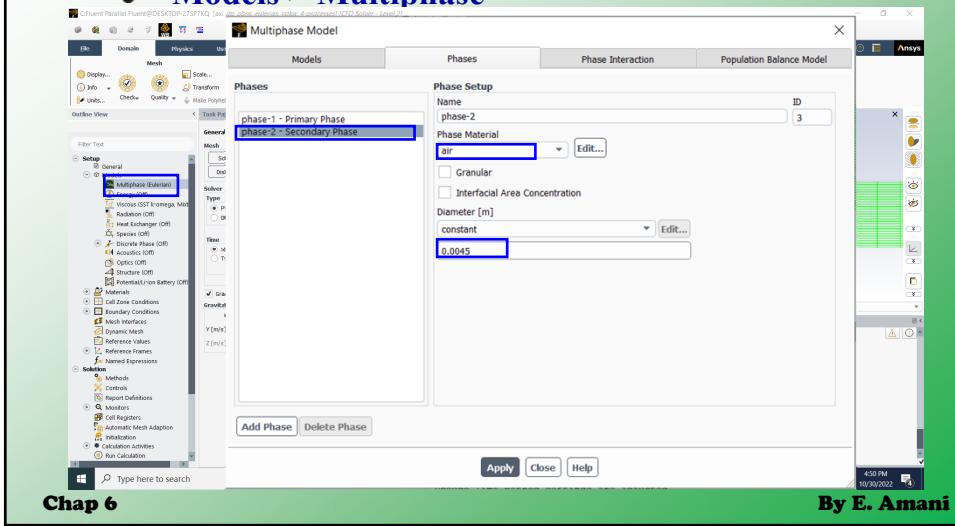


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Solution using ANSYS Fluent

Case set-up:

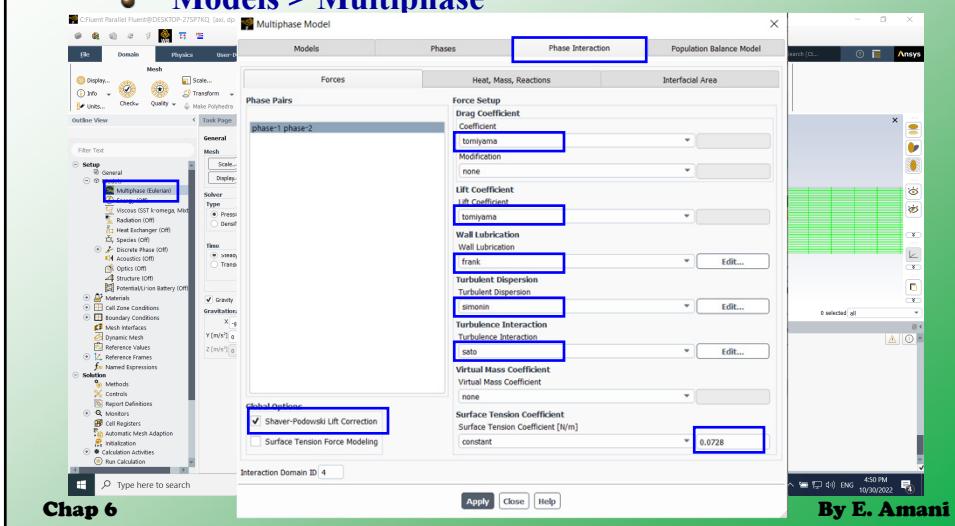
Models > Multiphase

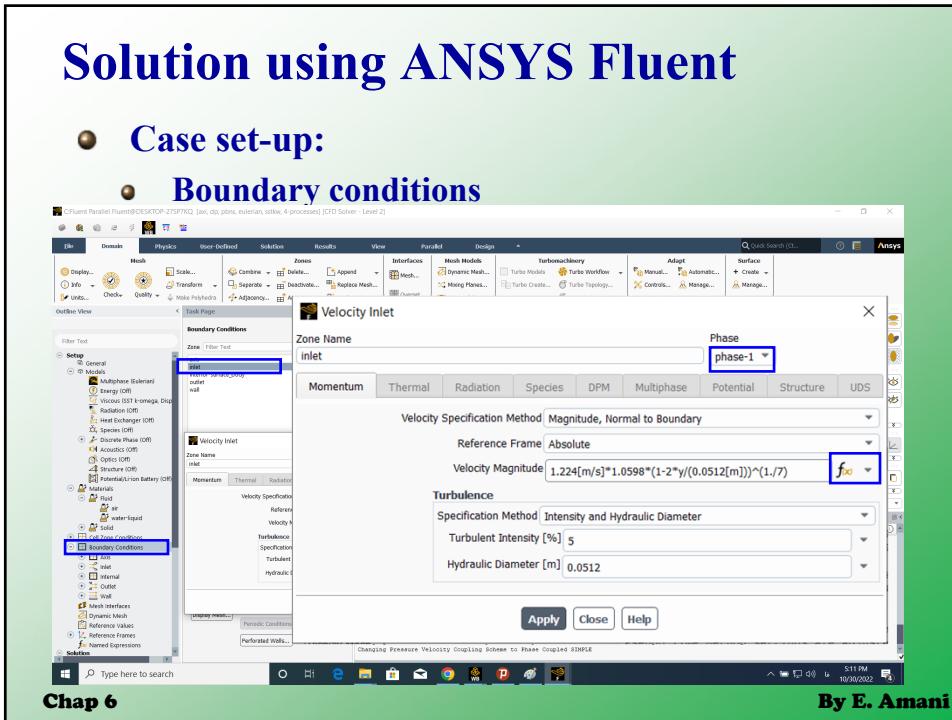
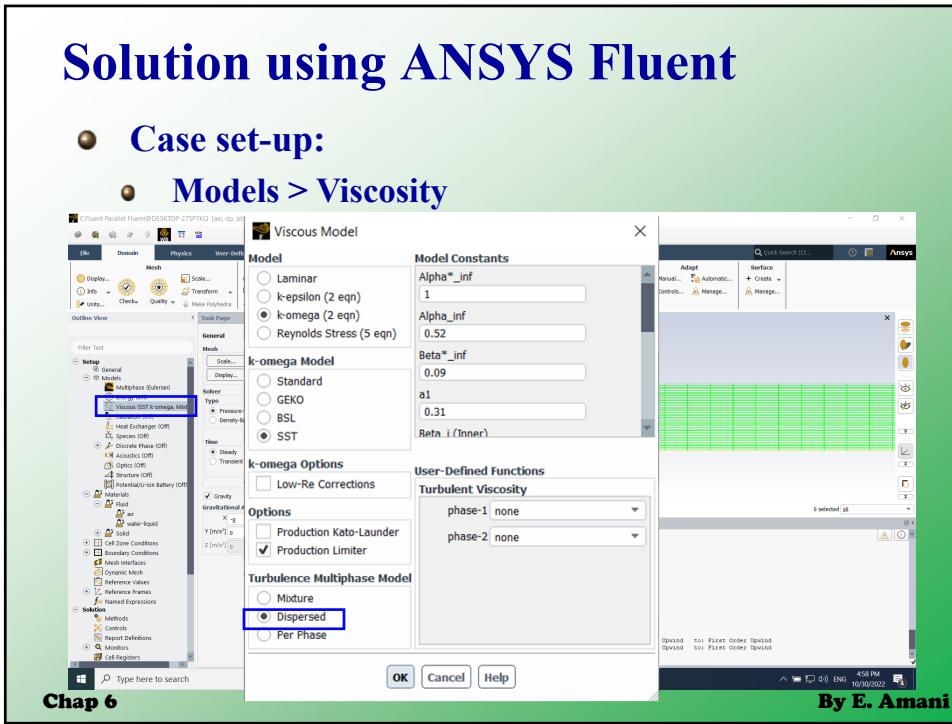


Solution using ANSYS Fluent

Case set-up:

Models > Multiphase

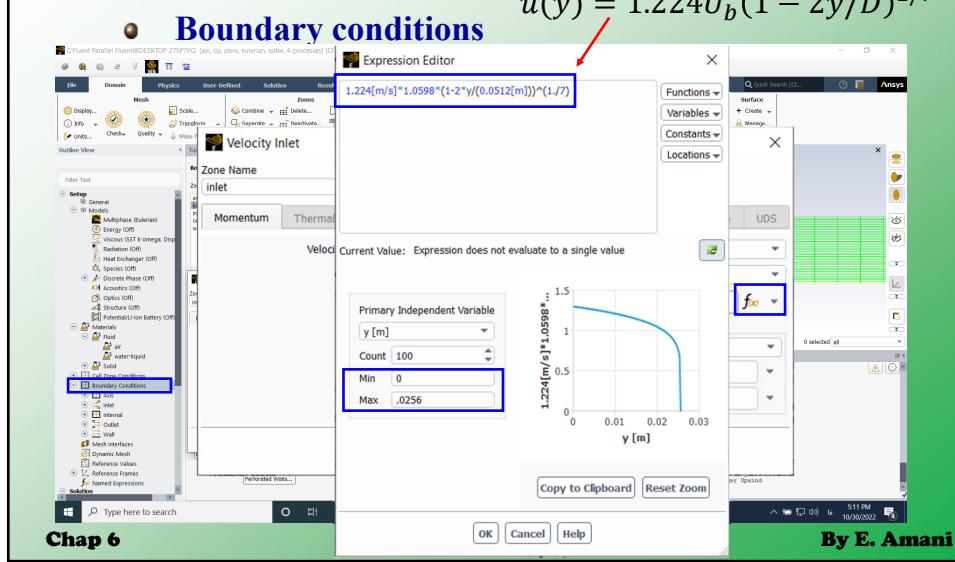




Solution using ANSYS Fluent

Case set-up:

Boundary conditions



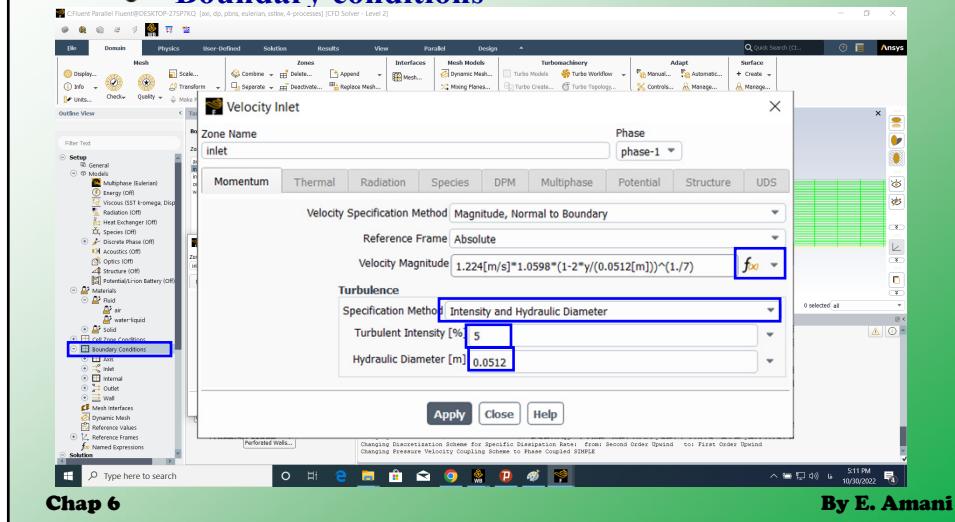
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Case set-up:

Boundary conditions



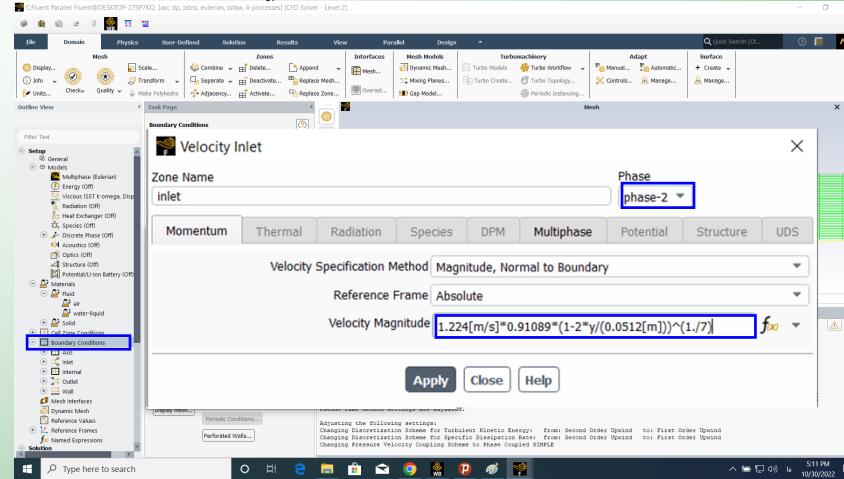
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Case set-up:

Boundary conditions



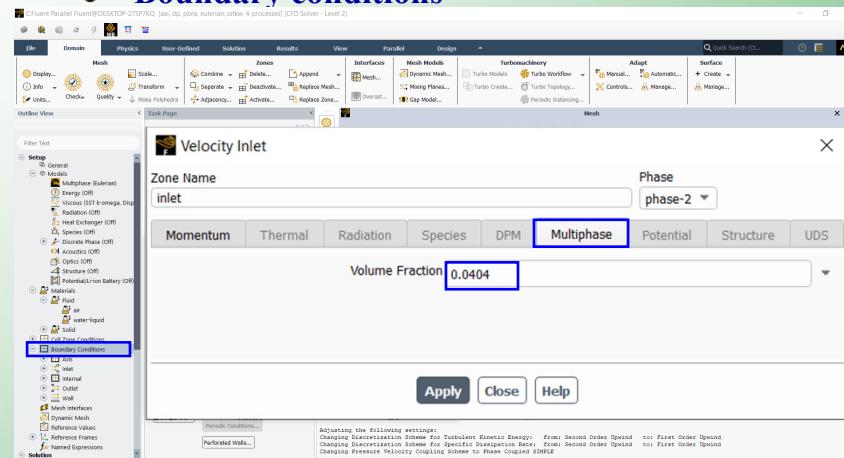
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Case set-up:

Boundary conditions



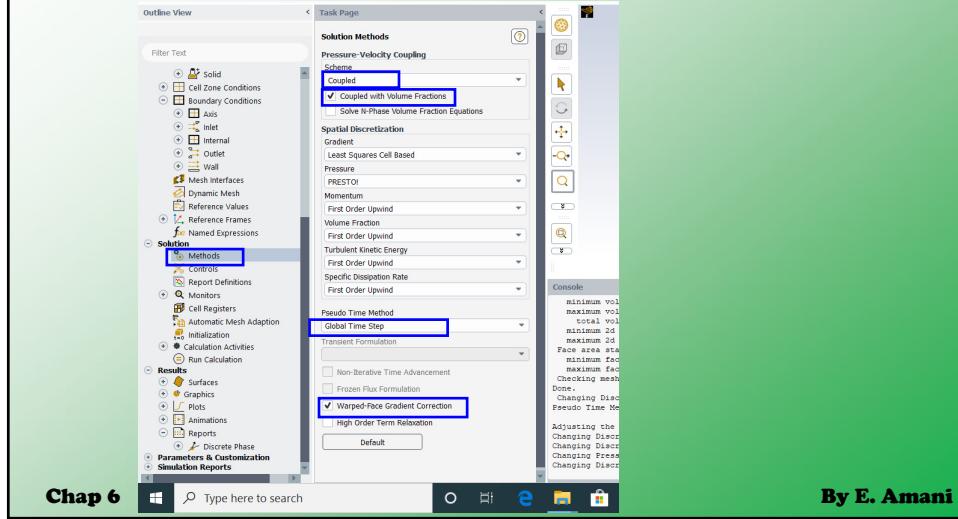
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Solution using ANSYS Fluent

- Case set-up:

- Solution > Methods



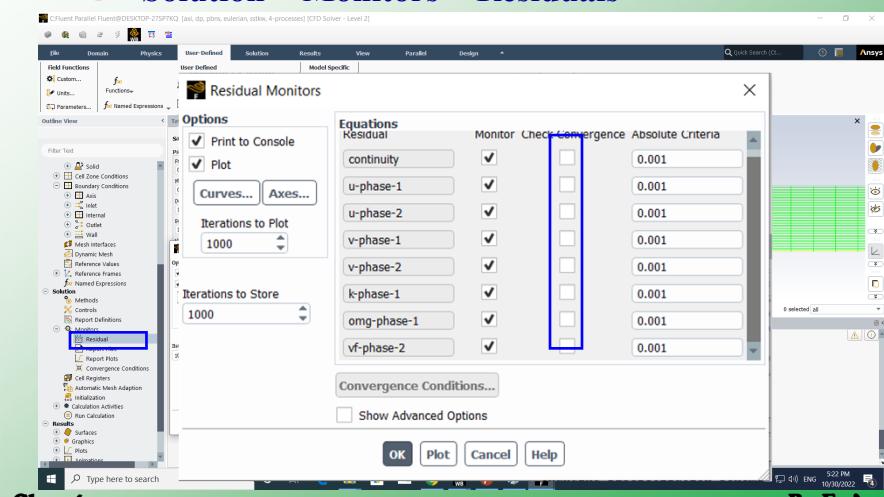
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Solution using ANSYS Fluent

- Case set-up:

- Solution > Monitors > Residuals



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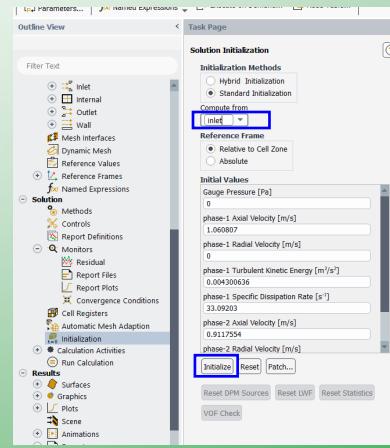
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Solution using ANSYS Fluent

- Case set-up:
- Solution > Initialization
- Solution > Run calculation > 1000 iterations

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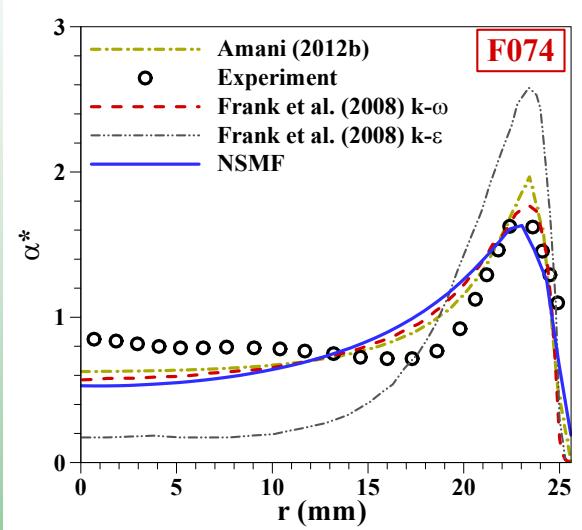
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Solution using ANSYS Fluent

- Results:

$$\alpha^*(r) = \frac{\alpha(r)}{\langle \alpha \rangle_A}$$



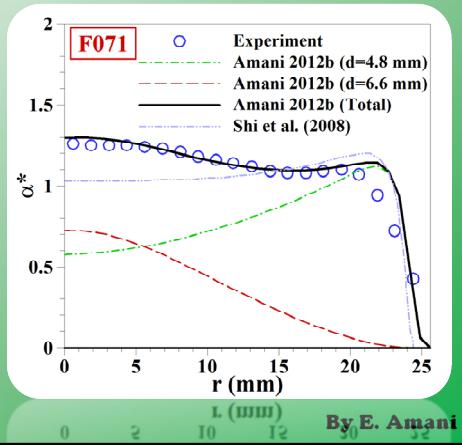
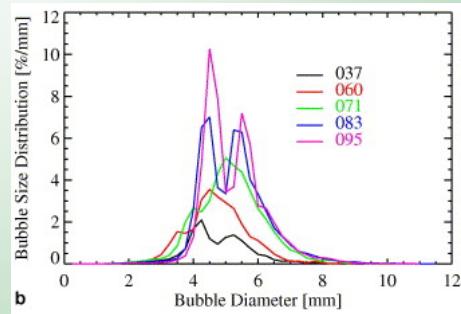
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Hands-on practice

HW#6:

- Reading FLUENT theory guide on ESS (Eulerian multiphase model)
- Transition bubbly-flow sub-regime: Three-phase simulation



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