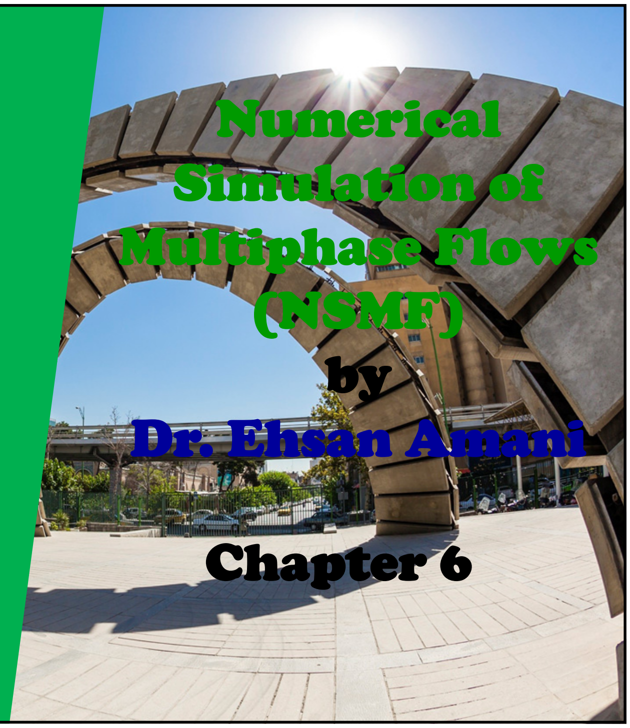


Numerical Simulation of Multiphase Flows (NSMF)

by

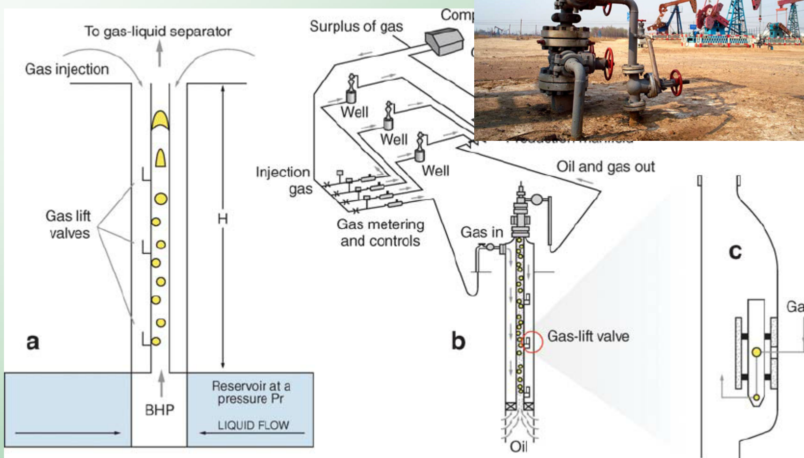
Dr. Ehsan Amani

Chapter 6

Case study #2: Gas-lift

Case study #2: Gas-lift

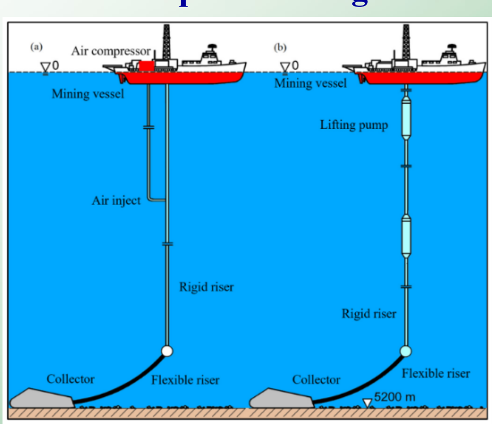
- **Applications:**
  - **Gas-lift in oil wells**

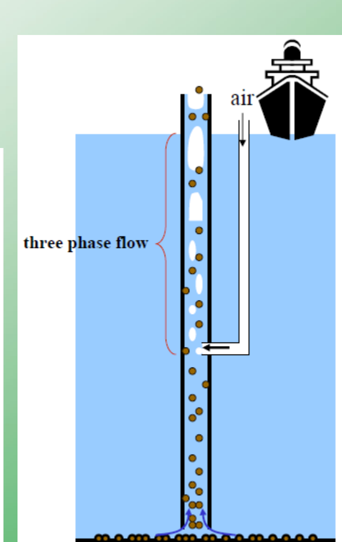


Chap 6 By E. Amani

Case study #2: Gas-lift

- **Applications:**
  - **Gas-lift in oil wells**
  - **Deep-sea mining**





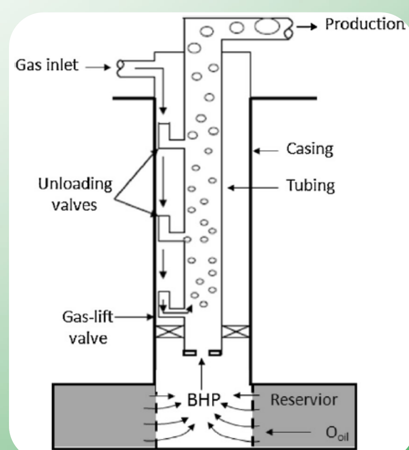
Chap 6 By E. Amani

Case study #2: Gas-lift

- **Applications:**
  - **Gas-lift in oil wells**
  - **Deep-sea mining**
  - **…**

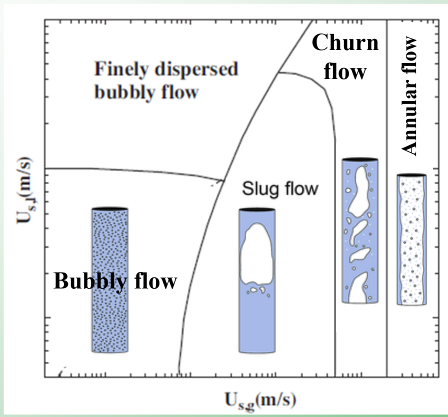
Case study #2: Gas-lift

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



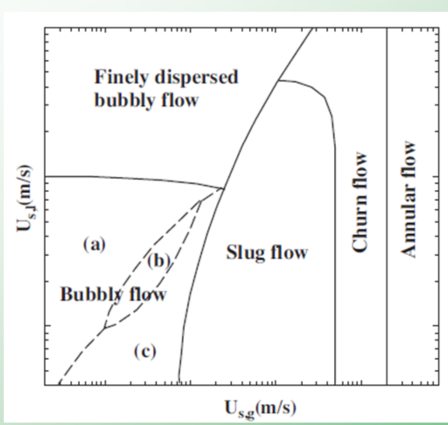
Case study #2: Gas-lift

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

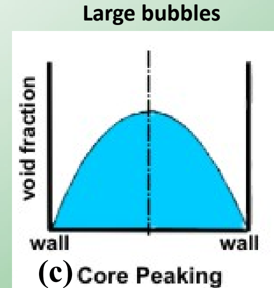


Case study #2: Gas-lift

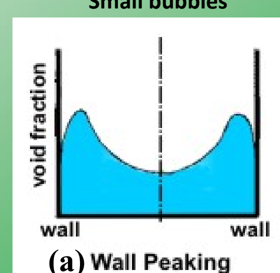
- Gas-lift in oil wells:



Large bubbles



Small bubbles



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**

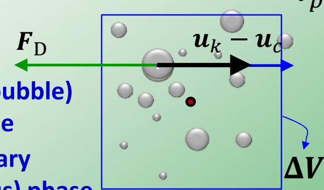
Model closures

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

Model closures

- **Drag force**
  - **Assuming dispersed flow regime (*k*=*p*)**

Drag force on a single bubble or particle (Chapter 9) ⇨ $\boldsymbol{F}_{\mathrm{D}} = m_p \frac{\boldsymbol{u}_c - \boldsymbol{u}_p}{\tau_p}$; $\tau_p = \tau_v = \frac{1}{f_D} \frac{\rho_p d_p^2}{18 \rho_c \upsilon_c}$



$k = p$ → Particle (bubble) phase

c → Primary (continuous) phase

Friction factor

$f_D = \frac{Re_p}{24} C_{\mathrm{D}}$

Drag coefficient

Particle Reynolds number

$Re_p = \frac{|\boldsymbol{u}_c - \boldsymbol{u}_p| d_p}{\upsilon_c}$

- **Assuming monodispersed bubbles**

$$\boldsymbol{F}_{ck}^{\mathrm{drag}} = \frac{\boldsymbol{F}_{\mathrm{D}}}{A_p} a$$

Interfacial area concentration

$$a = \delta_s = \delta(\varphi_k)|\boldsymbol{\nabla}\varphi_k| = |\boldsymbol{\nabla}\chi_k| \sim |\boldsymbol{\nabla}C|$$

Chap 6 **By E. Amani**

Model closures

- **Drag force**
  - **Assuming dispersed flow regime (*k*=*p*)**
  - **Assuming monodispersed bubbles**

$$\boldsymbol{F}_{ck}^{\mathrm{drag}} = \frac{\boldsymbol{F}_{\mathrm{D}}}{A_p} a = \underbrace{3\rho_c \upsilon_c \frac{f_D}{d_p} a}_{K_{cp}} \left(\boldsymbol{u}_c - \boldsymbol{u}_p\right) = K_{cp}\left(\boldsymbol{u}_c - \boldsymbol{u}_p\right)$$

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

? ?

Chap 6 **By E. Amani**

Model closures

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

$$a = \frac{NA_p}{\Delta V} = \frac{N\overset{\pi d_p^2}{A_p}}{N\underset{\frac{\pi}{6}d_p^3}{V_p}/\alpha_p} = \frac{6\alpha_p}{d_p}$$

Model closures

- **Drag force**
  - **Assuming dispersed flow regime (*k*=*p*)**
  - **Assuming monodispersed bubbles**
  - **Drag coefficient:**
    - **Schiller-Neumann (solid particles - drops)**

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

    - **Tomiyama et al. (bubbles)**

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

Model closures

- **Lift force**
  - **Assuming dispersed flow regime (*k*=*p*)**
  - **Similarly, from lift force $\boldsymbol{F}_{\mathrm{D}}$ on a single bubble or particle (Chapter 9)**

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

Lift coefficient

Chap 6 By E. Amani

Model closures

- **Lift force**
  - **Tomiyama correlation (assuming larger-scale deformable bubbles in the ellipsoidal and spherical cap regimes):**

Modified Eotvos number

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

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

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

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

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

Chap 6 By E. Amani

Model closures

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

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

Chap 6 By E. Amani

Model closures

- Wall lubrication force
  - Assuming dispersed flow regime (k=p)

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

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 .

Chap 6 By E. Amani

Model closures

- **Virtual mass force**
  - **Assuming dispersed flow regime (k=p)**
  - **Similarly, from lift force $\boldsymbol{F}_{\mathrm{vm}}$ on a single bubble or particle (Chapter 9)**

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

$$\frac{D}{Dt} = \frac{\partial}{\partial t} + \boldsymbol{u}_c.\boldsymbol{\nabla}$$

$$\frac{d}{dt} = \frac{\partial}{\partial t} + \boldsymbol{u}_p.\boldsymbol{\nabla}$$

Chap 6 By E. Amani

Model closures

- **Turbulent dispersion force**
  - **Assuming dispersed flow regime (k=p)**

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

  - **Simonin model for the drift velocity, $\boldsymbol{U}_{pm}$.**

Chap 6 By E. Amani

Problem definition

- **Validation case (Lucas et al. 2005):**

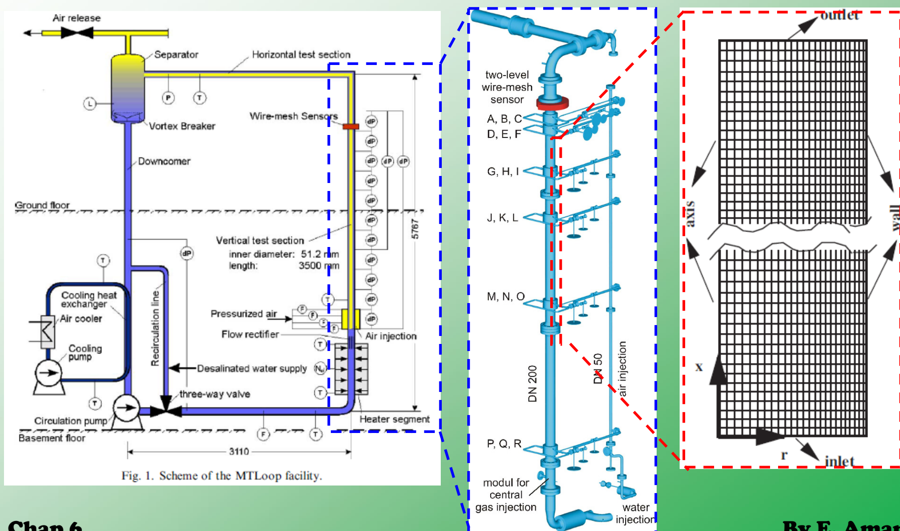
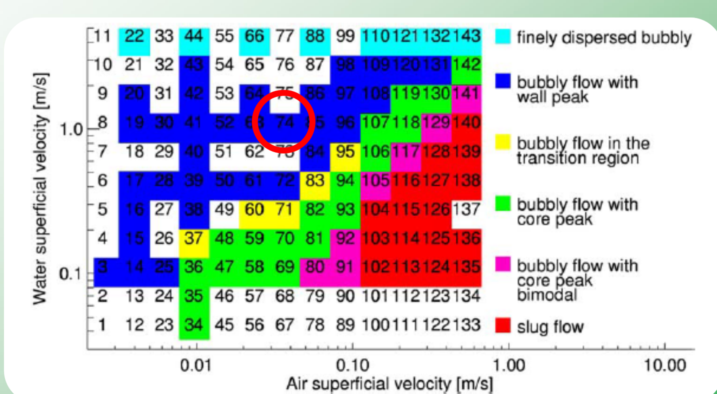


Fig. 1. Scheme of the MTLoop facility.

Chap 6 **By E. Amani**

Problem definition

- **Validation case (Lucas et al. 2005):**



Chap 6 **By E. Amani**

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
	F042[a]	5.12	1.611	0.0096	3.6	2.01
(2) Wall-peak	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
	W1[e]	5.715	0.43	0.4	3.2	1.56
(3) Wall-peak	W2[e]	5.715	0.73	0.1	2.8	1.166
	F107-1[a]	5.12	1.017	0.14	2	0.57
	F118[a]	5.12	1.017	0.219	6.74	8.46
(4) Core-peak	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
	L3[c]	5.72	1.0	0.1	6.6	8.05
(5) Core-peak	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).

Chap 6 By E. Amani

Problem definition

- **Validation case (Lucas et al. 2005):**
  - **Case F074**

$D = 5.12\ cm$

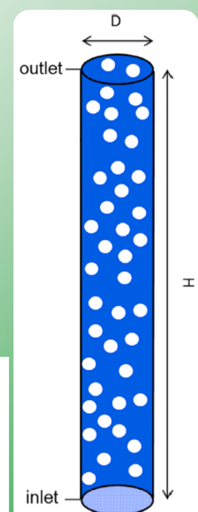
$H = 3.5\ m$

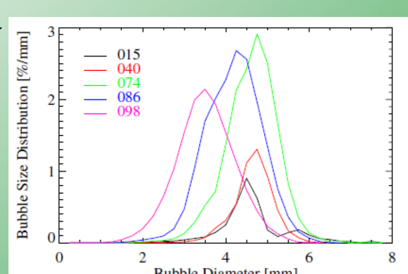
Water-air (bubbly regimes)

$\sigma = 0.0728\ N/m$

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

$d_p = 4.5\ mm$





Chap 6 By E. Amani

Problem definition

- **Validation case (Lucas et al. 2005):**
  - **Case F074**

$D = 5.12\ cm$

$H = 3.5\ m$

Water-air (bubbly regimes)

$\sigma = 0.0728\ N/m$

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

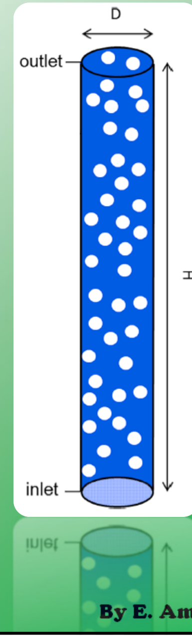
$d_p = 4.5\ mm$

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

Assuming Uniform inlet

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

Incompressible flow



Chap 6 **By E. Amani**

Problem definition

- **Validation case (Lucas et al. 2005):**
  - **Case F074**

$D = 5.12\ cm$

Grid: 40×400

$H = 3.5\ m$

Water-air (bubbly regimes)

$\sigma = 0.0728\ N/m$

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

$d_p = 4.5\ mm$

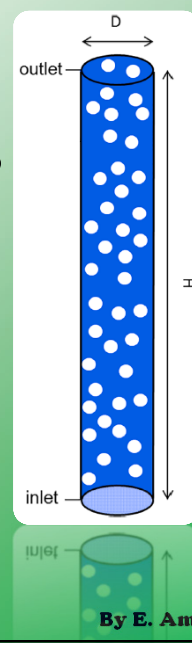
$\langle U_{sl} \rangle_A = 1.017\ m/s \quad \langle U_{sg} \rangle_A = 0.0368\ m/s$

Assuming Uniform inlet

$\alpha_{g,in} = 0.0404$

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

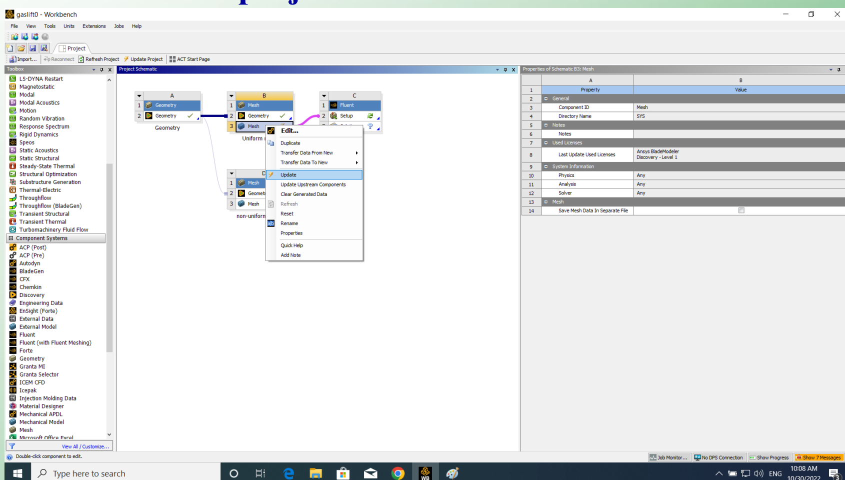
$$\widetilde{U}_{l,in} = \frac{1.017}{1 - 0.0404} = 1.0598\ m/s$$



Chap 6 **By E. Amani**

Solution using ANSYS Fluent

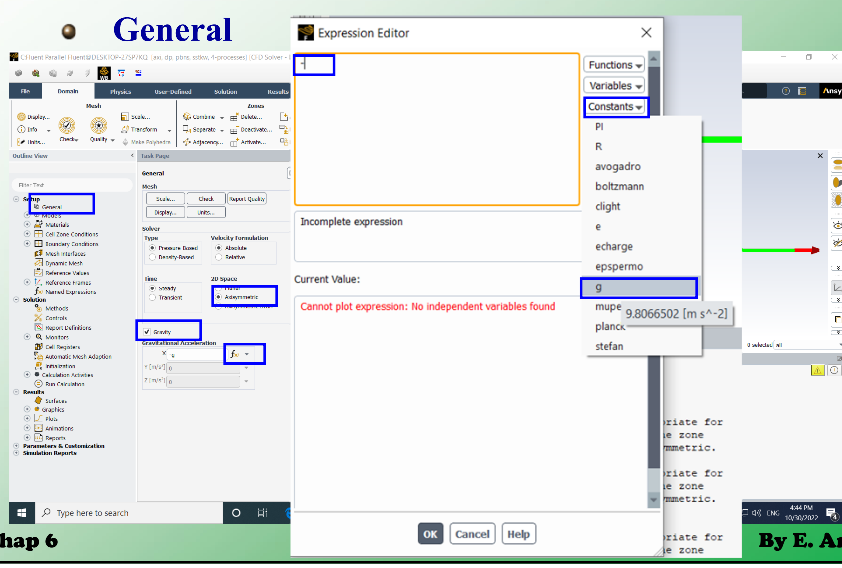
- **Case set-up:**
  - **ANSYS project > Fluent**



Chap 6 By E. Amani

Solution using ANSYS Fluent

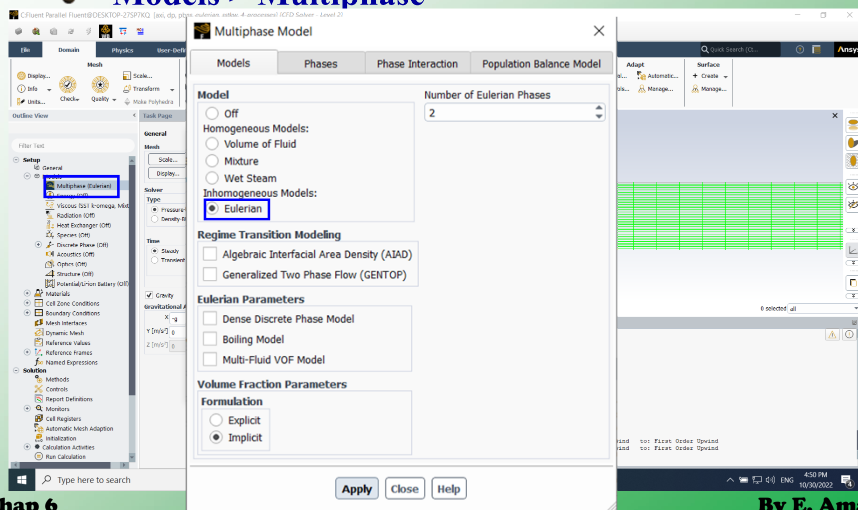
- **Case set-up:**
  - **General**



Chap 6 By E. Amani

Solution using ANSYS Fluent

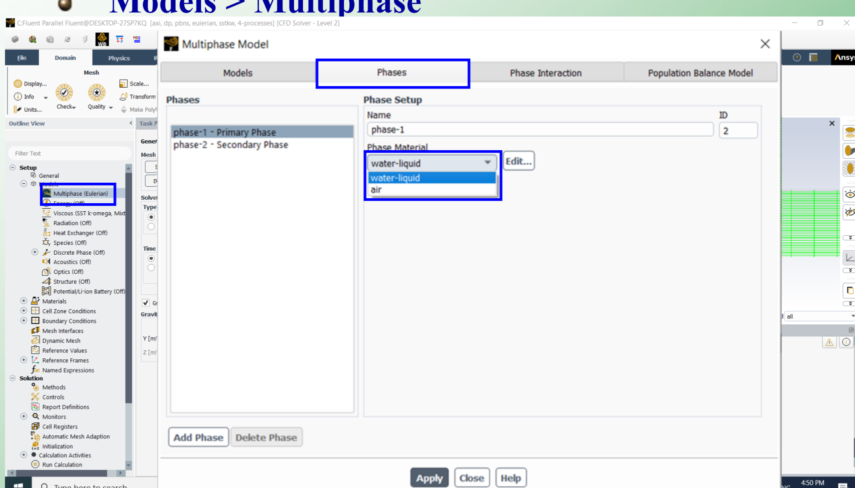
- **Case set-up:**
  - **Models > Multiphase**



Chap 6 By E. Amani

Solution using ANSYS Fluent

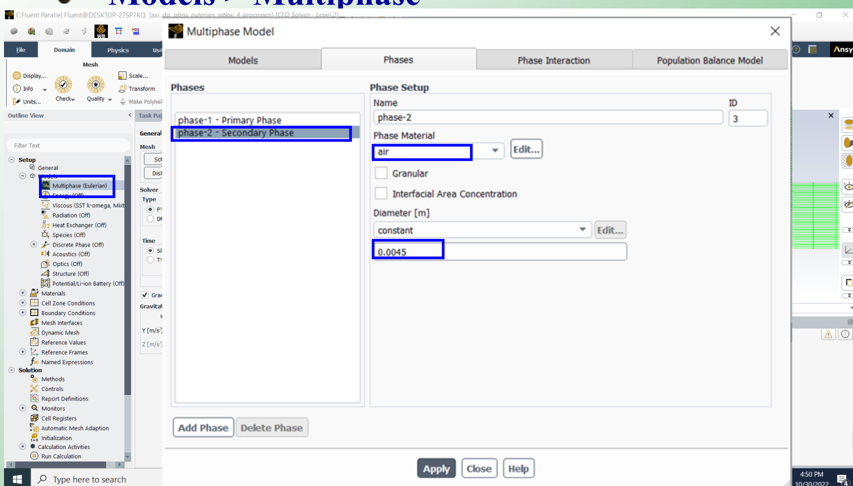
- **Case set-up:**
  - **Models > Multiphase**



Chap 6 By E. Amani

Solution using ANSYS Fluent

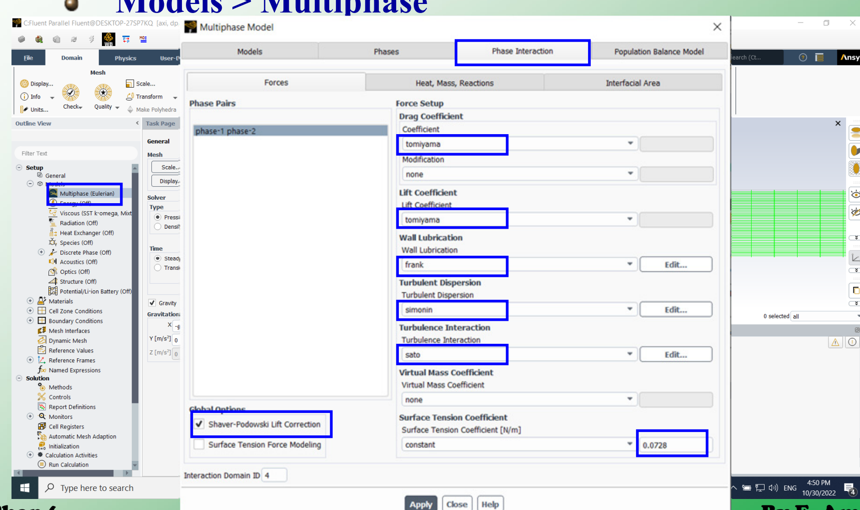
- **Case set-up:**
  - **Models > Multiphase**



Chap 6 **By E. Amani**

Solution using ANSYS Fluent

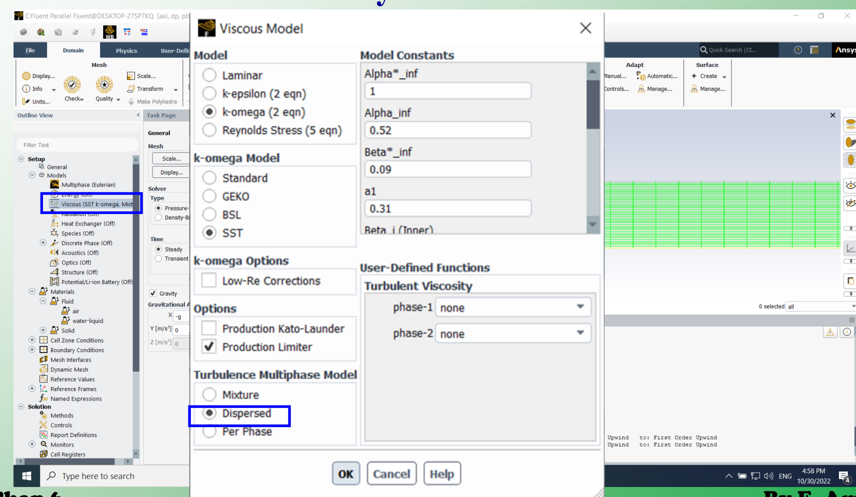
- **Case set-up:**
  - **Models > Multiphase**



Chap 6 **By E. Amani**

Solution using ANSYS Fluent

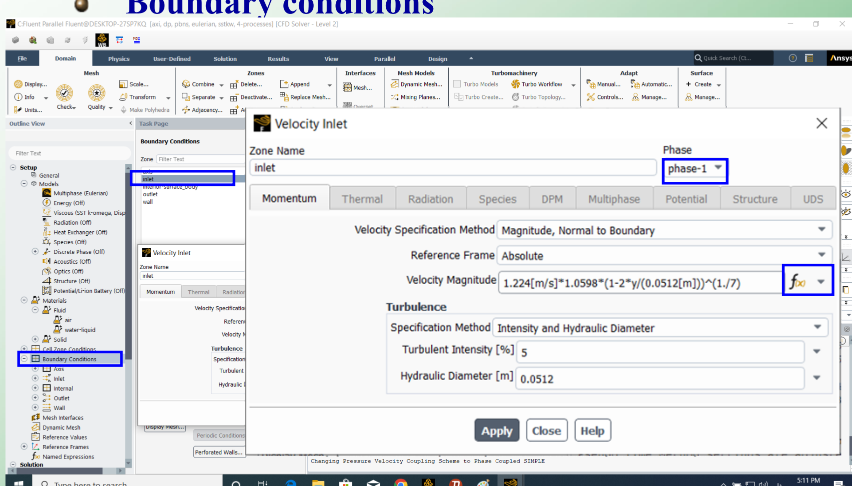
- Case set-up:
  - Models > Viscosity



Chap 6 By E. Amani

Solution using ANSYS Fluent

- Case set-up:
  - Boundary conditions

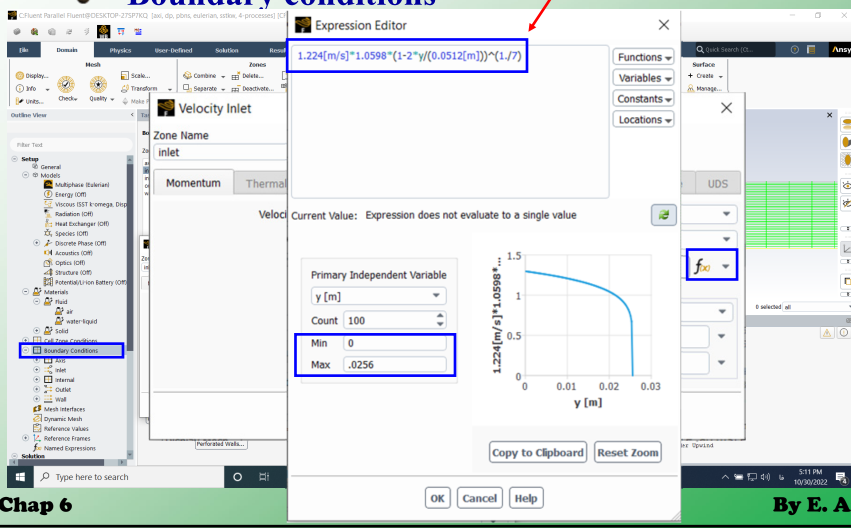


Chap 6 By E. Amani

Solution using ANSYS Fluent

- **Case set-up:**
  - **Boundary conditions**

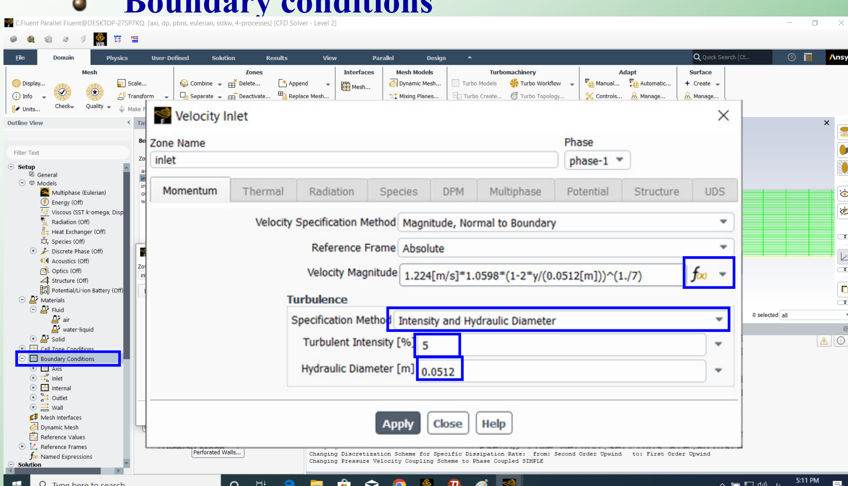
$$u(y) = 1.224U_b(1 - 2y/D)^{1/7}$$



Chap 6 **By E. Amani**

Solution using ANSYS Fluent

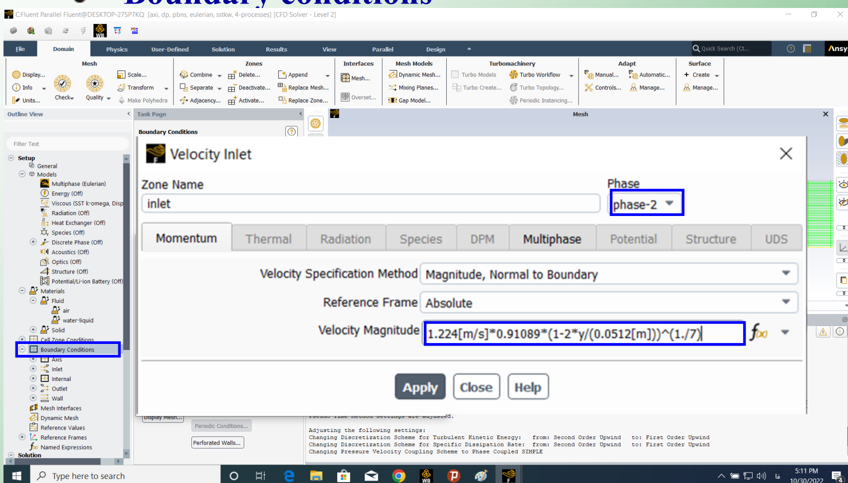
- **Case set-up:**
  - **Boundary conditions**



Chap 6 **By E. Amani**

Solution using ANSYS Fluent

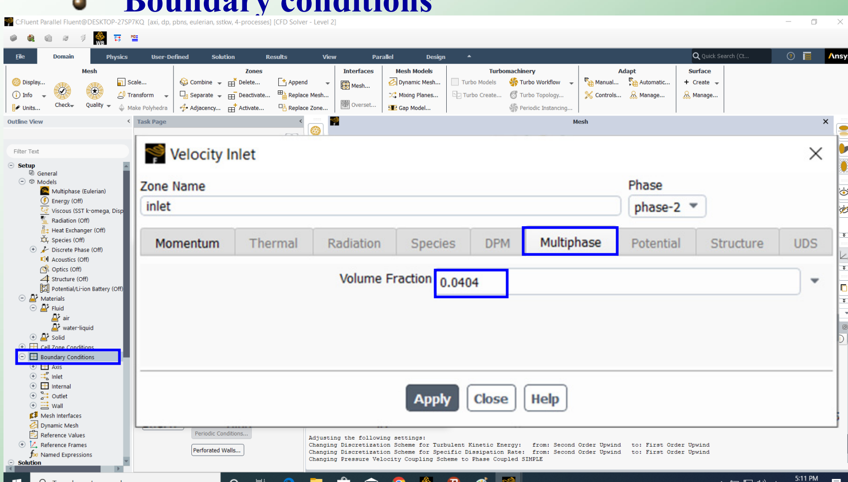
- Case set-up:
  - Boundary conditions



Chap 6 By E. Amani

Solution using ANSYS Fluent

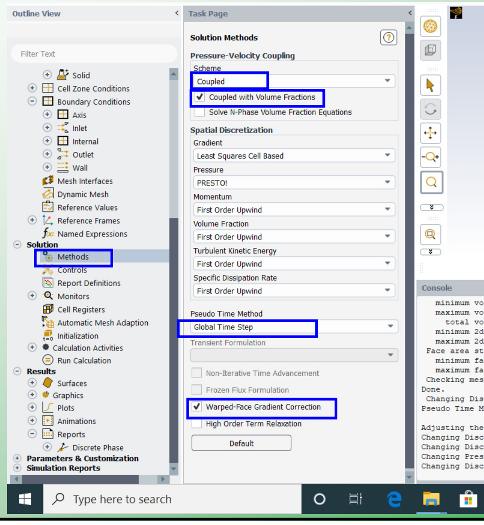
- Case set-up:
  - Boundary conditions



Chap 6 By E. Amani

Solution using ANSYS Fluent

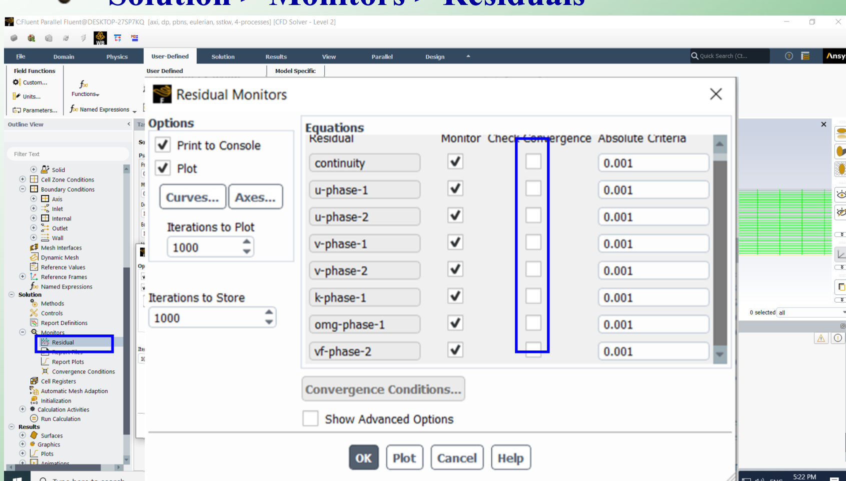
- Case set-up:
  - Solution > Methods



Chap 6 By E. Amani

Solution using ANSYS Fluent

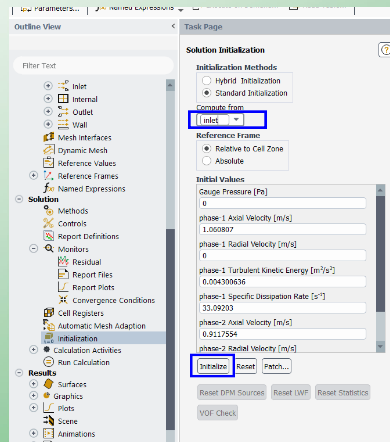
- Case set-up:
  - Solution > Monitors > Residuals



Chap 6 By E. Amani

Solution using ANSYS Fluent

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

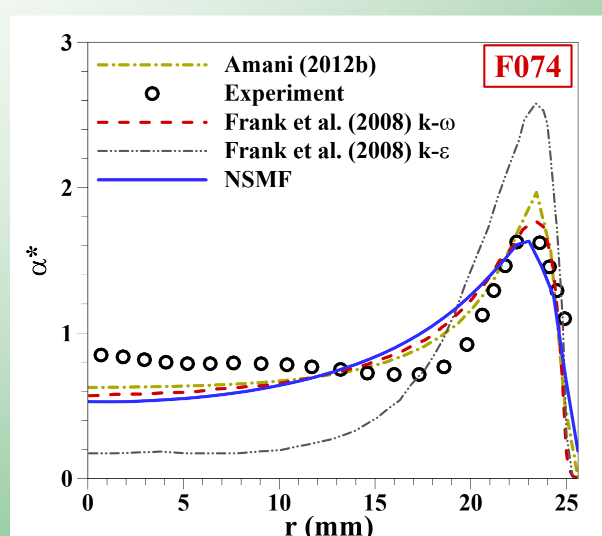


Chap 6 By E. Amani

Solution using ANSYS Fluent

- Results:

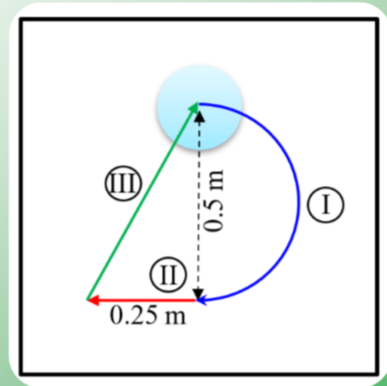
$$\alpha^*(r) = \frac{\alpha(r)}{\langle\alpha\rangle_A}$$



Chap 6 By E. Amani

Hands-on practice

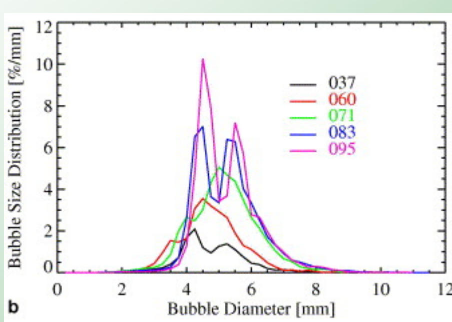
- **HW#6:**
  - Checking the FLUENT standard tutorial on VOF
  - Test of FLUENT VOF-based interface advection strategies

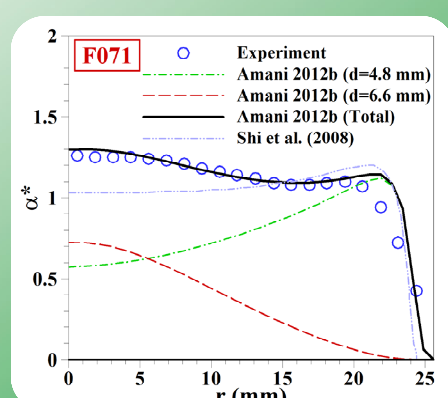


Chap 6 By E. Amani

Hands-on practice

- **HW#6:**
  - Reading FLUENT theory guide on ESS (Eulerian multiphase model)
  - Transition bubbly-flow sub-regime: Three-phase simulation





Chap 6 By E. Amani