Elementary Lecture on the Pressure Drop Due to Friction in Single and Two-phase Flows

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URAL Federal University – Ekaterinburg – Russia
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OUTLINE

- Definition of pressure drop *(Δp)* /friction factor *(f)*.
- Basic estimation of *Δp* & *f* in single phase flow.
- Performance of drilling mud in well drilling.
- Cases of Non Newtonian fluids.
- Cases of Two phase flow (Newtonian/ non-Newtonian)
- Multi layer 2 phase flows.
- Conclusions & recommendations

INTRODUCTION

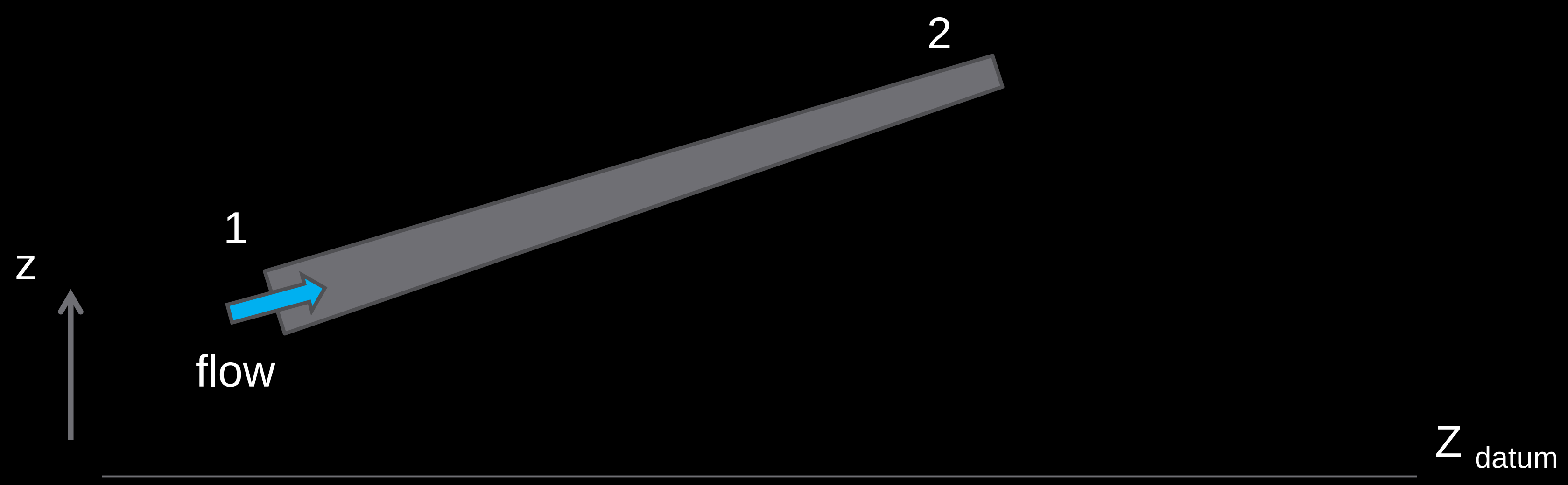
- Oil and gas pipelines play a critical role in delivering the energy resources needed to power communities around the world.

- According to US (DOT)- more than 2.5 million miles of pipelines enough to circle the earth approximately 100 times.

- Deliver oil and gas to homes and businesses.
- Usually involved multiphase flow such as (oil/water, gas and sand mixtures).

EXERCISE

Write the flow equation between 1 & 2 in your piece of paper



FLOW EQUATIONS

$$\frac{p_1}{\rho g} + \frac{v_1^2}{2g} + z_1 = \frac{p_2}{\rho g} + \frac{v_2^2}{2g} + z_2$$

head

$$p_1 + \frac{v_1^2}{2}\rho + z_1\rho g = p_2 + \frac{v_2^2}{2}\rho g + z_2\rho g$$

pressure

Incompressible, frictionless

$$\frac{p_1}{\rho g} + \frac{v_1^2}{2g} + z_1 = \frac{p_2}{\rho g} + \frac{v_2^2}{2g} + z_2 + h_l$$

head

$$p_1 + \frac{v_1^2}{2}\rho + z_1\rho g = p_2 + \frac{v_2^2}{2}\rho g + z_2\rho g + \Delta p$$

pressure

$$\frac{\Delta p}{\rho g} = h_l$$

Incompressible, friction due to viscosity

FLOW EQUATIONS

$$\frac{p_1}{\rho g} + \frac{v_1^2}{2g} + z_1 = \frac{p_2}{\rho g} + \frac{v_2^2}{2g} + z_2$$

$$p_1 + \frac{v_1^2}{2}\rho + z_1\rho g = p_2 + \frac{v_2^2}{2}\rho g + z_2\rho g$$

Bernoulli Eqn.

$$\frac{p_1}{\rho g} + \frac{v_1^2}{2g} + z_1 = \frac{p_2}{\rho g} + \frac{v_2^2}{2g} + z_2 + h_l$$

$$p_1 + \frac{v_1^2}{2}\rho + z_1\rho g = p_2 + \frac{v_2^2}{2}\rho g + z_2\rho g + \Delta p$$

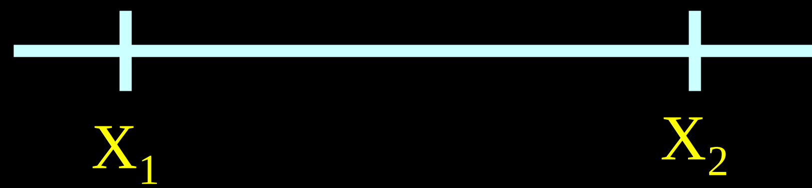
$$\frac{\Delta p}{\rho g} = h_l$$

Energy Eqn.

ity

BASIC DEFINITIONS

Δ is usually = state 2 – state 1

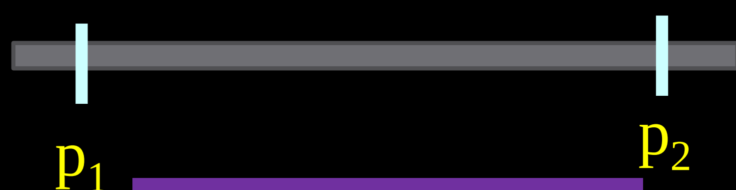


$$\Delta X = X_2 - X_1$$

$$\frac{\Delta p}{\rho g} = h_l$$

For the pressure drop in fluid flow

Δ*p* is usually = Pressure 1 – Pressure 2



$$\Delta p = p_1 - p_2$$

FRICTION FACTOR SINGLE PHASE

- Circular , non circular pipes
- Laminar , turbulent flow
- Smooth or rough
- Horizontal, inclined, vertical

$$\frac{\Delta p}{\rho g} = h_l = f\,\frac{L}{D_H} \times \frac{v^2}{2g}$$

L = pipe length

D_H = 4 cross section area/ perimeter

v = mean velocity

FRICTION FACTOR
SINGLE PHASE

$$\frac{\Delta p}{\rho g} = h_l = f\,\frac{L}{D_H}\,\text{X}\,\frac{v^2}{2g}$$

Laminar or turbulent flow?

Laminar:

$$f = \frac{64}{Re}$$

Turbulent:

$$f = f\,(Re, \varepsilon)$$

FRICTION FACTOR SINGLE PHASE

$$\frac{1}{\sqrt{f}} = -20\log\left(\frac{\varepsilon/D}{3.7} + \frac{2.51}{Re\sqrt{f}}\right)$$

Colebrook Eqn.
Smooth pipe , or rough pipe

1. Smooth pipe, ε = 0

$$\frac{1}{\sqrt{f}} = -20\log\left(\frac{2.51}{Re\sqrt{f}}\right)$$

Prandtl Eqn.

2. Fully rough zone, Re = ∞

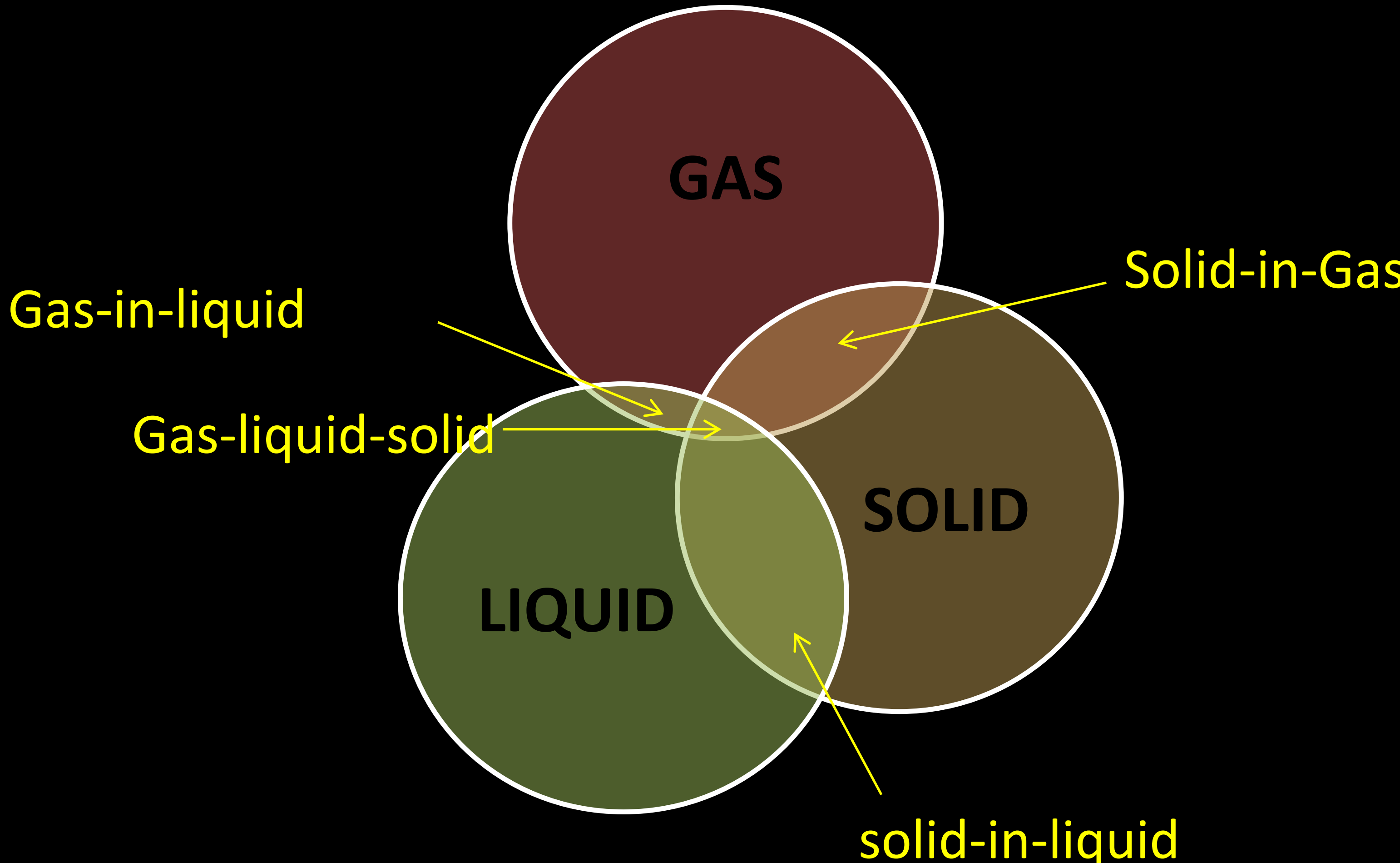
$$\frac{1}{\sqrt{f}} = -20\log\left(\frac{\varepsilon/D}{3.7}\right)$$

Von Karman Eqn.

The eqn. is implicit……..
and can converge very fast
Using Haaland Eqn. as first guess

$$\frac{1}{\sqrt{f}} = -1.8\log\left(\left(\frac{\varepsilon/D}{3.7}\right)^{1.11} + \frac{6.9}{Re}\right)$$

BASICS OF TWO PHASE FLOW



BASICS OF TWO PHASE FLOW

- A phase is simply one of the state of matter and can be either a **gas** , a **liquid** or a **solid**.
- Multiphase flow is a simultaneous flow of several phases . Two-phase flow is the simplest case of multiphase flow .
- Gas - liquid mixtures are referred to as two-phase two - component flow,
- while as liquid - vapor mixture referred to as two-phase single - component mixture.

BASICS OF TWO PHASE FLOW

- Steam generators and condensers, steam turbines (Power Plants).
- Refrigeration .
- Coal & Co-fired furnaces .
- Fluidized bed reactors .
- Liquid sprays .
- Separation of contaminants from a carrier fluid .
- Transportation of O & G.
- Drilling

TWO PHASE
DRILLING & CUTTING TRANSPORT

Horizontal or vertical or inclined ?

Newtonian or non-Newtonian ?

One, two, three layers ?

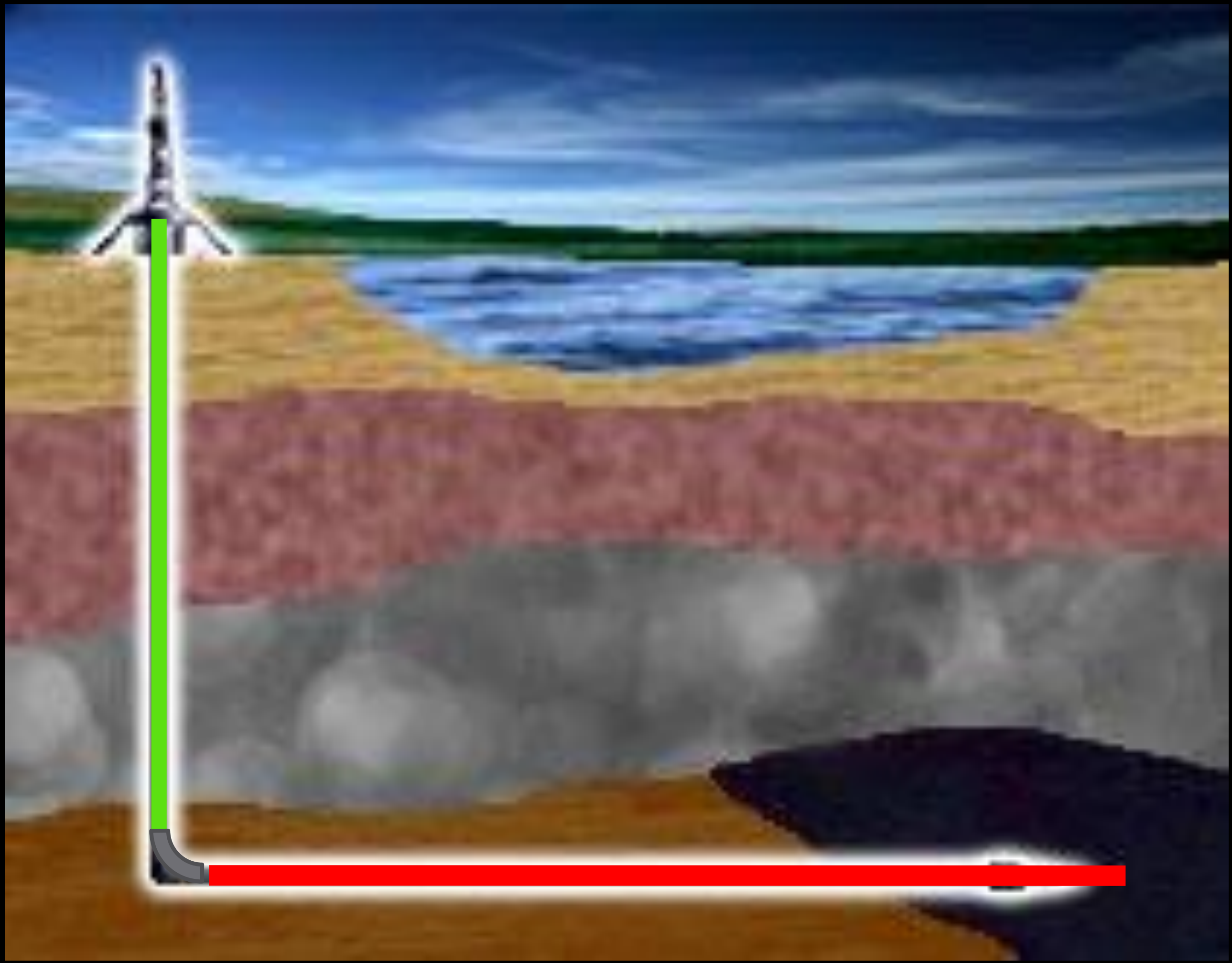
Pipe or annular flow ?

TWO PHASE DRILLING & CUTTING TRANSPORT

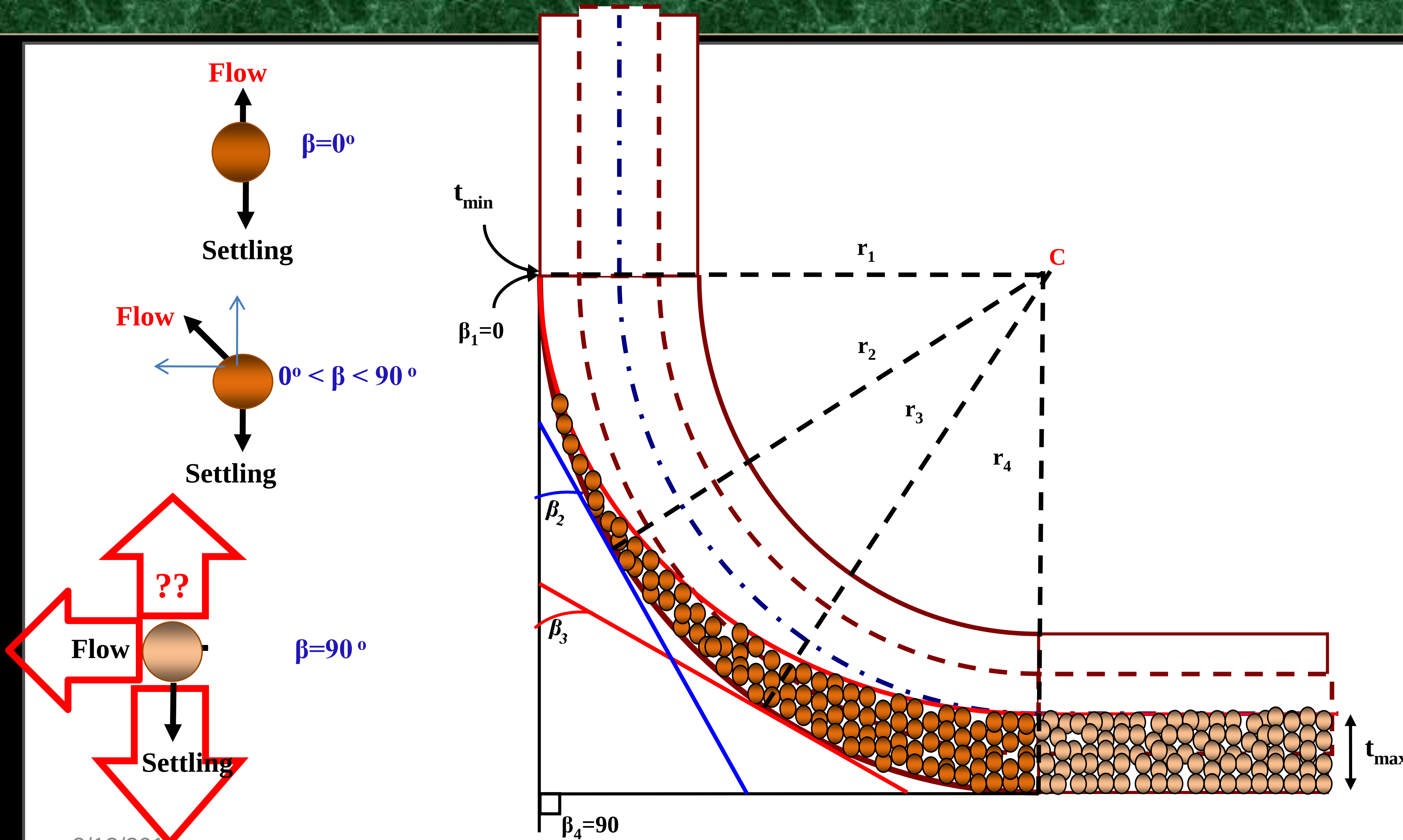
Vertical
$\beta = 0^o$

Inclined
$0^o < \beta < 90^o$

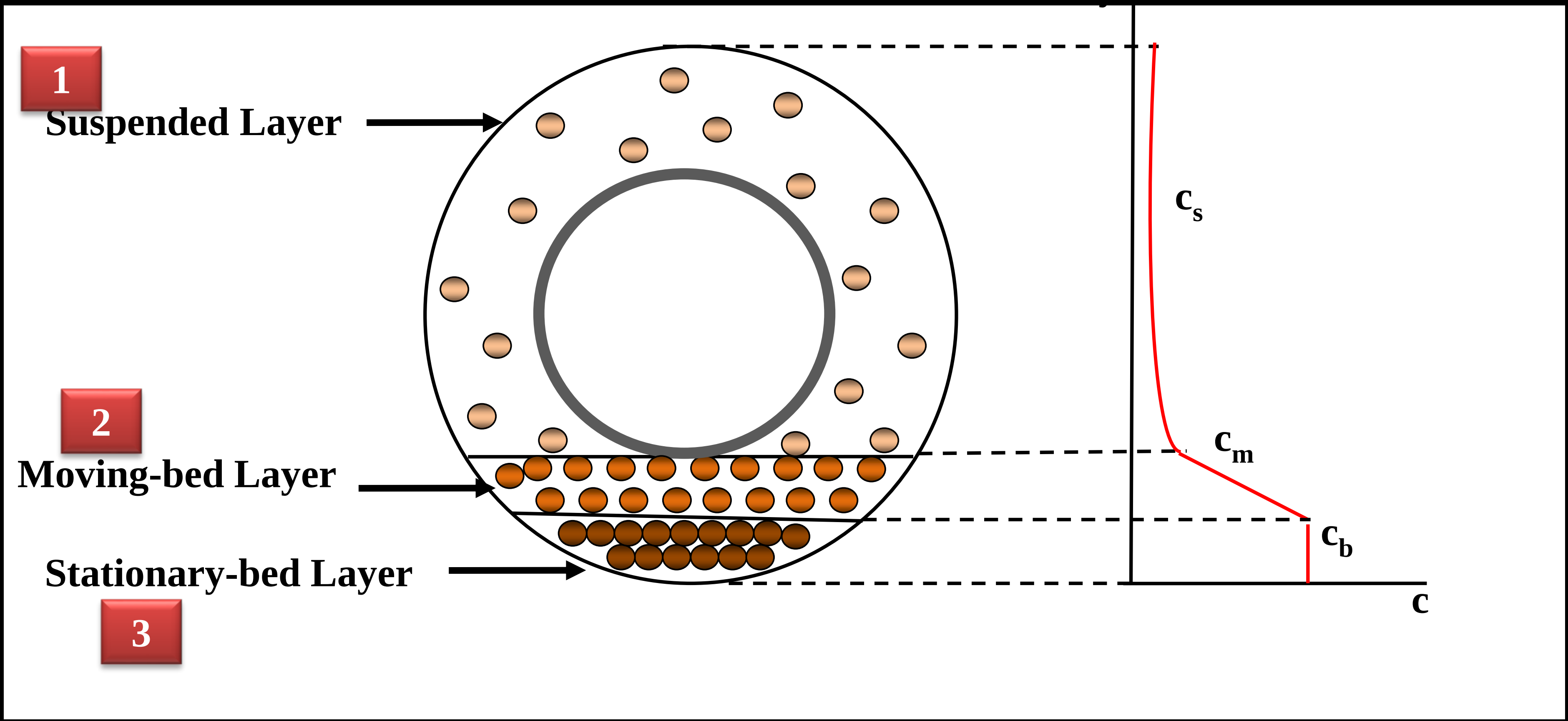
Horizontal
$\beta = 90^o$



TWO PHASE
DRILLING & CUTTING TRANSPORT



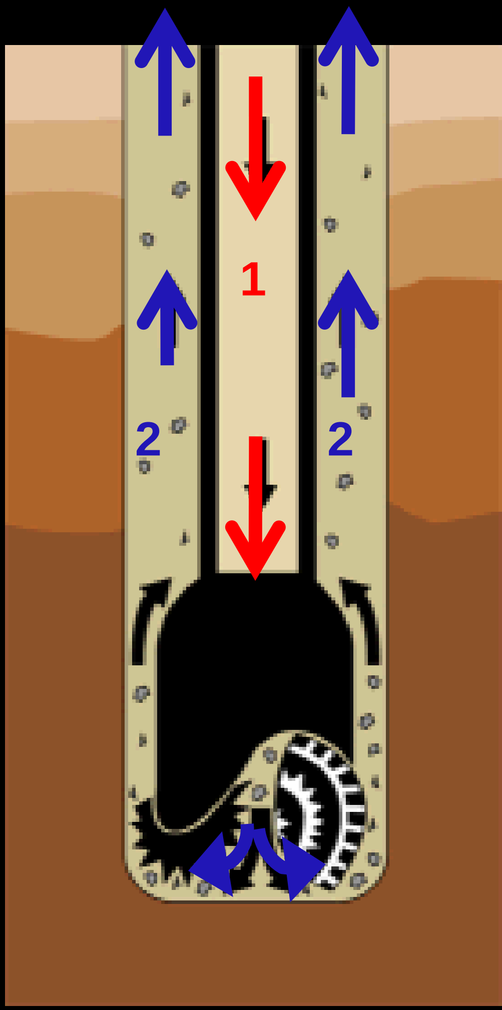
TWO PHASE
DRILLING & CUTTING TRANSPORT



Two-phase pressure drop relationships- adiabatic

- Empirical correlation based on the homogeneous model
- Empirical correlation based on the two-phase friction multiplier concept
- Direct empirical models
- Flow pattern specific models

TWO PHASE
DRILLING & CUTTING TRANSPORT



Homogenous vertical

Newtonian

NOTICE:

1. Injected as pipe flow, single phase

2. Extracted as annular flow, two phase

Drilling mud is non-Newtonian

Cutting Particles are non-spherical

TWO PHASE DRILLING & CUTTING TRANSPORT

1. Non-Newtonian, single phase

Added complication, where the fluid viscosity is not constant.

Viscosity model is required

Sometime, experimental measurement are essential to evaluate the viscosity parameters.

$$\mu = K\left(du / dy\right)^{(n-1)}$$

K **= consistency index**

n **= index behavior**

$$\mathrm{Re} = \frac{8\rho\, U^{(2-n)} D_h^{\;n}}{K}\left(\frac{6n+2}{n}\right)^{-n}$$

$$\frac{1}{\sqrt{f}} = -20\log\left(\frac{\varepsilon/D}{3.7} + \frac{2.51}{Re\sqrt{f}}\right)$$

2. Homogeneous model , two phase

Suitable average properties are determined and the mixture is treated as a single fluid

- average values of the properties for both phases .
- e.g., for suspension, foam, mist, dispersed, bubbly flows.
- no detail of the flow is considered

$$\rho_{2p} = \rho_L (1-\alpha) + \rho_G \alpha$$

$$\mu_{2p} = \alpha \mu_G + (1-\alpha) \mu_L$$

$$\frac{1}{\sqrt{f}} = -20 \log\left(\frac{\varepsilon / D}{3.7} + \frac{2.51}{Re\sqrt{f}}\right)$$

TWO PHASE SOLID-IN-LIQUID

3- Homogeneous , two phase, Non-Newtonian .

The case of cutting transport from the downhole to the surface

$$\rho_{2p} = \rho_L (1-\alpha) + \rho_G \alpha$$

$$\mu_{2p} = \alpha \mu_G + (1-\alpha)\mu_L$$

$$\mu_{2p} = K_{2p} (du/dy)^{(n-1)}$$

K_{2p} is the consistency index of the mixture

n is the index behavior

$K_s = K(1+2.5c_s)$

TWO PHASE SOLID-IN-LIQUID

$$\mathrm{Re}_{2p} = \frac{8\rho_{2p} U_{2p}^{(2-n)} D_h^{\,n}}{K_{2p}} \left(\frac{6n+2}{n} \right)^{-n}$$

$$\rho_{2p} = \rho_L (1-\alpha) + \rho_G \alpha$$

$$K_{2p} = K(1+2.5\alpha)$$

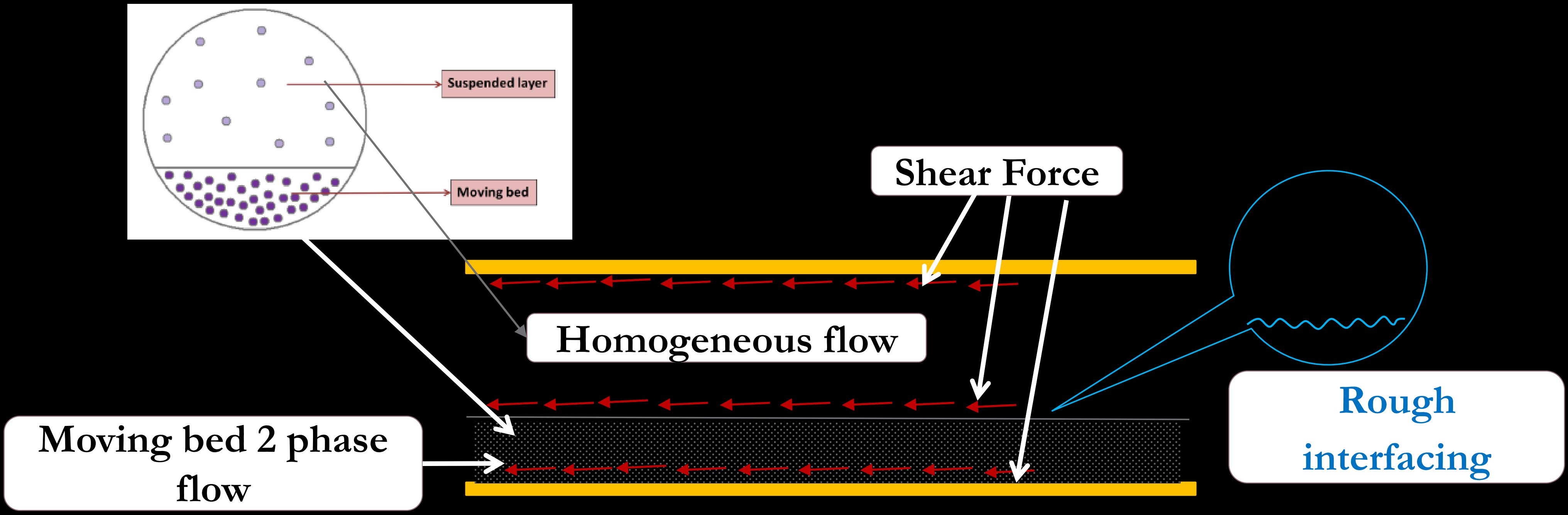
$$\lambda = 1.151^{\frac{1}{n}} \left(\frac{0.707}{n} + 2.12 \right) - \frac{4.015}{n} - 1.057$$

$$\frac{1}{\sqrt{f}} = -2\log\left(\frac{10^{-\lambda/2}}{\mathrm{Re}_{2p} f^{(2-n)/2n}} + \frac{d_p}{3.71 D_h} \right)$$

Diameter of particle

TWO PHASE, TWO LAYERS SOLID-IN-LIQUID

4. 2 layer, 2 phase solid-in-liquid flow



TWO PHASE, TWO LAYERS SOLID-IN-LIQUID

Sand settling in horizontal pipelines produced stationary sand deposit which creates a pressure drop and affects the rate of production.

Formation of sand bed inside the pipeline during the shutdown process creates many engineering challenges particularly during the restart-up process.

Transportation of the cutting particles in horizontal well drilling

TWO PHASE, TWO LAYERS SOLID-IN-LIQUID

The Pseudo Hydrostatic Pressure concept

- Based on the pseudo hydrostatic pressure concept, the hydrostatic pressure distribution along the moving bed wall can be defined as:

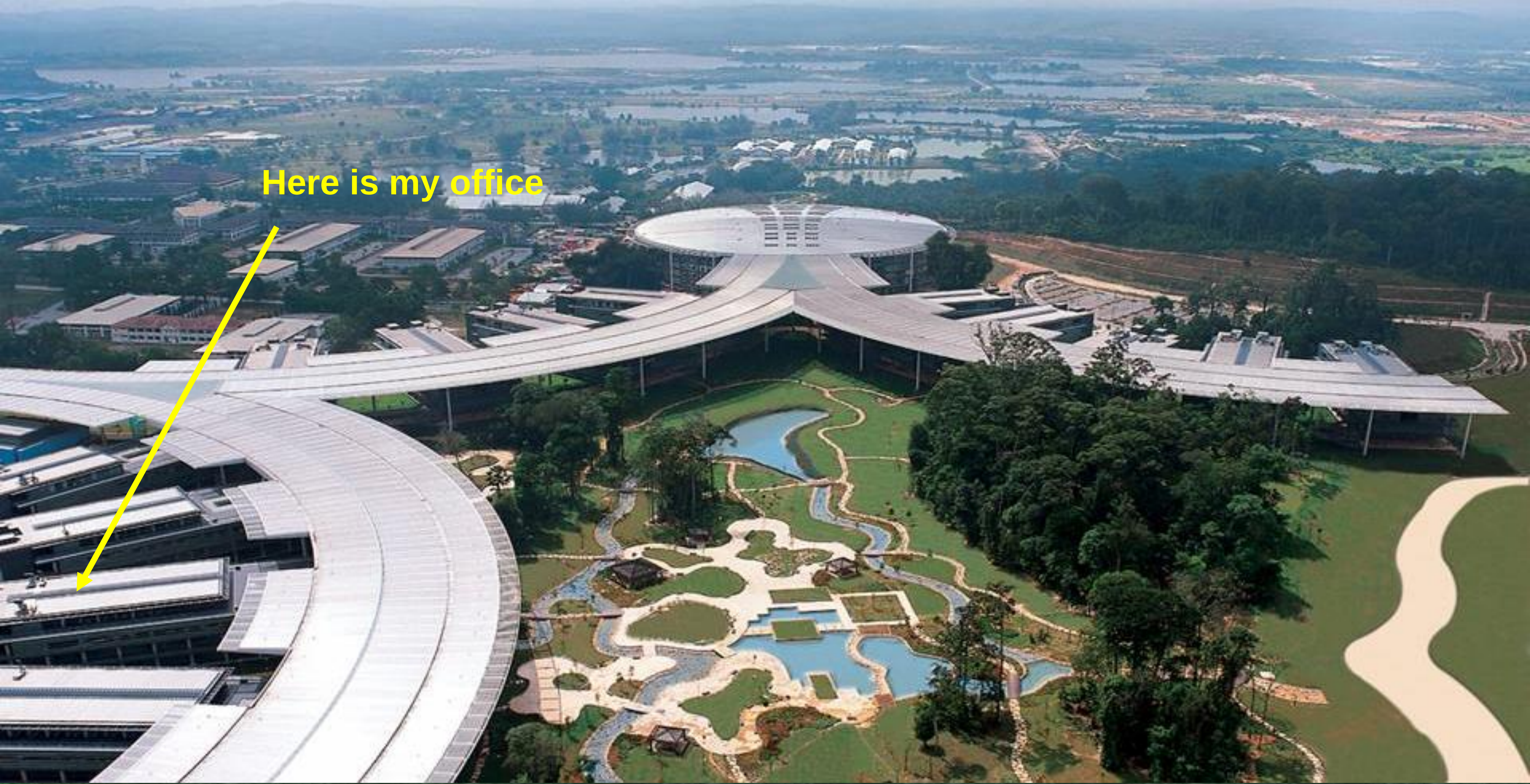
$$p_{pseudo} = \int_0^{t_m} \left(\rho_p c_m + \rho_f (1 - c_m)\right) g\,dt$$

TWO PHASE, TWO LAYERS SOLID-IN-LIQUID

Proposal for

experimental investigation on the dry friction factor between suspended and moving bed

$$F_d = \mu_d \left[\rho_p \left(\frac{\left(c_{m,\max} + c_s\right)}{2} \right) + \rho_f \left(1 - \frac{\left(c_{m,\max} + c_s\right)}{2} \right) \right] g t_m S_{mw}$$



THANK YOU

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TWO PHASE, TWO LAYERS SOLID-IN-LIQUID

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$$F_d = \mu_d \left[\rho_p \left(\frac{\left(c_{m,\max} + c_s\right)}{2} \right) + \rho_f \left(1 - \frac{\left(c_{m,\max} + c_s\right)}{2} \right) \right] g t_m S_{mw}$$

http://www.youtube.com/watch?v=a3anE3PEPP8