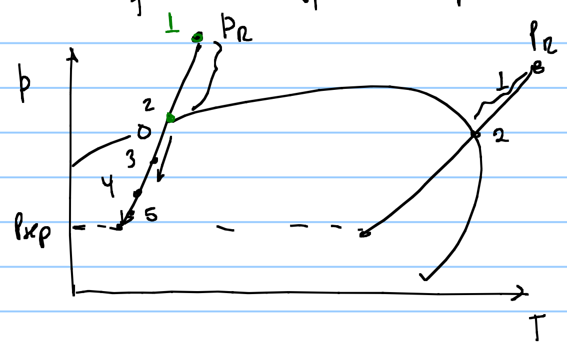
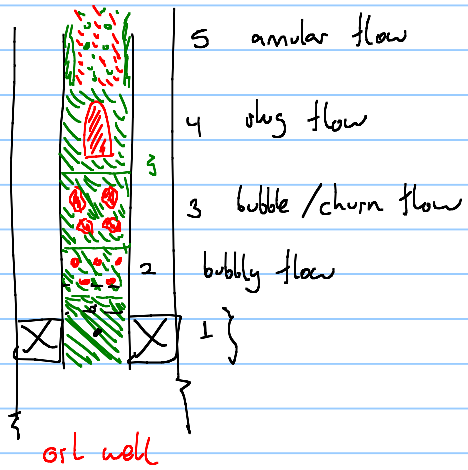
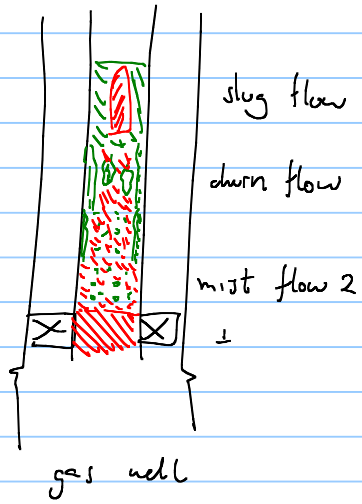
20180403 4 exercise sets.

flow equilibrium (pressure drop) calculations with multiphase flow







if you are interested on multiphase flow → TEP4250 Ole Jørgen Hydal

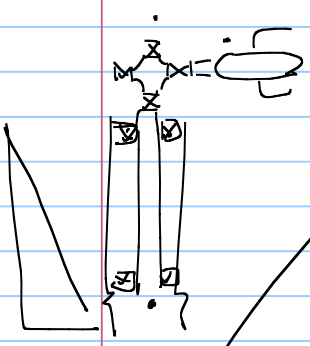
purpose: Δp along a condit (well, tubing, pipeline, flow line, etc.)

due to the variation in flow pattern, I have to perform this calculation in a stepwise manner.

Steps

1: Depart from a point with known p, T.

2: assume a rate ($q_{\bar o}$, $q_{\bar g}$), GOR, wc → $q_{\bar g}$, $q_{\bar w}$

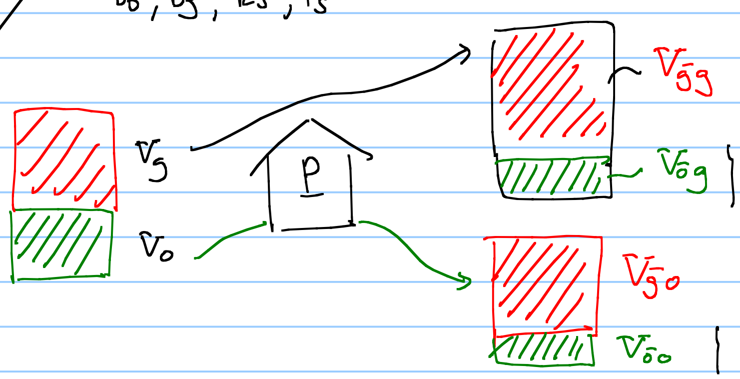


3: Calculate local rates / fluid properties

↓

BO properties

B_o, B_g, R_s, r_s



$$B_o = \frac{V_o}{V_{\bar o o}}$$

$$B_g = \frac{V_g}{V_{\bar g g}}$$

$$R_s = \frac{V_{\bar g o}}{V_{\bar o o}}$$

$$r_s = \frac{V_{\bar o g}}{V_{\bar g g}}$$

$\mu_o(p,T)$

$\mu_g(p,T)$

$\sigma_{og}(p,T)$

$\sigma_{ow}(p,T)$

$\sigma_{wg}(p,T)$

$$\begin{bmatrix} q_g \\ q_o \\ q_w \end{bmatrix}_{p,T} = \begin{bmatrix} \frac{B_g}{1-R_s \cdot r_s} & \frac{-B_g R_s}{1-R_s \cdot r_s} & 0 \\ \frac{-B_o r_s}{1-R_s r_s} & \frac{B_o}{1-R_s \cdot r_s} & 0 \\ 0 & 0 & B_w \end{bmatrix}_{@p,T} \cdot \begin{bmatrix} q_{\bar g} \\ q_{\bar o} \\ q_{\bar w} \end{bmatrix}$$

Bo properties come from:

- measured data (lab)
- BO correlations
- generate from EOS

EOS

calculate $\dot{m}_T$ $\dot{m}_T = q_{\bar{o}} \rho_{\bar{o}} + q_{\bar{g}} \cdot \rho_{\bar{g}} + q_{\bar{w}} \cdot \rho_{\bar{w}}$

need composition z_i C_1, C_2, C_3, CO_2, ⋮

perform a flash calculation @ P, T

↳ $\rho_g, \rho_o, \rho_w, \mu_g, \mu_o, \sigma_{og}, \sigma_{ow}, \sigma_{wg}$

↳ X_g ~ mass fraction of gas $X_g = \frac{\dot{m}_g}{\dot{m}_g + \dot{m}_o}$

$\dot{m}_g$

$\dot{m}_o$

$q_g = \frac{\dot{m}_g}{\rho_g}$ $q_o = \frac{\dot{m}_o}{\rho_o}$

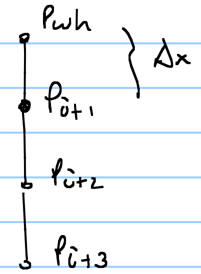
4: calculate $\frac{dP}{dx}$ at that position $\rho_o, \rho_g, \rho_w, \mu_g, \mu_o, \mu_w, \sigma_{og}, \sigma_{ow}, \sigma_{wg}, u_{sL}, u_{sg}, \phi, \theta, \varepsilon$

($u_{sL} \to \frac{q_o}{A}$, $u_{sg} \to \frac{q_g}{A}$, θ → pipe inclination, ε → roughness)

↳ correlation ✓
↳ mechanistic model
↳ homogeneous model
↳ drift flux model

$$\frac{dP}{dL} = \rho_m g + \frac{f}{\phi}\frac{v_m^2}{2g}$$

5: Integrate and find P_{i+1}



$\frac{dP}{dx}$ = constant

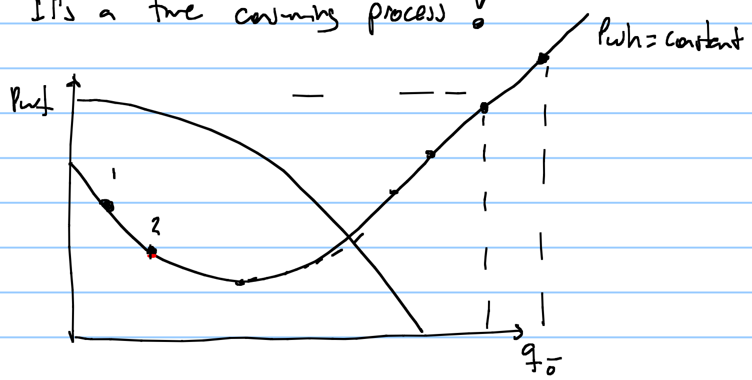
$P_{(x=0)} = P_{wh}$

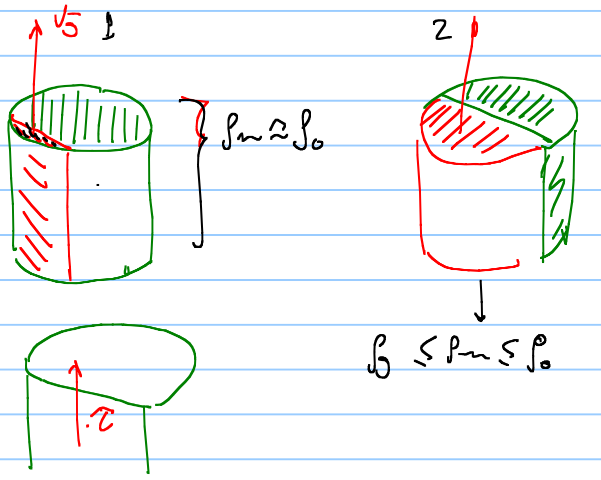
$P_{i+1} = ?$

$P_{i+1} = P_{wh} - \frac{dP}{dx}\Delta x$ EULER

or other implicit explicit methods

It's a true converging process!

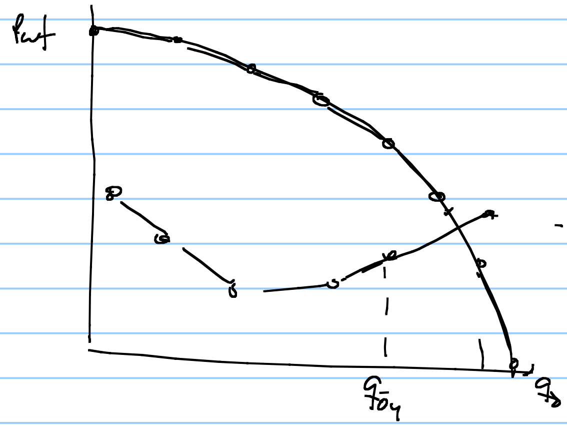




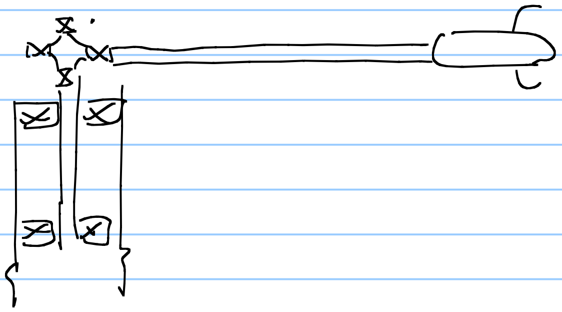
Pressure drop in multiphase flow is typically pre-computed and stored in "flow tables"

$P_{wh} = P_{wh1}$, $WC = WC_1$, $GOR = GOR_1$

q_o	P_{wf}	q_g	q_w	T_{wh}
q_{o1}	P_{wf1}			
q_{o2}	P_{wf2}			
q_{o3}	P_{wf3}			
q_{o4}	P_{wf4}			
q_{o4}	P_{wf5}			



there are some situations where P_{wh} is not known a priori



perform calculations for P_{wh1}, P_{wh2}, P_{wh3}

during the life of well WC will change, GOR also changes

↳ perform calculations for GOR_1 GOR_2, GOR_3, GOR_4
WC_1 WC_2, WC_3, WC_4 -

$P_{wh} = P_{wh1}$, $WC = WC_1$, $GOR = GOR_1$

q_o	P_{wf}	q_g	q_w	T_{wh}
q_{o1}	P_{wf1}			
q_{o2}	P_{wf2}			
q_{o3}	P_{wf3}			
q_{o4}	P_{wf4}			
q_{o4}	P_{wf5}			

$P_{wh} = P_{wh2}$, $WC = WC_1$, $GOR = GOR_1$

q_o	P_{wf}	q_g	q_w	T_{wh}
q_{o1}	P_{wf1}			
q_{o2}	P_{wf2}			
q_{o3}	P_{wf3}			
q_{o4}	P_{wf4}			
q_{o4}	P_{wf5}			

$P_{wh} = P_{wh3}$, $WC = WC_1$, $GOR = GOR_1$

q_o	P_{wf}	q_g	q_w	T_{wh}
q_{o1}	P_{wf1}			
q_{o2}	P_{wf2}			
q_{o3}	P_{wf3}			
q_{o4}	P_{wf4}			
q_{o4}	P_{wf5}			

$P_{wh} = P_{wh4}$, $WC = WC_1$, $GOR = GOR_1$

q_o	P_{wf}	q_g	q_w	T_{wh}
q_{o1}	P_{wf1}			
q_{o2}	P_{wf2}			
q_{o3}	P_{wf3}			
q_{o4}	P_{wf4}			
q_{o4}	P_{wf5}			

$P_{wh} = P_{wh1}$, $WC = WC_2$, $GOR > GOR_1$

q_o	P_{wf}	q_g	q_w	T_{wh}
q_{o1}	P_{wf1}			
q_{o2}	P_{wf2}			
q_{o3}	P_{wf3}			
q_{o4}	P_{wf4}			
q_{o4}	P_{wf5}			

$P_{wh} = P_{wh1}$, $WC = WC_3$, $GOR > GOR_1$

q_o	P_{wf}	q_g	q_w	T_{wh}
q_{o1}	P_{wf1}			
q_{o2}	P_{wf2}			
q_{o3}	P_{wf3}			
q_{o4}	P_{wf4}			
q_{o4}	P_{wf5}			

$P_{wh} = P_{wh1}$, $WC = WC_4$, $GOR > GOR_1$

q_o	P_{wf}	q_g	q_w	T_{wh}
q_{o1}	P_{wf1}			
q_{o2}	P_{wf2}			
q_{o3}	P_{wf3}			
q_{o4}	P_{wf4}			
q_{o4}	P_{wf5}			

$$N_{runs\ to\ make} = N_{rates} \cdot N_{P_{wh}} \cdot N_{GOR} \cdot N_{WCs} \approx 10^4$$

(5-10)

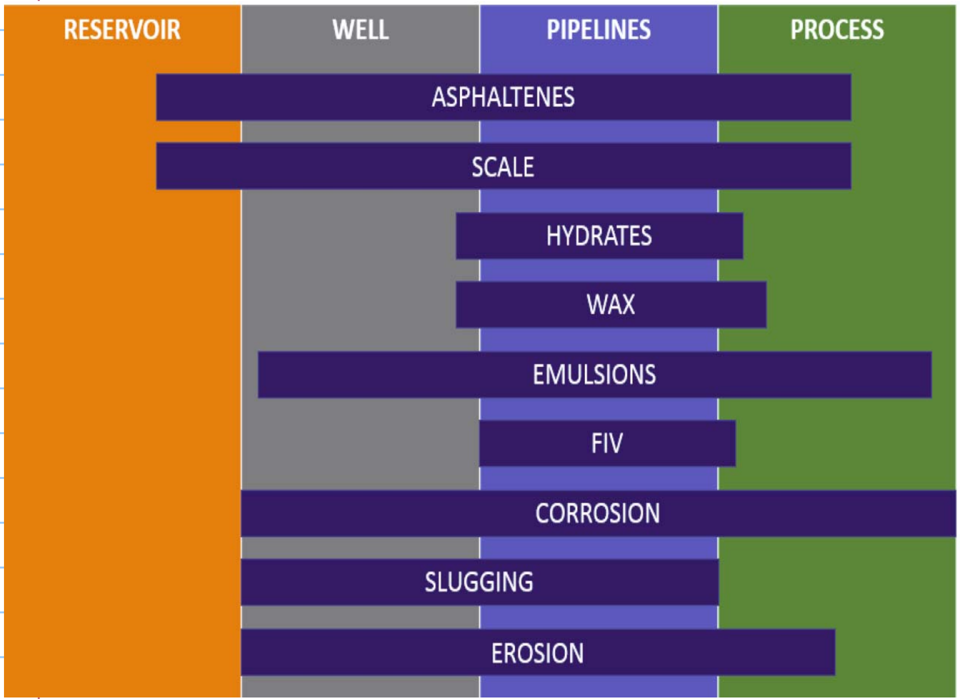
Flow assurance issues:

① Increased Δp, flow restriction, → blockage
② integrity problems
③ loss in functionality of components

flow assurance issue	consequence	corrective measures
wax	①	pigging, insulation, heat tracing ↓ pigging loop requirement chemical inhibitors ↳ chemical injection system
hydrate	①, ③	• inhibitor → chemical injection system • insulation • heat tracing
asphaltenes	①, ②	• chemical inhibitor, removal • mechanical removal
emulsion	①, ③*	• demulsifiers

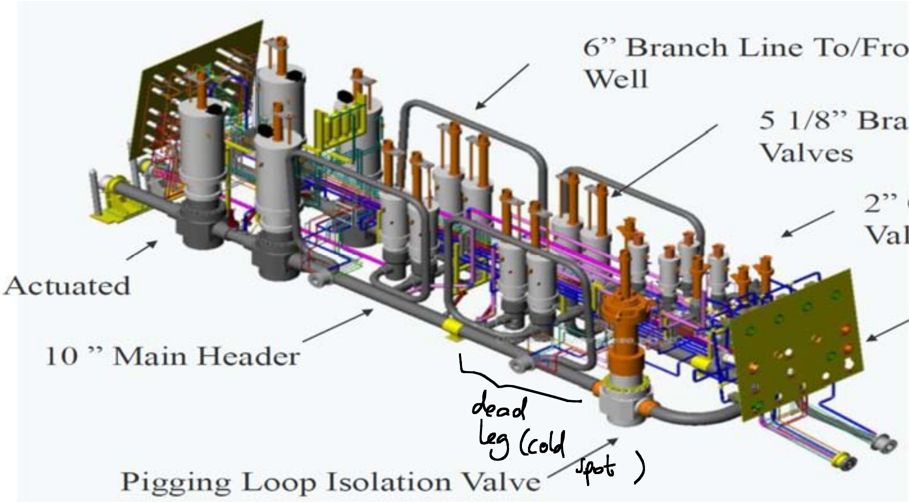
*topside separation

Scale	①, ③	scale inhibitor, remover mechanical removal
erosion	②, ③	• proper dimensioning of pipes / components • reduce rate
Corrosion	②, ③	• material selection • corrosion inhibitor
Slugging	①, ③, ②	• choke control • gas injection • dimensioning of pipes • use a slug catchers instead of separator,



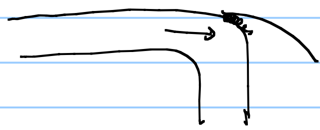
flow assurance considerations during field development:

- early studies: detect and flag possible show-stoppers { slugging, hydrate ←, wax
- FEED → • a specific development alternative is selected in detail study → hydrate management plan
  - ↳ wax " "
  - ↳ scale " "
  - ↳ prediction of T, p, velocities in production system → pipelines, flowlines, equipment, dead leg
- EPC



Engineering tools commonly used:

- multiphase flow simulator — p, T along pipe — gap, pipesim, hysys
- transient flow simulator — OLGA, ledaflow — slugging, shutin, startup
- PVT and lab test — Hydrate, wax, scale, emulsion, erosion
- CFD computational fluid dynamics



- FEA Finite element analysis — stresses
- standards

Tabell 5-2. Foreløpig oversikt over kjemikalietyper

Type kjemikalie	Konsentrasjon (ppm vol.)	Tilsettes i	Frekvens
Avleiringshemmer A	50	Produsert vann	Kontinuerlig
Avleiringshemmer B	20-50	Sjøvann	Kontinuerlig
Korrosjonshemmer	50	Produsert vann	Kontinuerlig
Emulsjonsbryter	50	Total væske 1)	Kontinuerlig ved behov
Skumdemper	5	Total væske	Periodisk
Flokkulant	10	Produsert vann	Kontinuerlig
Vokshemmer	150	Total væske 1)	Periodisk
Biocid	80	Total væske 1)	Kontinuerlig
Oksygenfjerner	5	Sjøvann	Kontinuerlig
H2S fjerner	150	Produsert vann	Kontinuerlig ved behov
MEG	Batch	Brønnstrøm	Ved behov

1) Olje og produsert vann.

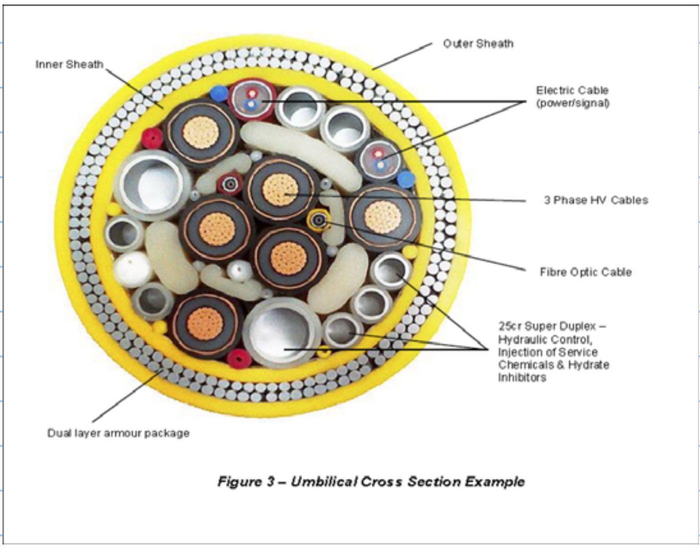
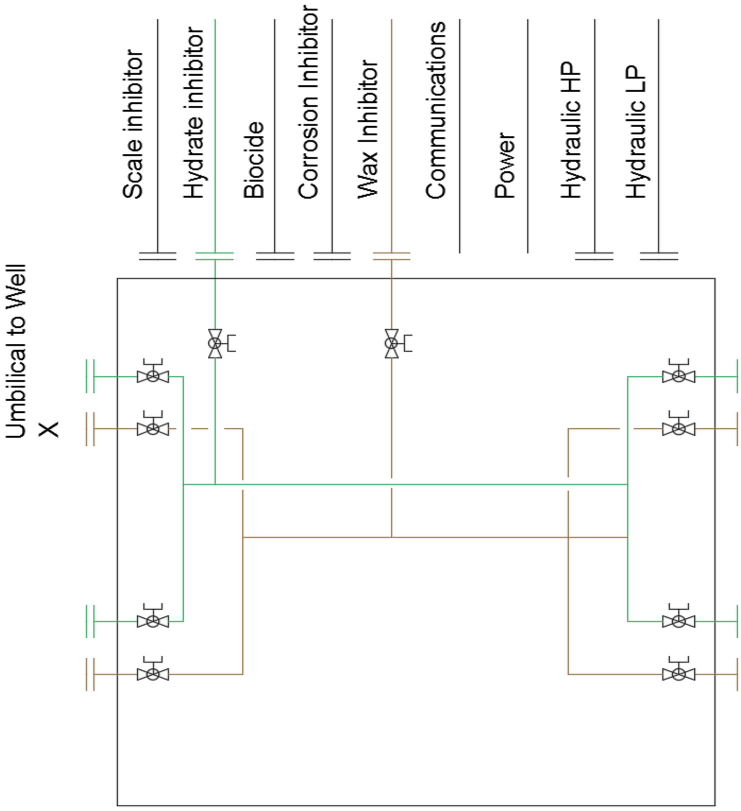
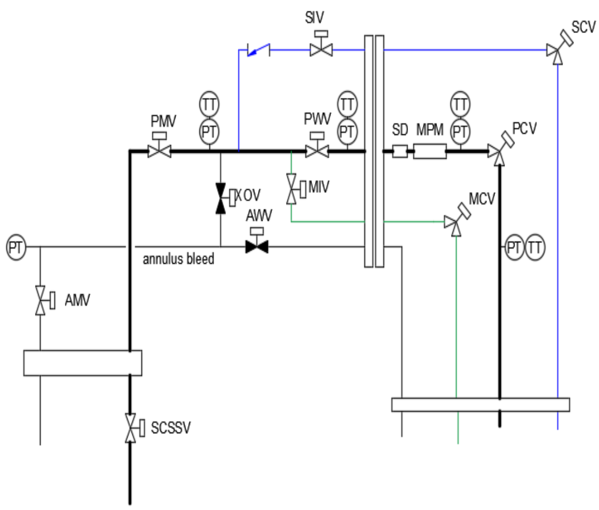


Figure 3 – Umbilical Cross Section Example





multi-bore connector.

Temperature calculations are performed based on energy conservation equation

$$\frac{dq}{dL} = \dot{m}\left[\frac{dh}{dL} + \sin\theta \cdot g + v\frac{dv}{dL}\right]$$

$h = f(T)$ if liquid $dh = C_p \cdot dT$

if gas $dh = C_p\, dT + \mu_T \cdot dP$

for liquid

$$\frac{dT}{dL} + T\cdot\frac{1}{A} - \frac{T_{amb}}{A\cdot} - \frac{\sin(\theta)\cdot g}{c_p} = 0$$

$$u\cdot\frac{dT}{dL} + u\cdot T\cdot\frac{1}{A} = u\cdot\left(\frac{T_{amb}}{A} + \frac{\sin(\theta)\cdot g}{c_p}\right)$$

$$u = e^{\frac{x}{A}}$$

$$e^{\frac{x}{A}}\cdot\frac{dT}{dL} + e^{\frac{x}{A}}\cdot T\cdot\frac{1}{A} = e^{\frac{x}{A}}\cdot\left(\frac{T_{amb}}{A} + \frac{\sin(\theta)\cdot g}{c_p}\right)$$

$$\frac{d\left(e^{\frac{x}{A}}\cdot T\right)}{dL} = e^{\frac{x}{A}}\cdot\left(\frac{T_{amb}}{A} + \frac{\sin(\theta)\cdot g}{c_p}\right)$$

$$e^{\frac{x}{A}}\cdot T\Big|_{T_0}^{T(x)} = \left(\frac{T_{amb}}{A} + \frac{\sin(\theta)\cdot g}{c_p}\right)\cdot A\cdot e^{\frac{x}{A}}\Big|_0^x$$

$$e^{\frac{x}{A}}\cdot T(x) - T_0 = \left(\frac{T_{amb}}{A} + \frac{\sin(\theta)\cdot g}{c_p}\right)\cdot A\cdot\left(e^{\frac{x}{A}} - 1\right)$$

$$T(x) = T_0\cdot e^{\frac{-x}{A}} + \left(\frac{T_{amb}}{A} + \frac{\sin(\theta)\cdot g}{c_p}\right)\cdot A\cdot\left(1 - e^{\frac{-x}{A}}\right)$$

Incompressible fluid

$dh = C_p\, dT$

$$A = \frac{\dot{m}\, C_p}{2\pi r_{out}\cdot U}$$