

Complete Subsea oil-water Separation

26th Nordic Process Control Workshop 2026

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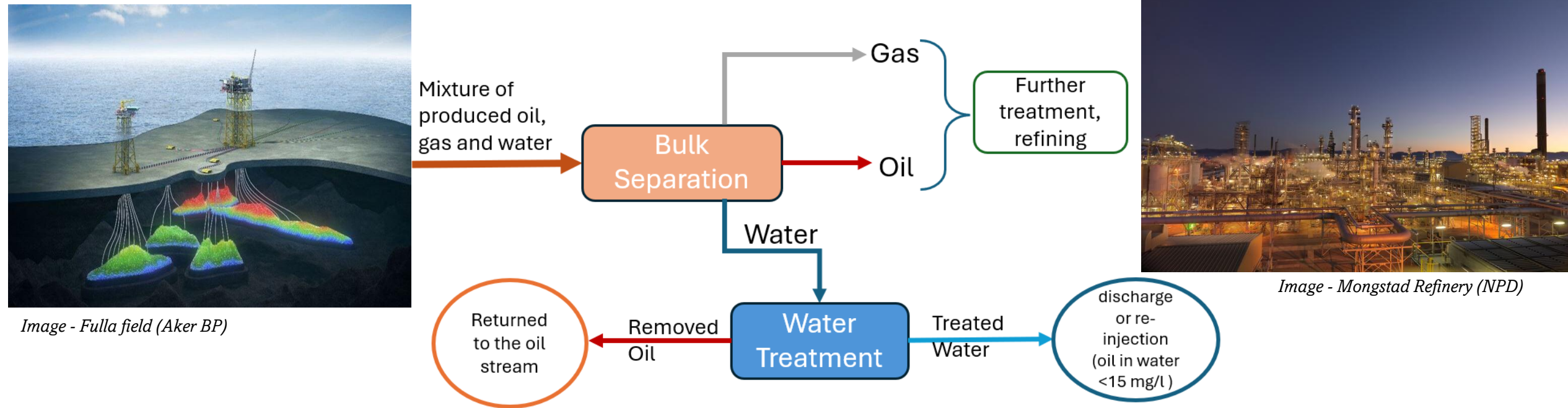
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Introduction



- **Produced water** – all water produced with oil and gas
- Increases with increasing field maturity

- Separation process can be done either on the **seabed** or on a **platform**

Motivation

Perform Complete subsea oil water separation in order to:

- Reduce the transportation of produced water to topside
- Meet injection and discharge requirements of oil concentration in water (<15 mg/l as weighted annual average)

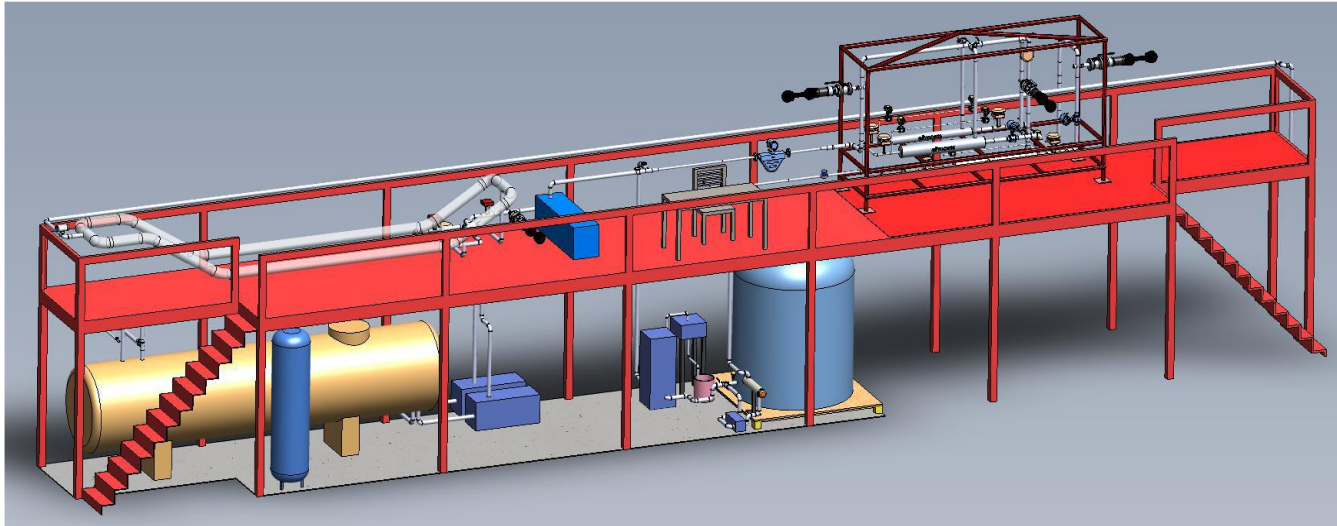
Why this poses as a challenge

- Harsh subsea environments require high pressure vessels
- Remote environments require compact vessels to ease installation process and costs
- Compact vessels reduce the residence time required for separation hence we need better control systems to make the process effective
- Measurement of the concentration of oil in water before release

Objectives

- Create control oriented models of the system to study the effects of control systems architecture
- Compare simulation results with the laboratory experimental results

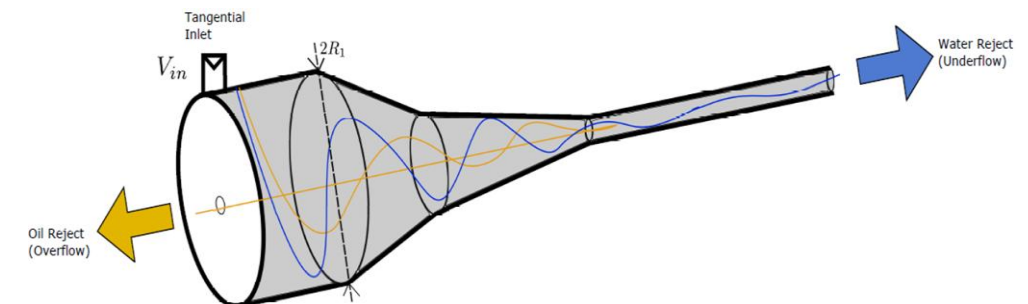
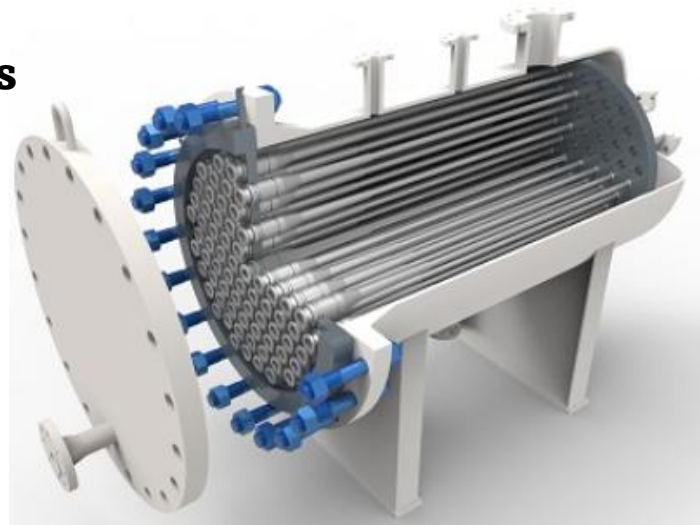
Facility – Main process equipment



- **Multiple Parallel Pipe separator (MPPS)**
– for oil water bulk separation

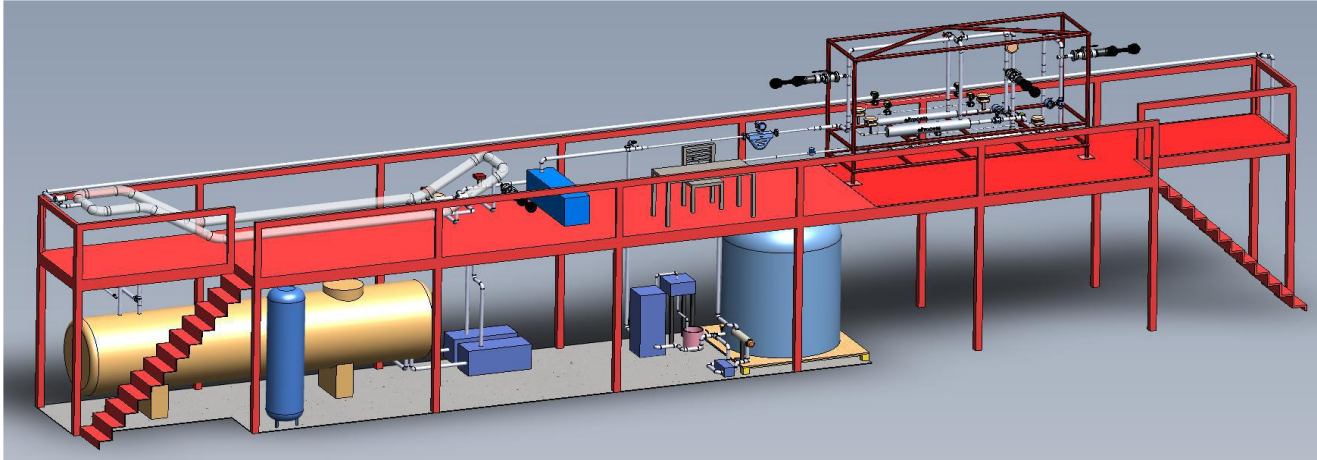


- **De-oiling hydrocyclones**
– for produced water treatment



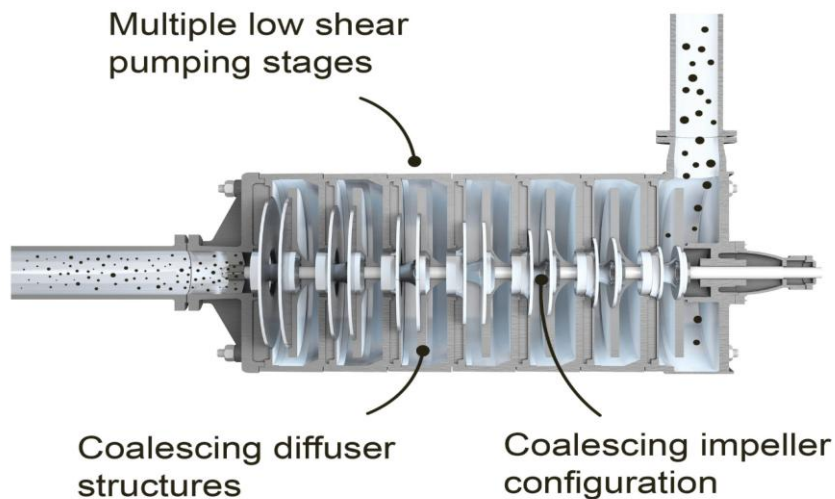
- There are 3 hydrocyclones (HC-1 has 2 liners and HC-2 and HC-3 have 1 liner each)

Facility – Main process equipment



Facility – Special features

- **Low shear coalescing pump** –between the MPPS and the de-oiling hydrocyclones
- Improving the separation efficiency by increasing the size of the droplets

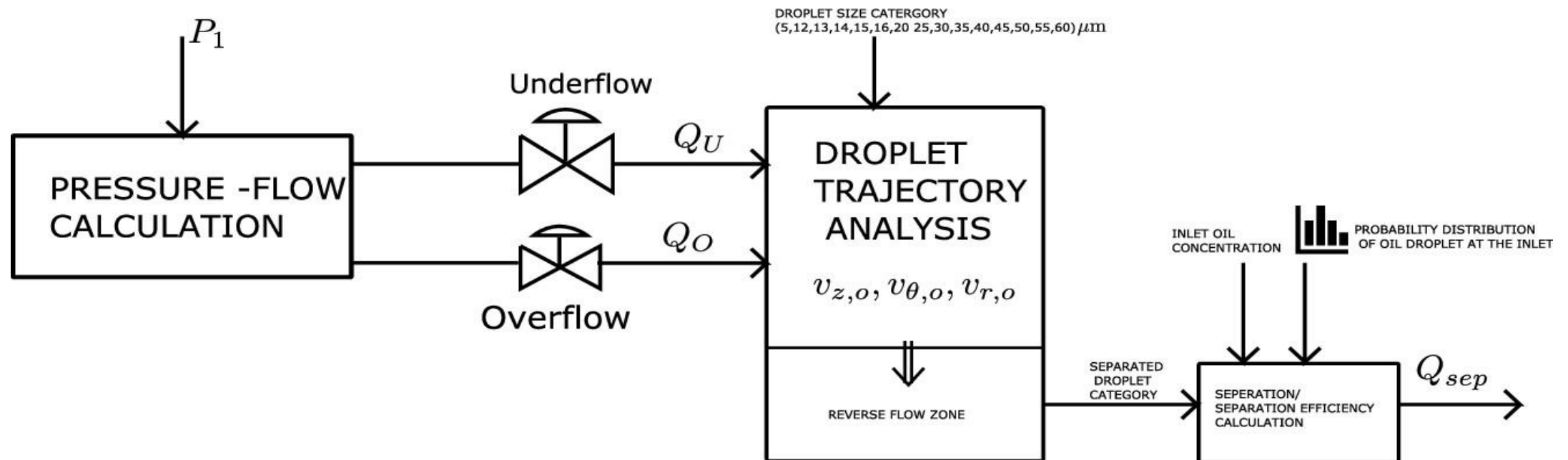


- **Online Oil in water analyzer** – uses ultrasound to measure the concentration of oil in water and the oil droplet distribution



Modeling – Deoiling hydrocyclone

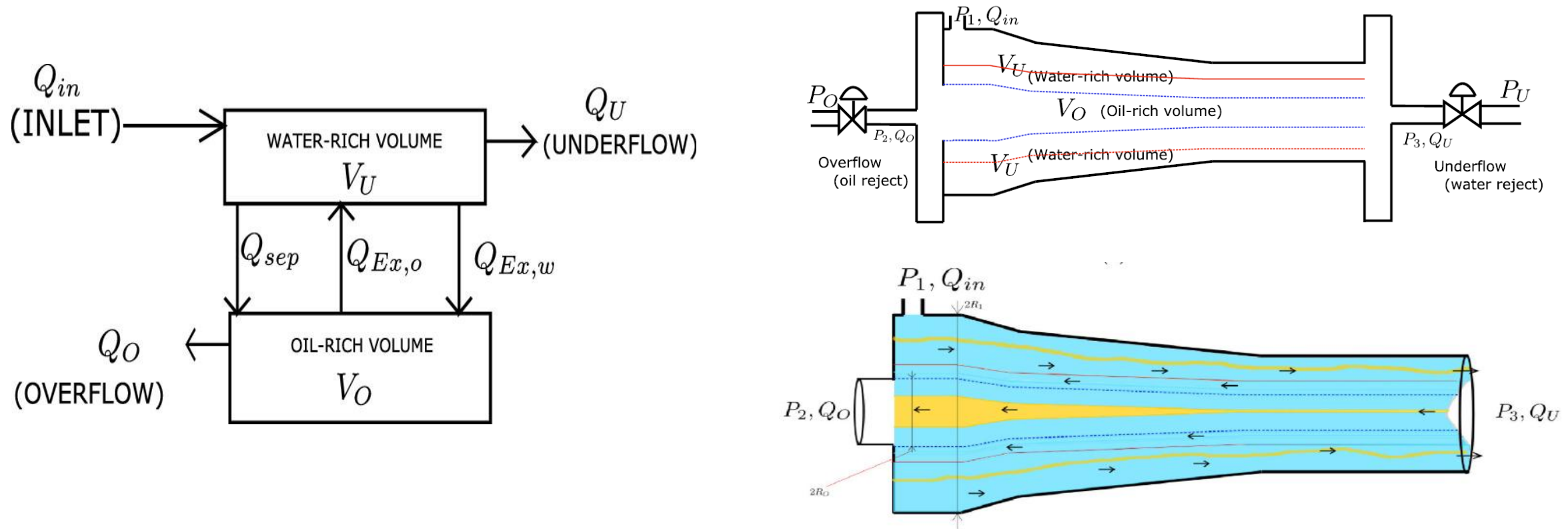
- Pressure-Flow relationship
 - Bernoulli's and valve equation
- Separation efficiency
 - Oil droplet trajectory analysis
 - Modeling of internal separation



(Vallabhan, Holden & Skogestad, 2020)

Modeling – Deoiling hydrocyclone

- Dynamic Mass-Balance Model – dividing the hydrocyclone into two main control volumes

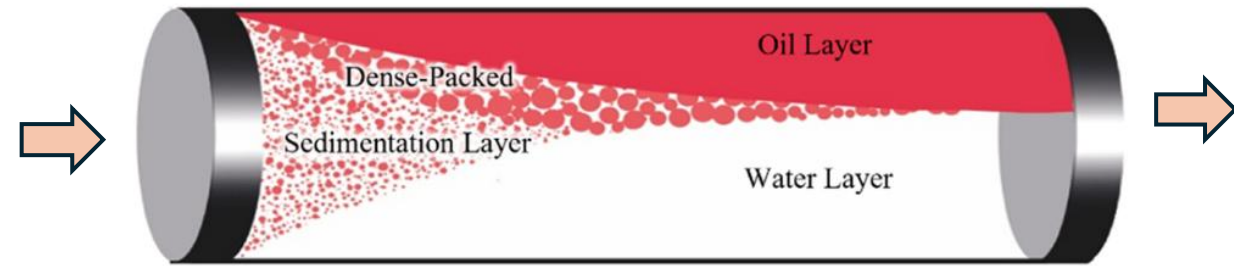


(Vallabhan, Holden & Skogestad, 2020)

Pipe separator modeling

The separation is dominated by

- Gravity
- Droplet-droplet coalescence
- Droplet-interface coalescence



Separation process of oil-water flow in a pipe [2]

- Stokes law

$$V_s = \frac{(\rho_D - \rho_C)gd^2}{18 \mu_C}$$



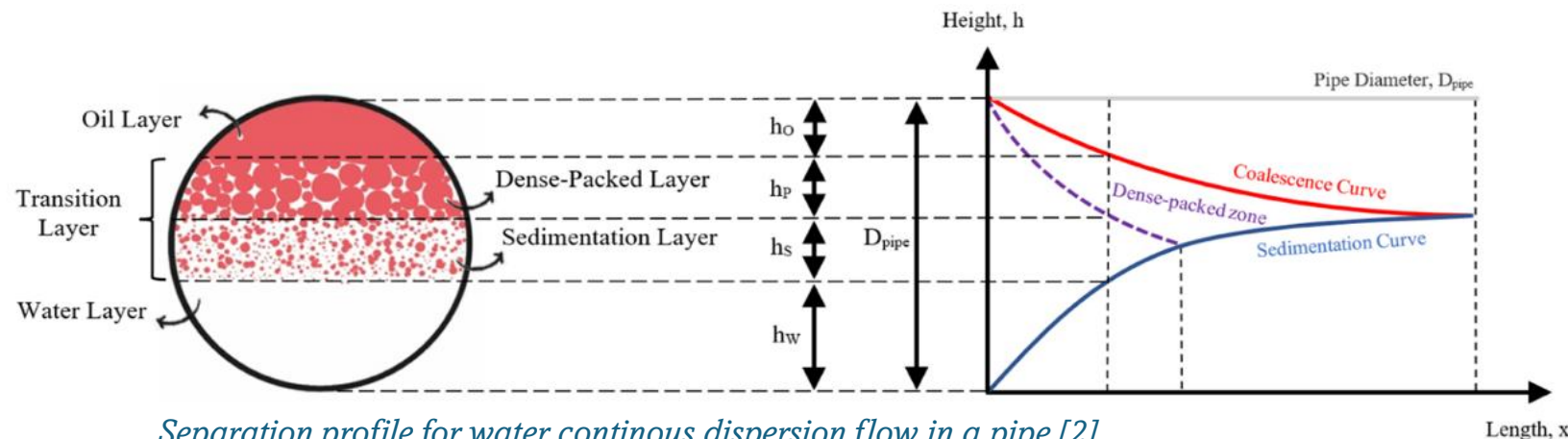
- Residence time

$$t_{res} = L_{eff} / (\dot{Q}_w / A_c)$$



- Critical droplet diameter

$$d_c = \sqrt{\frac{18 \mu_C (h_s - h_i)}{\Delta \rho g t_{res}}}$$



Separation profile for water continuous dispersion flow in a pipe [2]

Modeling – MPPTS

- **Considering three layers**

- Clean water layer
- Clean oil layer
- Emulsion layer

- **Governing PDEs**

- Water

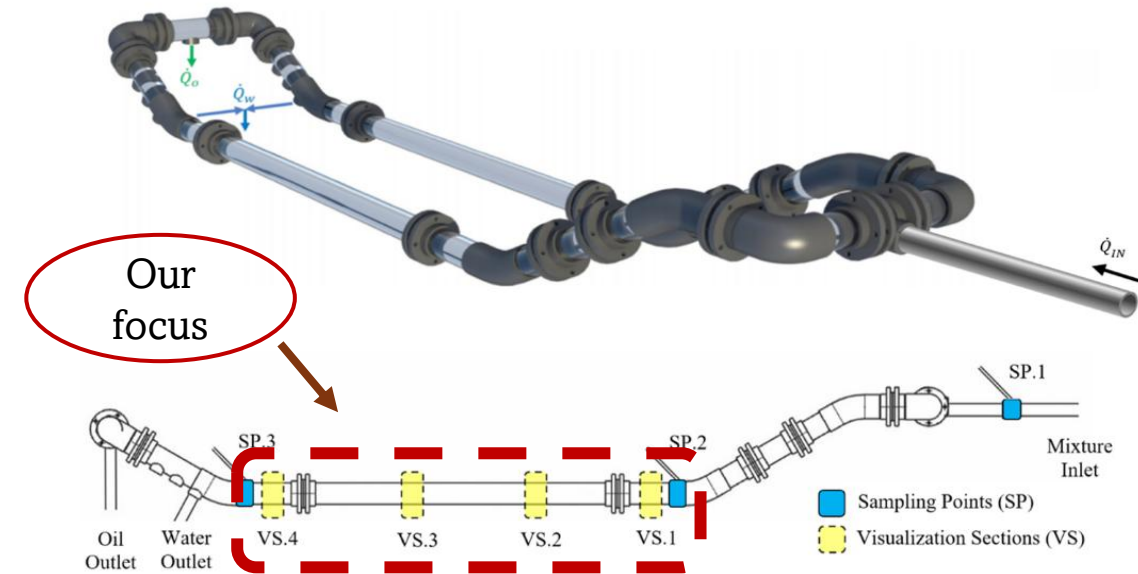
$$\frac{\partial h_w}{\partial t} + \frac{\partial q_w}{\partial x} = R_w$$

- Oil

$$\frac{\partial h_o}{\partial t} + \frac{\partial q_o}{\partial x} = R_o$$

- Emulsion

$$\frac{\partial h_e}{\partial t} + \frac{\partial q_e}{\partial x} = R_e$$



Where,

R – growth term

h – height of the layer

q – flow rate

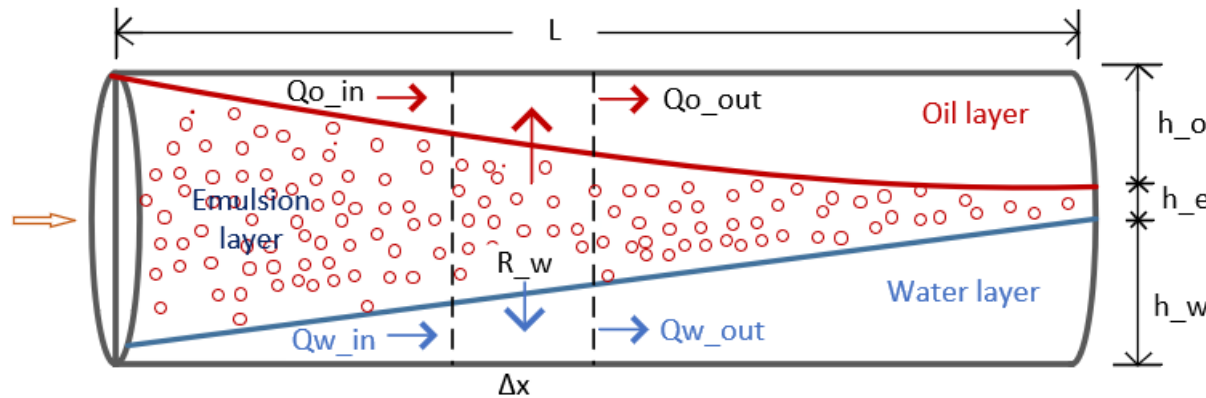
Subscripts:

o – oil

w – water

e – emulsion

Modeling – MPPS



- Conservation equations

For $i = 1:N$

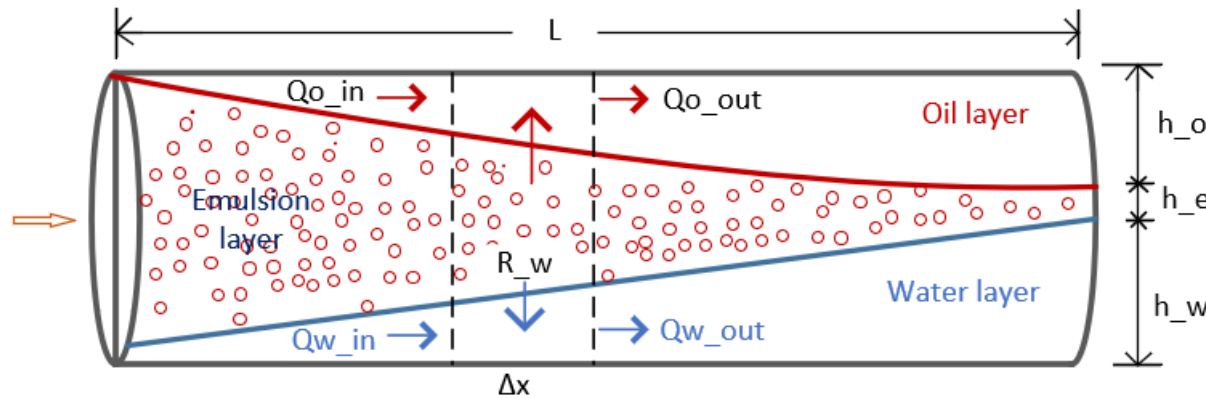
$$\frac{dh_{oi}}{dt} = \frac{Qo_{in_i} - Qo_{out_i}}{\Delta x} + R_{oi}$$

$$\frac{dh_{wi}}{dt} = \frac{Qw_{in_i} - Qw_{out_i}}{\Delta x} + R_{wi}$$

$$\frac{dh_{ei}}{dt} = \frac{Qe_{in_i} - Qe_{out_i}}{\Delta x} - R_{oi} - R_{wi}$$

- Spatial discretization, $N = L/\Delta x$

Modeling – MPPTS



- Conservation equations

For $i = 1:N$

$$\frac{dh_{oi}}{dt} = \frac{Qo_{in_i} - Qo_{out_i}}{\Delta x} + R_{oi} \quad (1)$$

$$\frac{dh_{wi}}{dt} = \frac{Qw_{in_i} - Qw_{out_i}}{\Delta x} + R_{wi} \quad (2)$$

$$h_{ei} = \max(H - h_{wi} - h_{oi}, 0) \quad (3)$$

- Spatial discretization, $N = L/\Delta x$

Modeling – MPPS

- Volumetric flux

$$q = u * h$$

- Assumptions:

- S = oil water slip ratio

- $u_e = u_w$

- $u_o = Su_w$

- Uniform droplet size

- K_w and k_o are tuning parameters

Water separation/source term

- Assume the layer is growing through sedimentation
- Sedimentation velocity, v_s (Pilhofer and Mewes 1979)

$$R_w = k_w \times v_s$$

Oil separation term

- The layer is growing through coalescence of oil droplets

$$R_o = k_o \frac{2}{3} \frac{d}{t_{coal}} A_{base}$$

Limiting factor

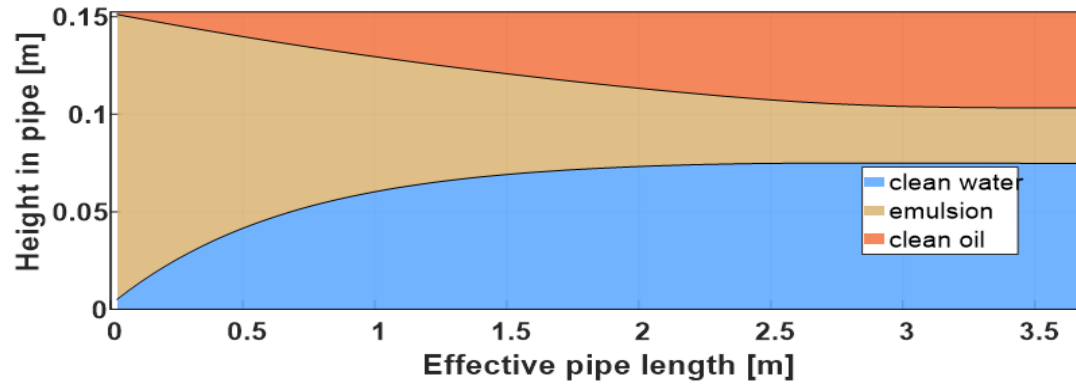
$$L = 1 - \frac{h}{h_{\infty}}$$

$$h_{w,\infty} = WC_{in} * H$$

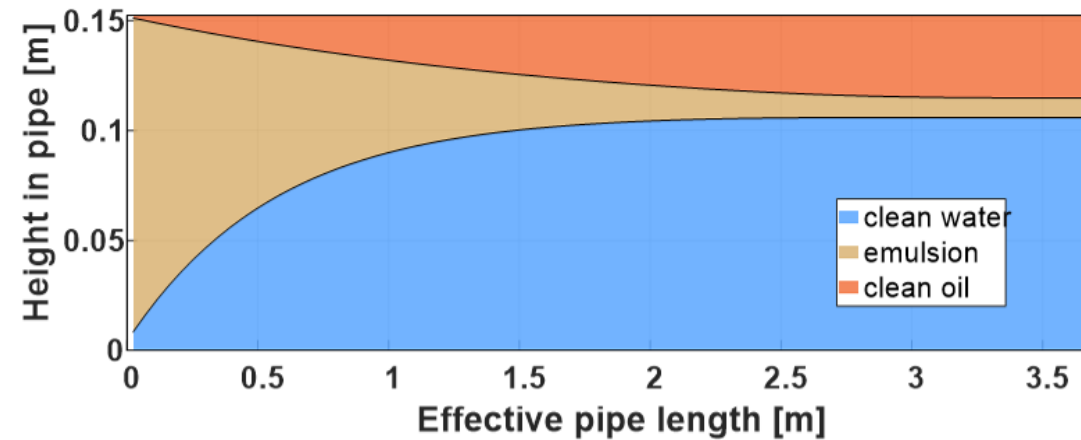
$$h_{o,\infty} = (1 - WC_{in}) * H$$

Results

Model results

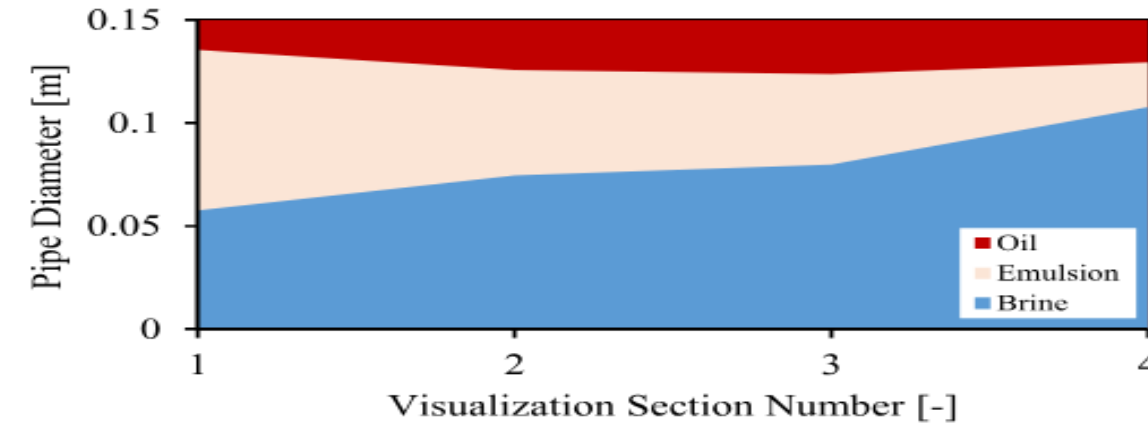
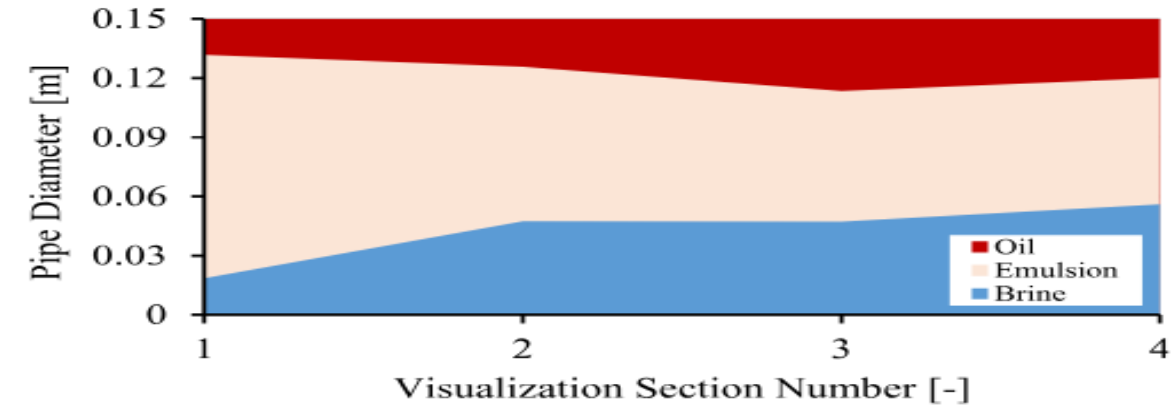


WC = 0.5



WC = 0.7

Experimental results [2]



Conclusion

- Fairly correct behavior of the separation on the MPPS is predicted
- Further improvement is needed
- Control studies on the MPPS and the combined system

References

1. KG, M. V., Holden, C., & Skogestad, S. (2020). A first-principles approach for control-oriented modeling of de-oiling hydrocyclones. *Industrial & Engineering Chemistry Research*, 59(42), 18937-18950
2. Asaadian, H., & Stanko, M. (2024). Design methodology for multi-parallel pipe separator (MPPS). *Chemical Engineering Research and Design*, 208, 141-160

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