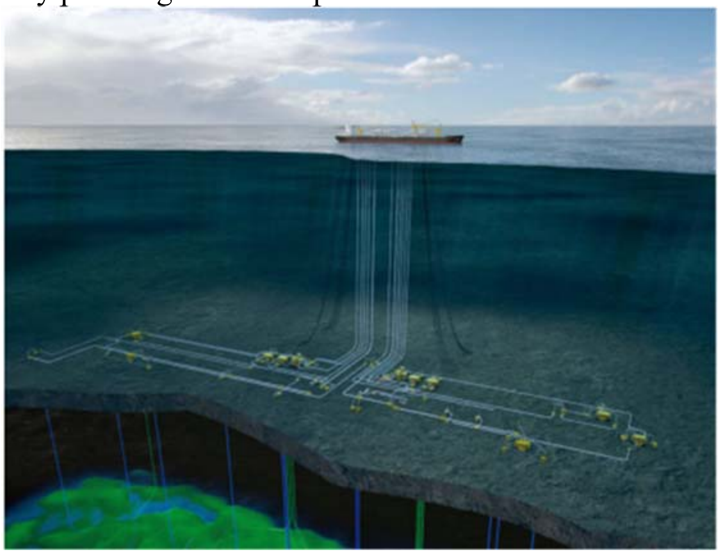
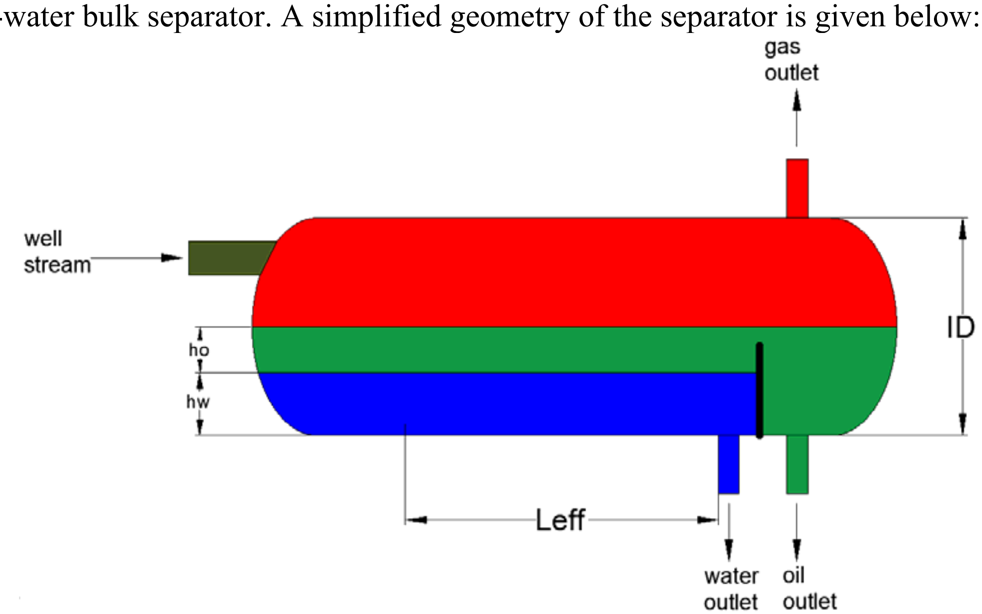
Problem 1: Verification of the separation capacity of the three-phase horizontal separator on an FPSO

Aker Energy is currently planning the development of the Pecan field offshore Ghana[1].



Aker Energy has requested the company Yinson Holdings Berhad to provide the FPSO (Floating, production, offloading and storage vessel). To reduce costs, Yinson has proposed to "redeploy" an FPSO that was previously used in another field in the region. However, FPSOs are usually tailored for the specific oil and gas characteristics and production profiles expected from the field, and weather conditions, water depth, so it is unclear if it will work for the Pecan field.

You are part of the field development engineering team in Aker Energy. Your tasks are to evaluate the feasibility of using the FPSO suggested by Yinson. Specifically, you will perform a simple verification if the first stage separator that is currently on deck will work. The separator is a gas-oil-water bulk separator. A simplified geometry of the separator is given below:



[1] https://www.dieselgasturbine.com/7010387.article

- The internal diameter of the separator is ID is 3 m

During normal operations:

- The separator is half full of liquid
- The oil height (h_o) is 0.75 m
- The water height (h_w) is 0.75 m
- The length where the main separation takes place (L_{eff}) is 5 m.

Part 1:

The production profile projected for the field is given in the Excel file attached. Determine if the separator will be able to provide adequate separation considering the following data:

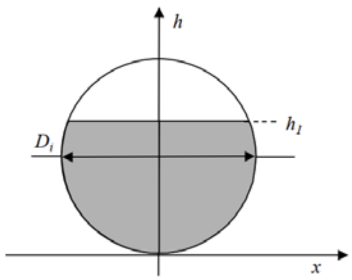
- Settling velocity of an oil droplet in the gas layer ($t_{s,OiG}$): 1.6 E-1 m/s
- Settling velocity of a water droplet in the gas layer ($t_{s,WiG}$): 1.84 E-1 m/s
- Settling velocity of a water droplet in the oil layer ($t_{s,WiO}$): 1.5 E-2 m/s
- Settling velocity of an oil droplet in the water layer ($t_{s,OiW}$): 3.7 E-3 m/s

Some additional parameters:

- Oil density at separator conditions: 875 kg/m3
- Water density at separator conditions: 1068 kg/m3
- Gas specific gravity Sg = 0.7
- Oil volume factor B_o at separator conditions= 1.2
- Dry gas volume factor B_{gd} at separator conditions = use the Excel sheet attached. The VBA function to use is “Bg”.[2] However, you will need to calculate the Z factor before. This is done using the VBA function “ZfacStanding”.
- Separator pressure = 50 bara
- Separator temperature = 60 °C
- How to calculate the shaded area[3] (This equation is programmed in Excel using VBA, name “Aw”):

[2] VBA functions in Excel are invoked either by 1) typing on a cell the sign “equal” followed by the name of the function and open parenthesis or by 2) pressing the icon fx, select the menu “user defined functions”, and select your function. To know which user defined functions are available in the Excel sheet, click Alt+F11 to open the VBA module. On the tree to the left click on “Microsoft Excel Objects” and “Modules”

[3] Taken from Grødal, E., Realff, M. Optimal design of two- and Three-Phase Separators: A Mathematical Programming Formulation. SPE56645.



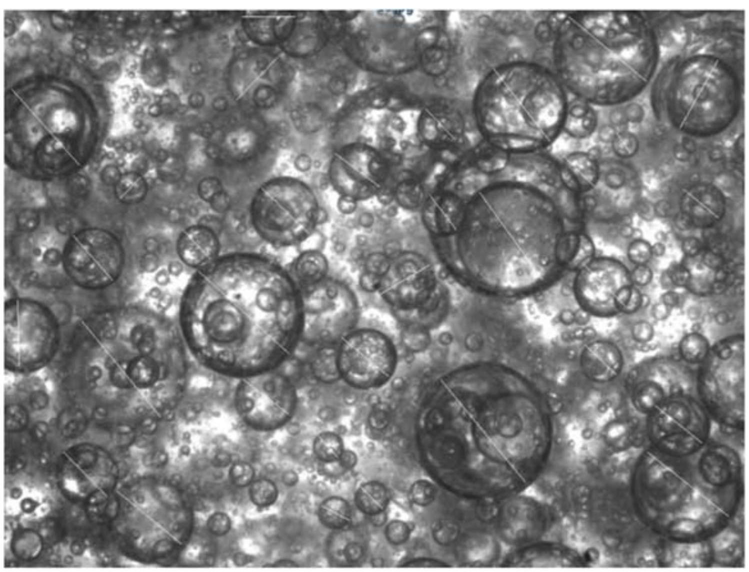
$$A = \left(h_1 - \frac{D_i}{2}\right)\sqrt{D_i h_1 - h_1^2} + \frac{D_i^{\,2}}{4}\sin^{-1}\left(\frac{2h_1}{D_i} - 1\right) + \frac{\pi D_i^{\,2}}{8}$$

Part 2:

The settling velocities provided in part 1 were determined using the following average diameters given by the experts in the company and based on a similar project:

- Diameter of an oil droplet in the gas layer ($d_{p,OiG}$): 100 E-6 m (µm)
- Diameter of a water droplet in the gas layer ($d_{p,WiG}$): 100 E-6 m
- Diameter of oil droplet in the water layer ($d_{p,OiW}$): 200 E-6 m
- Diameter of water droplet in oil layer ($d_{p,WiO}$): 500 E-6 m

Your team has ordered some laboratory tests where they have mixed vigorously oil and water in a bottle and have taken pictures of the resulting dispersion of oil in water using a PVM[4]. The intention of the mixing was to emulate the shear stress that the mixture will encounter when flowing from wellhead to platform and when it enters the first stage separator.
The photos show droplets of oil in a matrix of water.



[4] https://www.mt.com/my/en/home/phased_out_products/L1_AutochemProducts/FBRM-PVM-Particle-System-Characterization/PVM/ParticleView-V19-PVM-Technology.html

To verify the value assumed earlier for the diameter of oil droplets in the water layer ($d_{p,OiW}$) by the expert, you are requested to count[5] the droplets on this photo and perform a frequency analysis[6] (count how many droplets there are of each size). Plot the frequency of each droplet size versus droplet size (using a bar plot) and the cumulative frequency of each droplet size versus droplet size (using a scatter line plot).

Using these results answer the following questions:

- Was the number assumed earlier of 200 µm appropriate?
- What percentage of the droplets will be separated if one sizes the separator using a diameter of 200 µm?
- What volume percent of the total oil present in "droplet form" will be separated if one sizes the separator with 200 µm?[7]

Useful information:

- Use the Excel sheet provided
- The volume of a sphere is $V = \frac{\pi d^3}{6}$

[5] To determine the droplet diameter, use the online tool: https://ij.imjoy.io/. Upload the photo and use the "line" tool. The tool gives you dimensions in pixels. Convert from pixels to µm using a factor of 3.5 µm/pixel. Count at least 50 droplets. Use the Excel sheet provided.

[6] https://www.howtogeek.com/398655/how-to-use-the-frequency-function-in-excel/

[7] For this question you have to do the frequency analysis using volume of oil in droplet of size "x" and NOT droplet count.