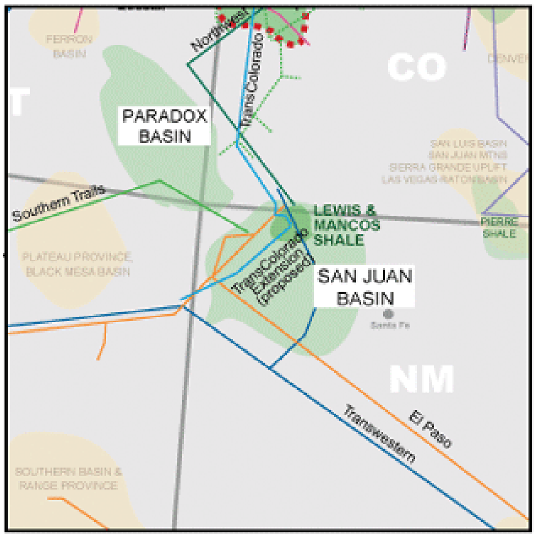
Exercise set 03

PROBLEM 1: Model-based production allocation on a multi-layer gas well using network solving

You have been asked for your expert advice to solve a problem on production allocation on a dry gas well from the San Juan area, New Mexico, US.

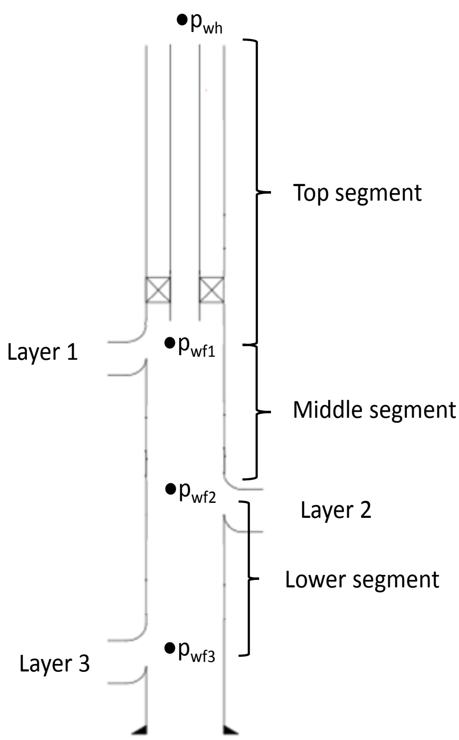


The well is the Dunavant 1-15 U 4 from the “Ignacio Blanco” Field. The well is producing **at a constant wellhead pressure of 45 bara and, as of today, it produces a gas flow rate of 218249.1 Sm^3/d.**

The well produces from three formations (3 layers) that have different ownerships:

Layer Name Company	FRUITLAND COAL	WATERISLAND COAL	SAN JUAN
BP	30 %	70 %	10 %
Chesapeake energy corp.	40 %	10 %	40 %
Marathon	30 %	20 %	50 %

Each layer has its own properties, permeability, porosity, reservoir pressure, deliverability, etc. The vertical separation between the layers is significant and must be considered. The well architecture is as follows:



Tasks:

You are asked to determine:
1). what fraction of the total gas flow rate is coming from each layer for the current date
2). What fraction of the total gas flow rate corresponds to each company for the current date (allocation fraction)
3). Calculate the variation in the allocation fractions in the next year using a time step of 120 days.

Solving Suggestions

- Transform the three layer well in an equivalent downhole network (consider from reservoirs until wellhead).
- Assume that there are no other wells producing from layers 1, 2 and 3.
- Assume that during the next year there will be no stop in the production from the well.
- To estimate the cumulative production of a layer, use the rectangle integration method (the rate calculated at a time t_i remains constant until time t_{i+1} .

Information provided

Inflow performance of the layer (backpressure equation)

$$q_{gsc} = C_R\left(p_R^2 - p_{wf}^2\right)^n$$

Tubing equation (for each vertical segment)

$$q_{gsc} = C_T\left(\frac{p_{in}^2}{e^s} - p_{out}^2\right)^{0.5}$$

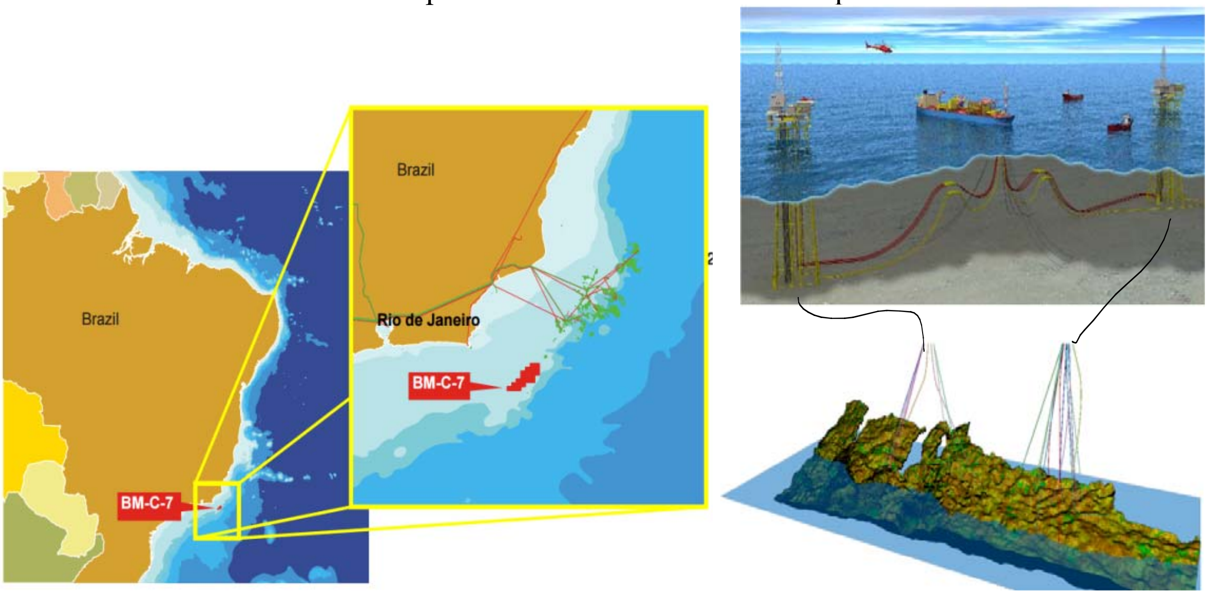
The material balance for each layer has been approximated by the reservoir specialist by the following equation:

$$p_R = p_i - m \cdot G_p$$

All relevant data is given in the attached excel sheet.

PROBLEM 2: ESP design and verification with output from reservoir simulator for the Peregrino field

Peregrino is the largest oil field operated by Statoil outside of Norway. The field is located 85 km offshore Brazil in the Campos Basin at about 100 water depth.



The field is developed with two fixed platforms from which wells are drilled and completed. There are 40 producing wells in total. The production is taken to an FPSO where the processing takes place. The separated water is transported back to the platforms and injected in the lower part of the formation.

Wells are deviated with ESPs installed in them. The wells are classified in low, medium and high producers.

A particular ESP model has already been suggested by a manufacturer (Baker Hughes) based on the well layout and production rates desired.

On the 20th of March, 2018 your company (Statoil, the field operator) sent you to NTNU to attend a training session about ESP design analysis and verification session using Excel.

TASK 1

Back in the company, your task is to verify if the ESP proposed by the manufacturer will be able to produce the rate predicted by the reservoir simulator for four times provided in the excel sheet (In sheet "Data", dates 1.0, 3.3, 6.8 and 12.5 years). If it is not possible to deliver the rate, try to reduce or increase the rate so it will fall inside the operational envelope of the pump. Identify limiting factors. If you are using the excel solver to adjust automatically the rate, please specify clearly the objective, constraints and variables.

Determine ESP operational frequency, suction pressure, required power and emulsion viscosity for each year listed above.

If you are given budget to change something in the well, is there something in particular that you will prioritize to meet the reservoir production goals?.

Plot the operational points (both original rates from the reservoir simulator and corrected rates) overlapped in the ESP operational map for each year.

Provide your final recommendations if the ESP is adequate to deliver the desired rate or not.

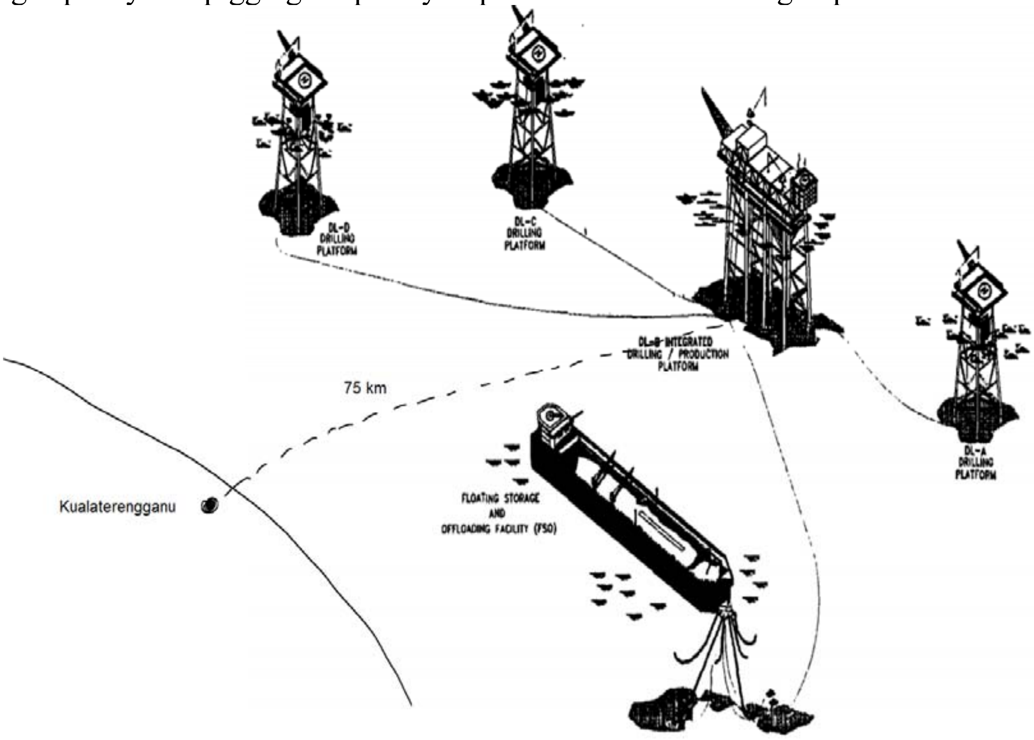
Assumptions:

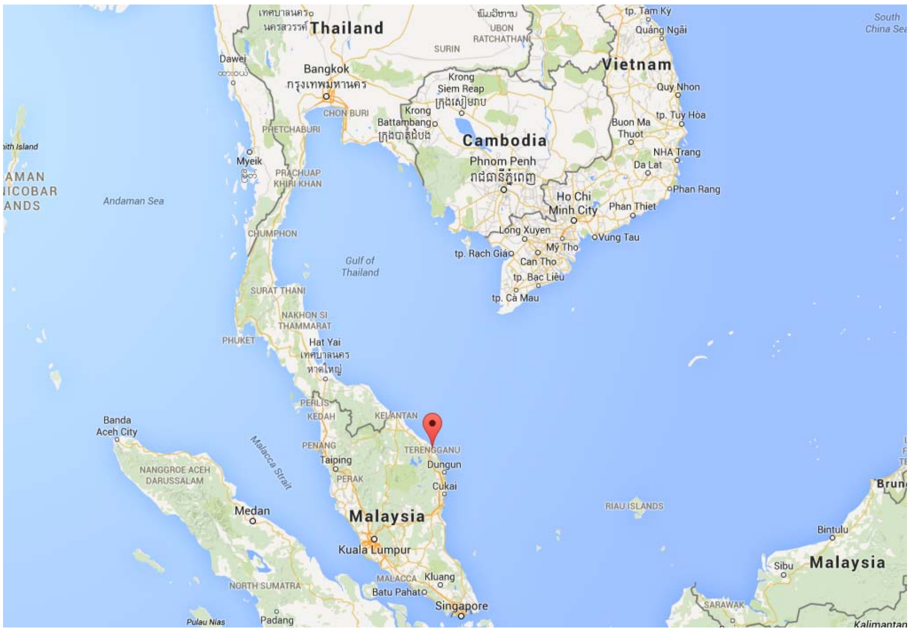
- Use the excel sheet provided.
- Assume maximum pump power = 950 Hp
- Assume that the total liquid productivity index (J) of the formation remains constant with time.

PROBLEM 3: **Temperature, pressure and wax deposition calculations in offshore oil export line.**

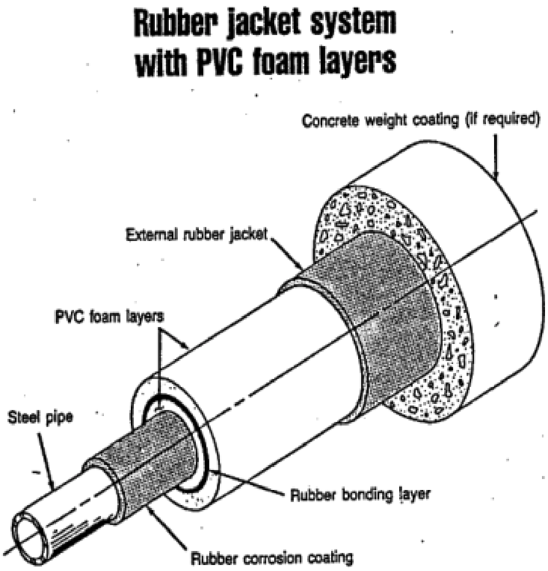
Field Description

The Dulang field is located 75 km offshore Kuala Terengganu in the South China Sea. The reservoir oil has tendencies to form wax crystals and to increase apparent viscosity with reduction of temperature (this is shown in sheet "Mu(T) digitized" in the attached excel file). Two development options are considered for oil export; (1) offshore loading terminal and (2) marine pipeline to shore.
To assess the feasibility of marine pipeline it is necessary to calculate the temperature and pressure profile and wax deposition in the export line at nominal oil flow rate. This to define pumping capacity and pigging frequency requirements at the Dulang-B platform.





The pipeline will be unburied, but two options are currently being considered for insulation: PVC, which gives an overall heat transfer coefficient of 1.5 W/m^2 K and Concrete, that gives an overall heat transfer coefficient of 5 W/m^2 K. Both overall heat transfer coefficients are expressed in terms of the outer pipe diameter.



The pipeline will be unburied, but two options are currently being considered for insulation: PVC, which gives an overall heat transfer coefficient of 1.5 W/m^2 K and Concrete, that gives an overall heat transfer coefficient of 5 W/m^2 K. Both overall heat transfer coefficients are expressed in terms of the outer pipe diameter (with insulation).

The pressure of the receiving terminal onshore (slug catcher) is kept constant at 50 bara. The temperature of the crude leaving the platform is 60 C.

Your tasks are the following:

1. Calculate and plot the temperature and pressure profile of the pipe for the two insulations proposed.

   1.a. Estimate the power required by the pump on the platform assuming that the suction pressure is 4 bara and the pump efficiency is 70%.

   1.b. Will there be any problems with wax deposition along the pipe? Please explain.

2. For the cases where wax deposition is a problem, calculate and plot the wax deposition along the pipeline for times 10 days, 30 days, 60 days and 120 days. To make your calculations simpler, assume that the wax doesn't affect the heat transfer coefficient with the sea and neglect the reduction in pipe cross section.

2.a. If the maximum amount of wax that can be removed from the pipe is 200 kg. How often is it necessary to pig the pipeline?.

Data and information

-All data required is given in the Sheet "Input Data" in the excel sheet attached.
-Discretize the pipeline in 500 m steps. Assume the pipeline is horizontal.
-Estimate the pressure drop in the pipe using the Bernoulli equation with head loss and using the Moody friction factor predicted by the Haaland empirical correlation. This equation has already been programmed for you as a VBA function ("Pin" or "Pout", depending if you are calculating pressure downstream a location or upstream a location). Please note that the volumetric rate to use in this function is the **local volumetric rate**, not the standard conditions rate. The local volumetric rate will change will pressure and temperature changes along the pipe. Use the Oil volume factor (Bo) to calculate the local rate. The Bo factor has been already programmed for you as a VBA function ("Bo"). Your pressure calculations must be performed counter-current, as the pressure at the outlet of the pipe is known but not at the inlet.

$$\frac{1}{\sqrt{f}} = -1.8 \cdot \log\left[\frac{6.9}{N_{RE}} + \left(\frac{\varepsilon}{3.7 \cdot D}\right)^{1.11}\right]$$

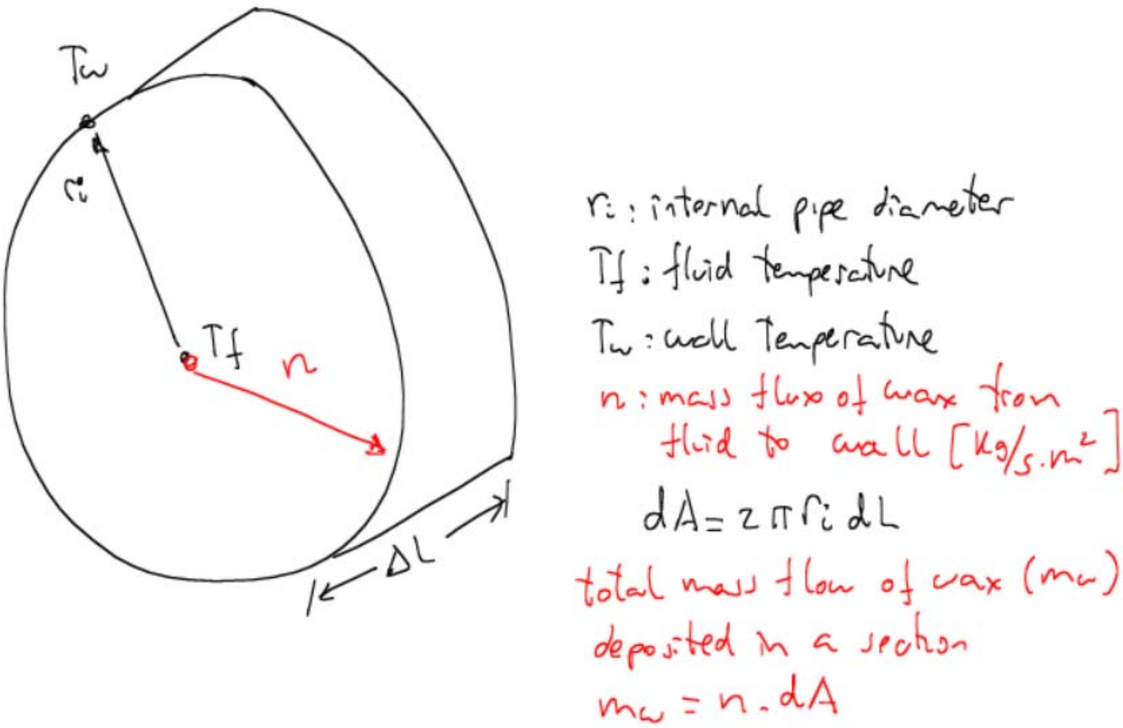
-Assume that the viscosity of oil is mainly a function of temperature and interpolate on the table provided in sheet "Mu(T) digitized" to find the viscosity at a given temperature. To interpolate the viscosity, you can use the VBA function "tabinterpol" provided (remember to freeze with F4 the input).
-The temperature distribution of an unburied pipeline, with a nearly incompressible liquid can be estimated using the equation below:

$$T(x) = T_{amb} + \left[T(x=0) - T_{amb}\right] \cdot e^{-x/A}$$

$$A = \frac{(\dot{m} \cdot c_p)}{2 \cdot \pi \cdot r_a \cdot U}$$

Where:
T= Temperature of flowing fluid [°C]
x = position in pipe, measured from pipe inlet [m]
T(x=0) = Temperature of flowing fluid at pipe inlet [°C]
Tamb = Ocean bottom water temperature [°C]
m = mass flow rate, [kg/s]
Cp =heat diffusivity of soil, k_e/( ), [m^2/s]
ra = External radius of the conduit (with insulation) [m]
c_p = heat capacity of flowing fluid, [J/kg °C]
U = Overall heat transfer coefficient [W / m^2 °C]
-Assuming the main wax deposition mechanism is molecular diffusion and that all wax that precipitates out of solution will immediately deposit, the wax deposition rate (n in kg/s / m^2) can be estimated using the equation below:

$$n = \rho_{wax} \cdot \frac{B}{\mu_o} \cdot \frac{dC}{dT} \cdot \frac{dT}{dr}$$



REMEMBER: there will be wax deposition only when the temperature of the fluid goes below the WAT!

Where:
rho_wax = wax density [kg/m^3]
mu_o = oil viscosity [Pa s]
B = molecular diffussion coefficient [N] (provided in the excel sheet).
dC/dT = wax solubility coefficient [1/C] (provided in the excel sheet).
dT/dr = temperature gradient [C/m]
Estimate the temperature gradient dT/dr as the difference between temperature of the fluid and temperature of the inner pipe wall.
-The temperature of the inner pipe wall can be estimated from the expression:

$$\dot{q} = 2 \cdot \pi \cdot r_i \cdot h_i \cdot \left(T_{fluid} - T_{innerwall}\right)$$

Where:
q = heat per meter, [W/m]
ri = pipeline inner radius [m]
hi = forced convection heat transfer coefficient inside the pipe [W / m^2 K]
T_fluid = fluid temperature [C]
T_innerwall = temperature of pipe inner wall [C]
-For your calculations, assume the forced convection heat transfer coefficient is constant. The value is provided in the sheet "Input data" in the attached excel file.
-Remember that the heat per meter can also be calculated from the overall heat transfer expression:

$$\dot{q} = 2 \cdot \pi \cdot r_a \cdot U \cdot \left(T_{fluid} - T_{amb}\right)$$