Proposal - Group 5

Problem Summary - 'Why'

Bitumen, a viscous oil product used mainly for road surfacing, is traditionally produced by surface mining and separation. Recently however, due to technological advancements, thermal recovery by steam injection has developed as a method to extract deep bitumen deposits from tar sands. As bitumen does not flow as easily as traditional oil, it is heated so as to reduce its viscosity so that it can be extracted through a well. Although there was a ban on Oil and Gas exploration, due to the damage the COVID pandemic has had on the economy, the ban has now been deferred and new projects arising.

Due to the influx of new projects being developed, there was a successful pilot scale thermal recovery project which began in March 2021. The project involved two cycles of 260 degree steam injection into a well which in turn produces an oil-water mixture. Todd Energy has proposed a commercial joint venture with Ngai Tahu. Todd Energy must take into account the possible side effects for the stakeholders, which include:

1. Ngai Tahu - the local iwi who are mainly concerned with the success of the project
2. Todd Energy - the applicants who wish to expand their company, maximising bitumen extraction and revenue. However, they are also aware of the potential harm for the environment through the leaching of toxic organics and the expectations from other stakeholders
3. New Zealand Transport Agency - who support the resource consent application and are mainly concerned about overreliance on bitumen imports from Canada
4. GreenPeace and a group of local farmers - who are mainly concerned by leaching of toxic organics into groundwater
5. New Zealand Government - imposed the ban on oil and gas, who are mainly concerned about the impact on the local environment

Todd Energy's resource consent application can either be accepted fully, accepted partially or rejected. There are few cases to consider:

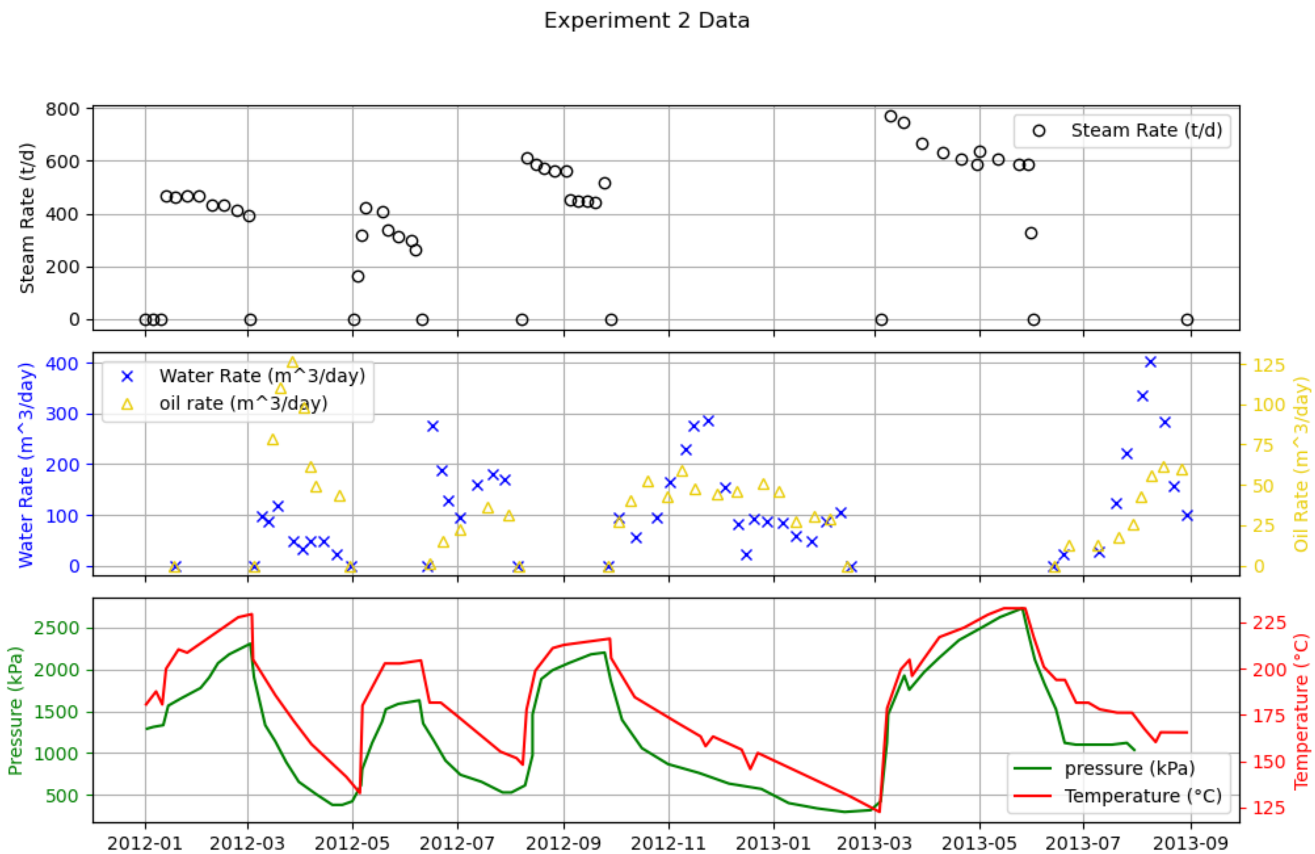
1. The resource consent application is fully accepted, which would involve the full amount of steam injection and production.
2. The resource consent application is rejected.
3. The resource consent application is partially accepted, that is there is a restriction on the amount of steam injection and production, so as to minimise the harmful effects the project has on the environment.

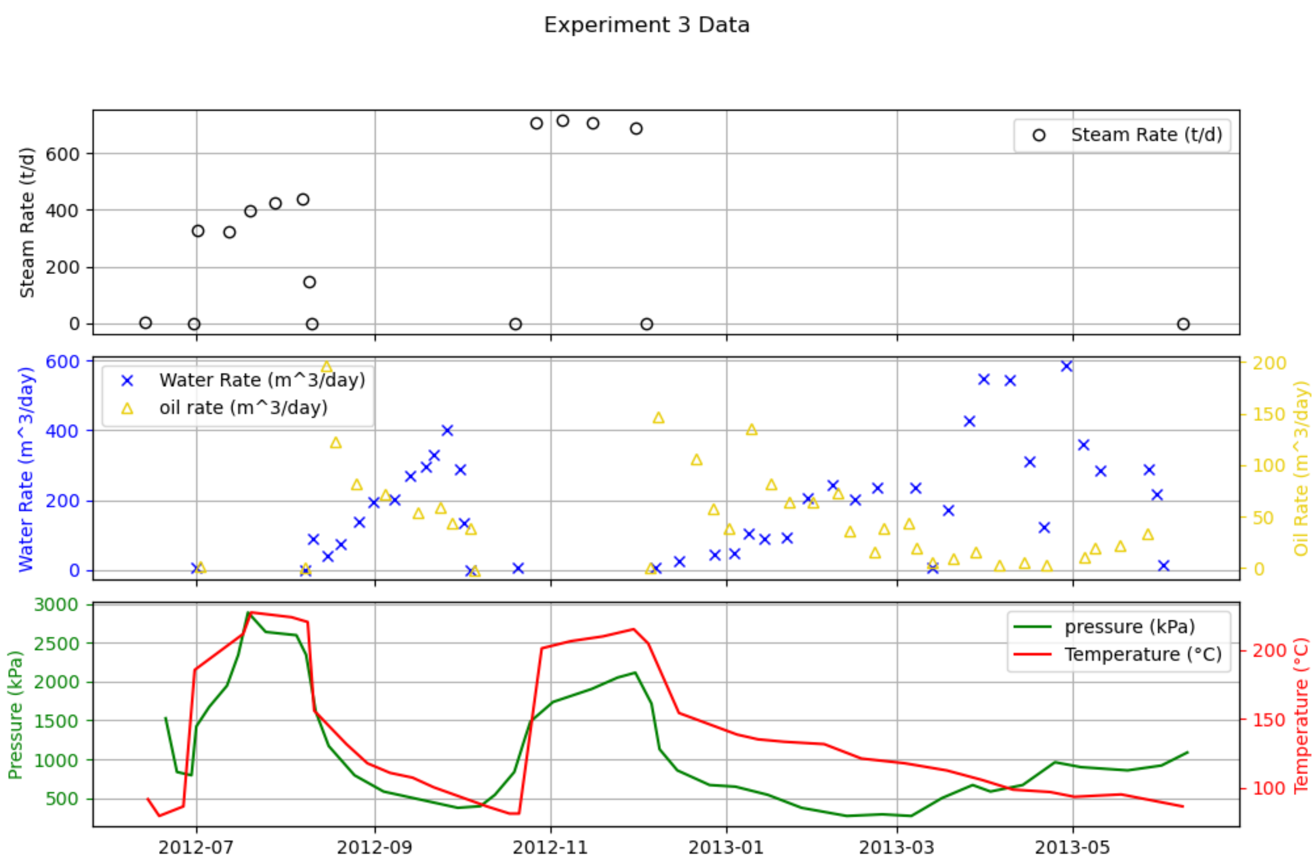
Contribution of Modelling Study - 'How'

We can use a computer model to simulate how the changes in pressure and temperature are affected during the production and injection phases. This will allow us to deduce the environmental and social consequences regarding the safety limits of the extraction of bitumen.

The results from this modelling study will give insight into the levels of injection and production rates that can be sustained without producing adverse effects to the surroundings. Previous studies have shown that bitumen recovery is determined by the type of solvent, the volume used and the solvent placement. However, it is essential to assess whether the extraction of bitumen will be retained within the safety limits to ensure satisfaction for the stakeholders.

Data Visualisation - ‘Given’





Data Description - ‘Given’

To develop the numerical modelling study, we have been provided with data. This data includes time series records of steam injection, the water and oil production during the pilot study, and time series records of pressure and temperature during both injection and production phases. We are also provided with the reservoir engineering reports which include the trace amounts of non-toxic oil in products in local groundwater.

We are given data for 2 pairs of wells, P1C (800m horizontal section length), drilled overbalanced, corresponding to Experiment 2 in the graph above, and P2C (450m horizontal section length), drilled balanced, corresponding to Experiment 3 in the graph above.

For the P1C wells, there are 4 injection periods over the span of 21 months. The steam rate varied about 400-600 tonnes per day for those periods, peaking at just under 800 tonnes per day. The oil and water rate fluctuated greatly after the injection periods, with the oil production rate peaking at just above 125m^3/day in the first production period and the water production peaking at just above 400m^3/day in the last production phase. For the second, third and fourth production periods, the oil production rate stayed lower, only twice reaching 150m^3/day. There were variations mainly around 0m^3/day and 75m^3/day for the oil production and between 50m^3/day and 300m^3/day for the water coming out of the well. The temperature peaks at about 200 to 230 degrees celsius during each of the injection periods, while the pressure, which corresponds to the increases in temperature, varies between 1500kPa and 2700kPa, peaking at that 2700kPa mark during the last injection period.

For the P2C wells, there are 2 main injection periods, both of which occur around 5 months apart. The steam rate for the first injection period is around 400 tonnes per day, whereas for the second it is rather higher, at about 700 tonnes per day. The oil production rate after the first injection period peaks at 200m^3/day, but only at a mere 150m^3/day, withering out, after an initial high, following both injection periods. The water production rate fluctuates between 200 and 400m^3/day, after both injection periods, peaking at, and staying at a high of around 600m^3/day, 4-5 months after the second injection period. The temperature varies about 200 degrees celsius over the two injection periods, peaking at about 225 degrees celsius and the pressure in the first injection period peaks at 2750kPa, significantly greater than just over 2000kPa in the second injection period.

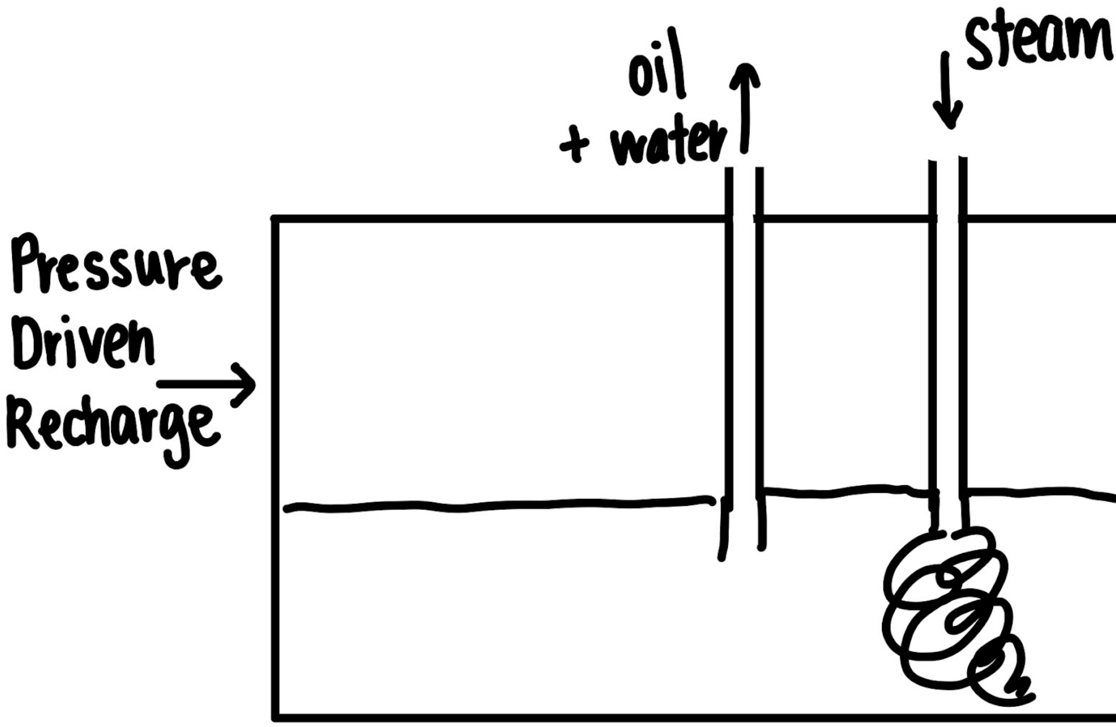
In both experiment 2 and 3, there is a clear correlation between pressure and temperature levels. It also seems that during a steam injection phase, pressure and temperature rise to a certain level and stay relatively stable after that. During production phases, pressure and temperature steadily decline.

Conceptual model justification - ‘Assume’

Physics

The main physics relevant to the thermal recovery of Bitumen are:

- Conservation of mass - governs fluid pressure changes through fluid diffusion. Represented by Darcy’s law
- Conservation of energy - governs heat flows through steam injection. Represented by Fourier’s law



As we are mainly concerned with the effects of the pressure and temperature on the thermal recovery of Bitumen, we will be neglecting other conservation equations. Both pressure and temperature are affected by injection/production rate of the well and thus, we are interested whether these rates will be sustainable and meet the required level of oil production. We are also concerned about the temperature reaching a certain point where contaminants dissociate from Bitumen and cause environmental damage to groundwater. Therefore, we will use our LPM to model both the pressure and temperature changes due to its previous usage and simplicity.

Domain and initial conditions
Our LPM model will be represented as a single control volume that the results of the model will adhere to.

The initial condition can be determined through the historical data on fluid pressure. Another way in which the initial condition can be determined is through model calibration and treating it as an unknown parameter. A boundary condition is the pressure driven recharge, this is included in the LPM ODE, this is an unknown condition and will also be determined through model calibration.

Further Assumptions Include:
- External pressure is constant (standard atmospheric pressure) as well as the volume of the reservoir
- Temperature does not exceed 240 degrees Celsius or else toxic organics will be released
- Ambient room temperature

Conceptual model formulation - ‘Formulate’

This LPM will be composed of two ODEs:
- Temperature
- Pressure

Conservation Of Mass: Darcy’s Law

The first ODE relates to conservation of mass.

$$\frac{dP}{dt} = \underbrace{-aq}_{\text{Extraction or injection}} - \underbrace{b(P-P_0)}_{\text{Recharge}}$$

Where P represents the pressure in the well, and Po is the pressure outside/surrounding of the well
a and b represent the lumped parameters that depend on the physical parameters of the system
q refers to the net mass flux in the well : q = qow + qsteam
Where qow is the mass flux out of the well from production/extraction of oil and water and qsteam is the mass flux into the well from the steam injected into the well.

Conservation of energy: Fourier Law
The second ODE relates to conservation of energy

$$\frac{dT}{dt} = \underbrace{\frac{q \cdot T}{M}}_{\text{Flow Out}} + \underbrace{\frac{b_p \cdot (P-P_0) \cdot T}{M \cdot a_p}}_{\text{Pressure Flow}} - \underbrace{b_p(T-T_0)}_{\text{Conduction}}$$

P represents the pressure in the well
Po is the outside/surrounding pressure of the well
q refers to the net mass flux in the well
a and b represent the lumped parameters that depend on the physical parameters of the system
To is the outside/surrounding temperature
T refers to the temperature inside the well
M is the mass contents injected and extracted from the well