A Field-scale Reservoir Simulation Study of CO_2 Foam Generation in Enhanced Oil Recovery (EOR) Processes

Master Thesis in Reservoir Physics

By

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Abstract

CO_2 enhanced oil recovery (EOR) is a well-known method for mobilizing residual oil from existing oil fields. It has a dual purpose by increasing oil recovery while providing long-term anthropogenic CO_2 storage. CO_2 EOR is a promising technology for mitigating climate change as well as generating revenue for the industry to implement large-scale Carbon Capture, Utilization and Storage (CCUS). However, pure CO_2 injection suffers from poor sweep efficiency due to high CO_2 mobility compared to reservoir fluids, and results in an unfavorable displacement and low recovery. Recent studies of CO_2 foam for EOR suggests that foam improves both sweep efficiency and CO_2 sequestration compared to conventional CO_2 EOR.

This thesis presents a numerical investigation of CO_2 foam in EOR processes. CO_2 foam generation, strength and propagation were evaluated in a field-scale radial simulation model representing a foam injection well from a completed CO_2 foam field pilot. The main objective was to evaluate if foam was generated, how strong it was, and how far it propagated from the injection well. Foam generation verification, foam model sensitivity study, grid resolution sensitivity study and injection strategy sensitivity study are presented.

Results showed that foam was generated in all simulation cases with surfactant present, based upon higher bottom hole pressure (BHP) compared to their baselines without surfactant. All simulation cases showed foam propagation approximately 200 ft from the injection well, with the highest foam concentration occurring in the Base surfactant-alternating-gas (SAG) injection strategy with 10 days of surfactant solution injection followed by 20 days of CO_2 injection. In addition, the Base SAG generated the strongest foam compared to other injection strategies without reaching the formation fracture pressure. Overall, the results indicate that foam is a promising method for reducing CO_2 mobility in EOR and CO_2 storage process.

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A special thank you to my mother-in-law, Vivian, and to other family members, for countless hours of babysitting while I was working on my thesis.

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Part I. Introduction and Theory

1. Introduction

There is a huge challenge associated with rising greenhouse gas emissions (GHG) parallel to the increase in global demand for energy. Due to population and economic growth, the world's energy demand is increasing rapidly and a 2021 press release from The International Energy Agency (IEA) states that global electricity demand is growing faster than renewables (IEA, 2021). Combustion of fossil fuels are the largest contributor to climate change, that pose severe risks to the environment and human health. The Paris Agreements is an international treaty with the main goal of keeping global temperature rise below 2 degrees Celsius. Immediate actions are required, and there is a need to change the way people live today.

One major method to reduce industrial emissions on a global scale is Carbon Capture and Storage (CCS). CCS involves capturing anthropogenic CO_2 and depositing it deep underground so that it does not enter the atmosphere. CO_2 can be stored in aquifers or reservoirs where in the latter case, CO_2 can be injected for CO_2 enhanced recovery (EOR) and long-term storage. To reach the world's climate goals, the energy industry must accelerate the development of CCS technology. In order to reach the ambitious goal, annual GHG emissions are required to be cut by 15 Gt of CO_2, but today we are far from this goal (Huang et al., 2021). The development of CCS is thus of vital importance and in desperate need of upscaling to reach its full potential of reducing emissions. A possible way to generate a profit from CCS is to utilize CO_2, which is then called Carbon Capture, Utilization and Storage (CCUS).

CO_2 can be utilized for enhanced oil recovery (EOR) and is a widely known technique for mobilizing residual oil and improving recovery. However, conventional CO_2 injection comes with downside risks associated with operational constraints such as pipeline corrosion and poor sweep efficiency. This work is a part of an international research program on CO_2 foam, led by the Reservoir Physics group at University of Bergen. The aim was to test CO_2 foam for CO_2 EOR and CO_2 storage for CCUS. The numerical investigation presented in this thesis was conducted in order to evaluate foam generation, strength and propagation in a field-scale radial simulation. In addition, sensitivity studies with the aim to improve model fit to observed data from a recently completed field pilot was conducted.

2 Fundamentals of Reservoir Engineering

2.1 Relative Permeability

Permeability is a measure of the ability to transmit fluids through a porous media. It is one of the most important properties of reservoir rocks and depends on parameters like pore size, porosity, fluid type and saturation (Mavko & Nur, 1997). With only one fluid present, it is called absolute permeability. The effective permeability is the flowability of one fluid with two or more immiscible fluid present. The ratio between the effective permeability of a fluid and the rocks absolute permeability gives the fluid's relative permeability (Honarpour & Mahmood, 1988) as shown in Equation 2.1.

$$k_{r_f} = \frac{K_f}{K} \tag{2.1}$$

Where k_{r_f} is the relative permeability of fluid f, K_f is the effective permeability of fluid f and fluid K is the absolute permeability of the rock. Relative permeability is often represented as a function of fluid saturation and increases when a fluid's saturation is increased. Wettability will also have a strong effect on the relative permeability (Anderson, 1987) .Wettability is the tendency of one fluid to spread on or adhere to a solid surface in presence of other immiscible fluids. In a rock/oil/brine system, the wettability is decided by the preference the rock has for either oil or water. In a water-wet system, water will contact the majority of the rock surface and fill the smaller pores while oil occupies the center of the larger pores. This will be reversed in the case of an oil-wet system (Anderson, 1986). Figure 2.1 shows the tendency of the relative permeability in strongly wetted systems (Anderson, 1987).

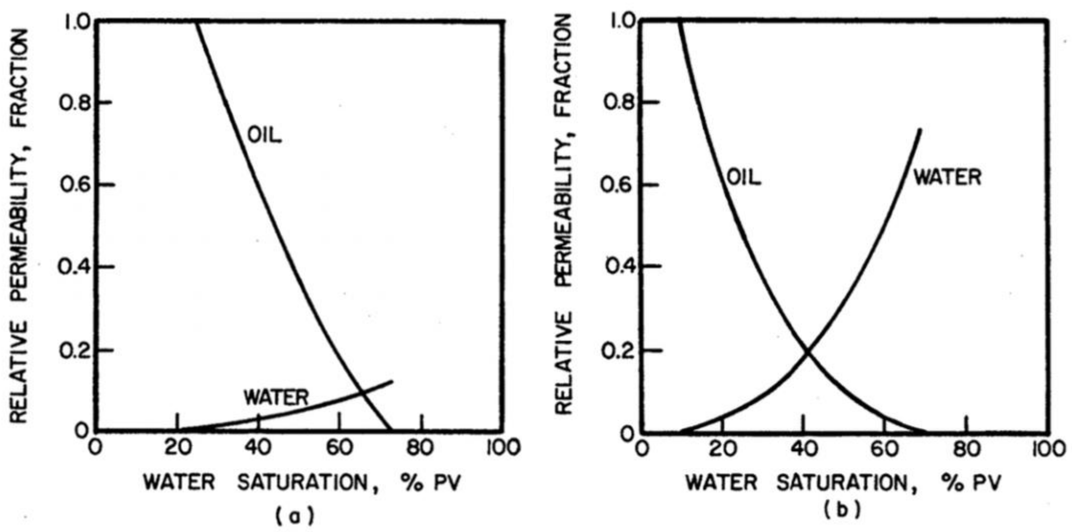

Figure 2.1 Relative permeability curves for (a): strongly water-wet system and (b): strongly oil-wet system (Anderson, 1987).

2.2 Capillary Pressure

Capillary pressure (P_c) is described as the difference in pressure across the interface between to immiscible fluids due to interfacial tension (IFT) between the two fluid surfaces (Anderson, 1987). Capillary pressure is defined as

$$P_c = P_{nw} - P_w \tag{2.2}$$

Or

$$P_c = \frac{2\,\sigma\,cos\theta}{r} \tag{2.3}$$

where P_c is the capillary pressure, P_{nw} is the pressure in the nonwetting fluid, P_w is the pressure in the wetting fluid, σ is the IFT, θ is the wetting angle between the fluids and r is the radius of the pore. Drainage and imbibition are two types of capillary pressure processes. When the non-wetting fluid displaces the wetting fluid it is a drainage process whereas the reverse occurs for imbibition (Anderson, 1987).

2.3 Stages of Oil Recovery

Phases of oil production can be divided into primary, secondary and tertiary recovery. Primary recovery is due to natural drive mechanisms in the reservoir such as pressure depletion and water influx. Generally, most of the oil reserves are left behind after primary recovery and other methods are used in many fields to mobilize the oil left behind in the reservoir (Brown, 2002). Secondary recovery techniques include injecting water or gas to displace the oil, where the fluids are usually immiscible with the reservoir oil. The main purpose of waterflood and gas injection is to maintain reservoir pressure and displace oil to producing wells (Romero-Zerón, 2012). Primary and secondary recovery are referred to as conventional recovery methods. These methods produce on average about one third of the original oil in place (OOIP). To further produce more oil, tertiary recovery or enhanced oil recovery (EOR) can be utilized (Alagorni et al., 2015).

EOR is the use of unconventional recovery methods, referring to chemical, miscible and thermal flooding processes with fluids and materials that are not naturally in place in the reservoir. The main goal of EOR methods is to improve oil displacement efficiency by increasing the macroscopic and microscopic displacement efficiency (Romero-Zerón, 2012). Gas injection is a widely used EOR method, where typical gases are CO_2, natural gas and nitrogen. The injected gas increases the reservoir pressure which leads to an increase in oil recovery. When the gas also mixes with the oil (miscible gas injection), the viscosity of oil decreases and will lead to a higher recovery. CO_2 is a common choice for gas injection due to the miscibility of CO_2 in oil, its costs and CO_2 storage in reservoirs. In this thesis, surfactant was utilized to increase the sweep efficiency of CO_2 by generating CO_2 foam.

3 CO_2 Properties / EOR

CO_2 injection has been used as an EOR method for over 50 years and was first implemented in the US (Verma, 2015). The main objective of CO_2 EOR is to recover unswept oil by reducing viscosity and density of oil, through generating miscibility and swelling the oil. CO_2 has been preferred for injection compared to other gases because of its miscibility in crude oil, lower cost, availability and possibilities for CO_2 storage (Holm et al., 1986). However, CO_2 injection is linked to challenges with poor sweep efficiency.

3.1 Properties of CO_2

CO_2 is a chemical compound composed of two oxygen atoms covalently bonded to a single carbon atom. It is widely used in EOR methods and it's therefore essential to know how CO_2 behaves under different conditions. CO_2 remains in gaseous phase under atmospheric temperature and pressure and becomes supercritical fluid when the reservoir conditions exceed critical pressure of 73.9 bar and critical temperature of 31.1°C (Freund, 2005). In supercritical state, CO_2 can extract hydrocarbon components from oil more easily than in gas phase. Figure 3.4 shows phase diagram for CO_2.

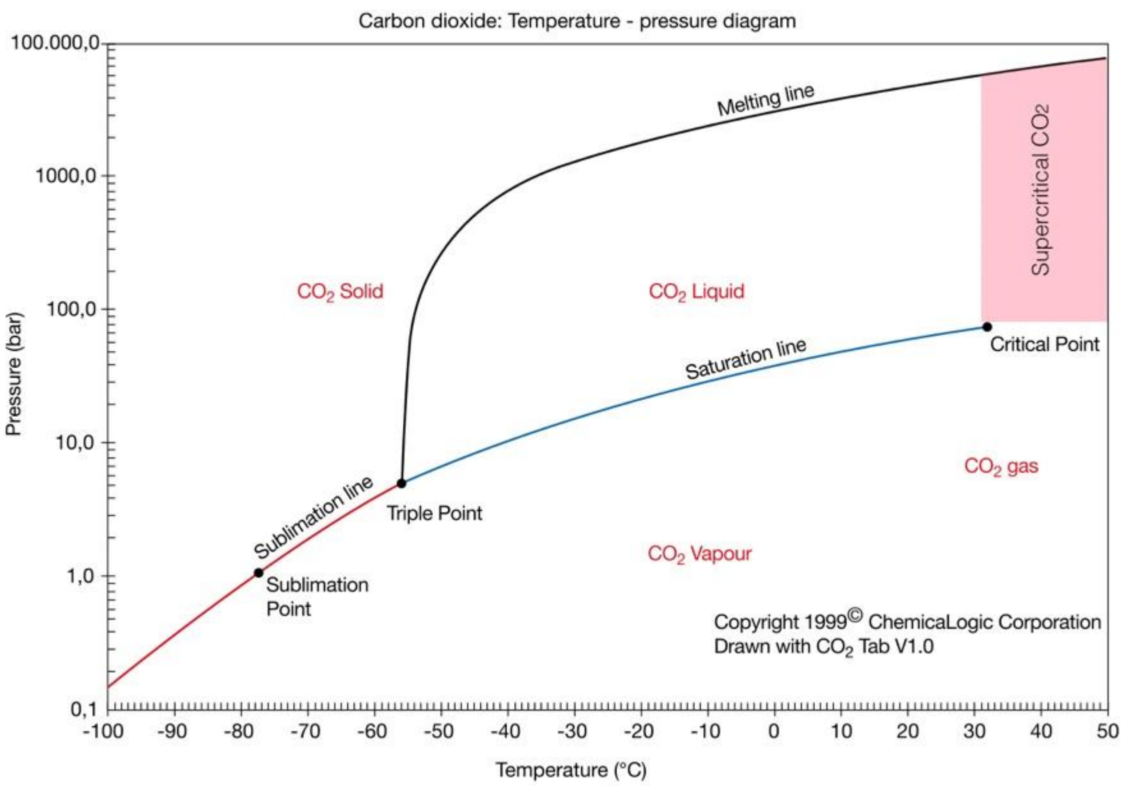

Figure 3.1 Phase diagram for CO_2 showing supercritical fluid above P=73.9 bar and T=31.1°C. Modified from (Freund, 2005).

3.2 Miscible Displacement

Miscibility between two fluids is determined by intermolecular forces between the molecules within each fluid. For the fluids to be miscible, the attraction between the molecules of the same fluid must be stronger than with the adjoining fluid. There are two types of miscible displacement: first- and multi-contact miscible displacement. First-contact is achieved when any amount of injected gas exists as a single phase with the reservoir oil (Holm, 1986). Multi-contact is achieved by the processes of vaporization- and condensing-gas drive. Miscible displacement can be described by a ternary phase diagram as seen in Figure 3.2, where the corners represent different fluid-components. The top represents light hydrocarbon (HC), bottom right represent intermediate HC and bottom left represent heavy HC. Inside the diagram, there is a mix of the HC components. The critical line on Figure 3.2 determines the type of miscible displacement. A displacement that only occurs in the one phase area is a first-contact miscible. A displacement that occurs in both two-phase and single-phase area is multi-miscible. CO_2 displacement can also be immiscible (Skarestad & Skauge, 2012). If the line crosses the two-phase region but not the critical line, it's an immiscible displacement.

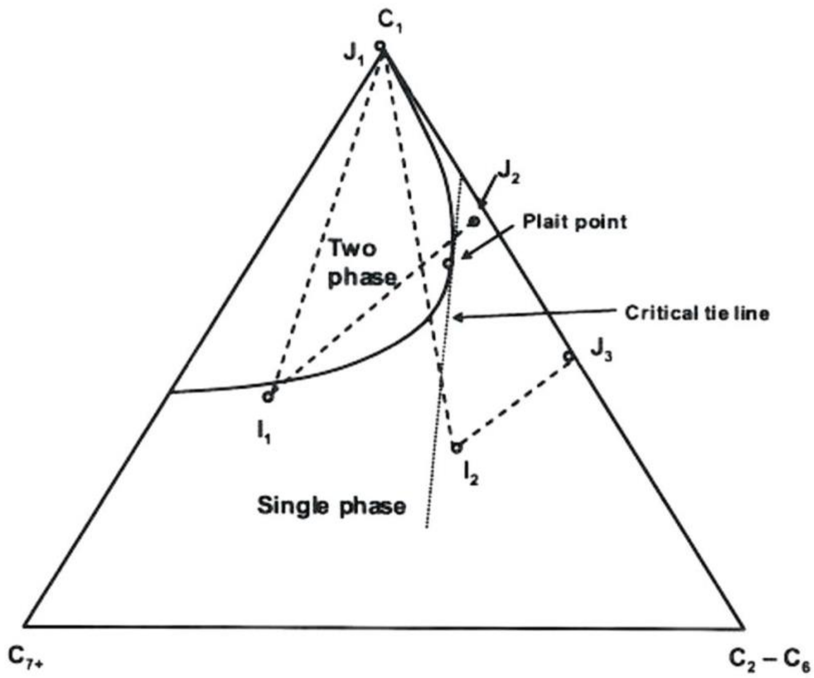

Figure 3.2 Ternary phase diagram that can be used to determine the CO_2 displacement (Skarestad & Skauge, 2012).

The solubility of a gas in a liquid is highly dependent on two properties, pressure and temperature. Miscibility between CO_2 and oil only occurs above a certain pressure, known as minimum miscibility pressure (MMP). MMP is dependent on the composition and temperature of the reservoir and properties of the gas injected (Yellig & Metcalfe, 1980). Figure 3.3 shows how MMP is determined from a slim tube experiment. The graph shows recovery measured experimentally as a function of pressure, where the MMP is characterized by the flattening of the curve (Skarestad & Skauge, 2012).

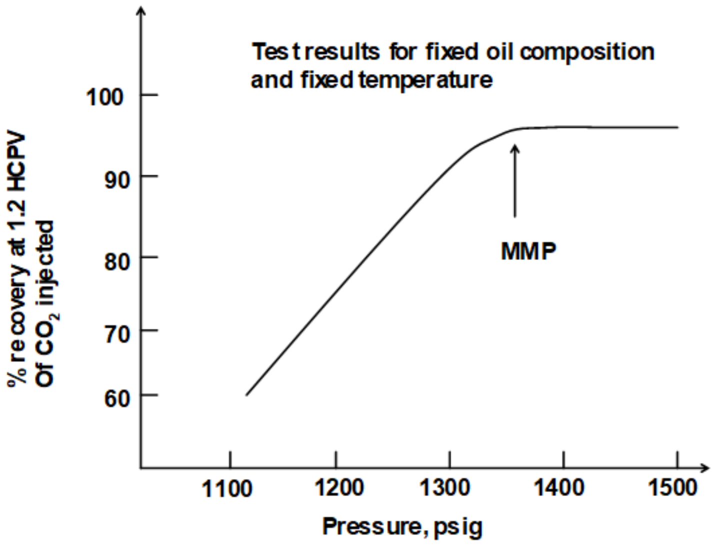

Figure 3.3 Minimum miscibility pressure (MMP) determined from slim tube experiment (Skarestad & Skauge, 2012).

3.3 Diffusion and Dispersion

Molecular diffusion and mechanical dispersion are the main mechanisms behind the gas and oil mixing that occurs in a miscible displacement process. Dispersion is the increased mixing that occurs because of the uneven fluid flow or concentration gradients resulting from fluid flow. Mechanical dispersion requires a variation in convective velocity field. Diffusion is a special case of dispersion that occurs when the fluid velocity is zero. When two miscible fluids are in contact, they will slowly diffuse into one another because of the concentration differences between the phases. Molecular diffusion takes place solely due to concentration gradient and does not require motion (Perkins et al., 1963; Shrivastava et al., 2002).

3.4 Oil Swelling

Oil swelling occurs when CO_2 is injected at such conditions where the gas mixes and dissolves into the reservoir oil and no free gas is present. This phenomenon increases the oil volume and the oil viscosity is reduced. The amount of swelling of the oil depends on the pressure, temperature, oil composition and amount of CO_2 dissolved in the oil (Mungan, 1981). In addition, oil swelling depends on the injection strategy, where CO_2 usually is injected after a secondary recovery waterflooding. The high water saturation creates what is called water shielding, where water is blocking the residual oil from contacting the injected CO_2. Water shielding prevents the gas from mixing with the oil and leads to lower recovery.

A study conducted by Campbell et al. (1985) demonstrated how CO_2 can contact the oil isolated by water. If given enough time, the CO_2 can diffuse through the water shield and swell the trapped pores as shown in Figure 3.4.

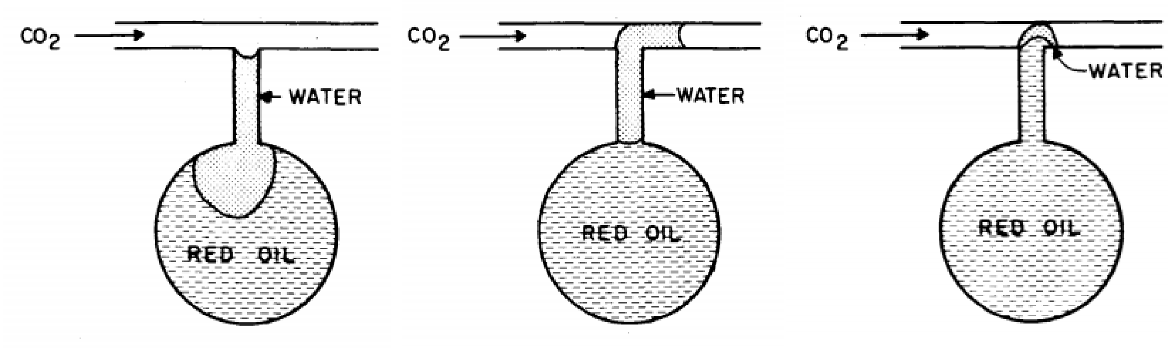

Figure 3.4 CO_2 diffused through the water shield and swelling the oil trapped by the water (Campbell et al., 1985).

3.5 CO_2 Injectivity and Injectivity index

CO_2 injectivity of a well is a valuable tool in foam simulation and is used as a measure for how easily the fluid is injected at a given pressure. The CO_2 injectivity can be expressed by the injectivity index, defined as:

$$I = \frac{q}{\Delta P} \tag{3.1}$$

Where I is the injectivity index, q is the volumetric injection rate in the well and ΔP is the pressure drop between the injected BHP and a reference pressure.

3.6 Challenges with CO_2

Pure CO_2 injection carries disadvantages associated with poor sweep efficiency that leads to lower recovery. The lower density and viscosity of the injected CO_2 compared to the reservoir oil results in an unfavorable mobility ratio. Mobility is the fluid ability to flow through the porous media, and the mobility ratio is defined as the displacing fluids mobility divided by the displaced fluids mobility:

$$M_{12} = \frac{\left(\frac{k_{r,1}}{\mu_1}\right)}{\left(\frac{k_{r,2}}{\mu_2}\right)} \tag{3.2}$$

Where phase 1 is the displacing fluids mobility and phase 2 is the displaced fluids mobility. A mobility ratio less than 1 is considered favorable and results in a stable displacement. Challenges such as gravity override and viscous fingering are direct consequences of a mobility ratio greater than 1. Gravity override is the tendency of CO_2 to migrate towards the upper part of the reservoir and is caused by the lower CO_2 density. Viscous fingering is fingers of CO_2 growing from the displacement front, causing early gas breakthrough. In addition, gas channeling is caused by high permeability streaks and fractures also causing poor sweep efficiency. Figure 3.5 shows challenges associated with CO_2 in the reservoir. (Talebian et al., 2013).

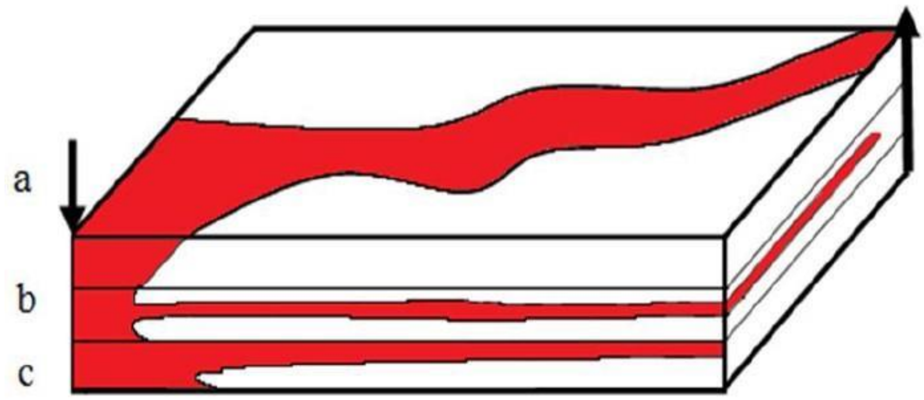

Figure 3.5 CO_2 enhanced oil recovery (EOR) mobility issues: CO_2 flow (red), Reservoir (white) for (a) Poor area sweep, (b) Gas channeling, (c) Gravity override (Hanssen et al., 1994).

To mitigate the problem of unfavorable mobility, water-alternating-gas (WAG) injection strategies, thickeners, foams and gels are used for mobility control. (Enick et al., 2012). The next chapter discusses the use of CO_2 foam mobility control.

4 CO_2 Foam Mobility Control

4.1 Foam Characteristics

Foam is an agglomeration of gas bubbles in liquid that are separated by thin liquid films called lamellae (Rossen, 1996). Figure 4.1 shows a schematic representation of a two-dimensional foam system. In the case of bulk foam, foam exists as a continuous interconnected liquid/film structure that contains gas bubbles. Whereas foam in porous media consists of individual gas bubbles in direct contact with the wetting fluid of the pore walls. Foam has shown to successfully mitigate challenges linked to pure CO_2 injection for EOR as described in chapter 3.5. CO_2 EOR suffers from poor sweep efficiency because of low gas density and viscosity that results in an unfavorable mobility ratio between CO_2 and the reservoir fluids. Consequently, challenges such as gravity override and viscous fingering occur. The use of CO_2 foam for mobility control can lead to higher recovery due to physical mechanisms such as trapped gas reducing its relative permeability and drag forces exerted by moving bubbles on the pore walls increasing the gas apparent viscosity.

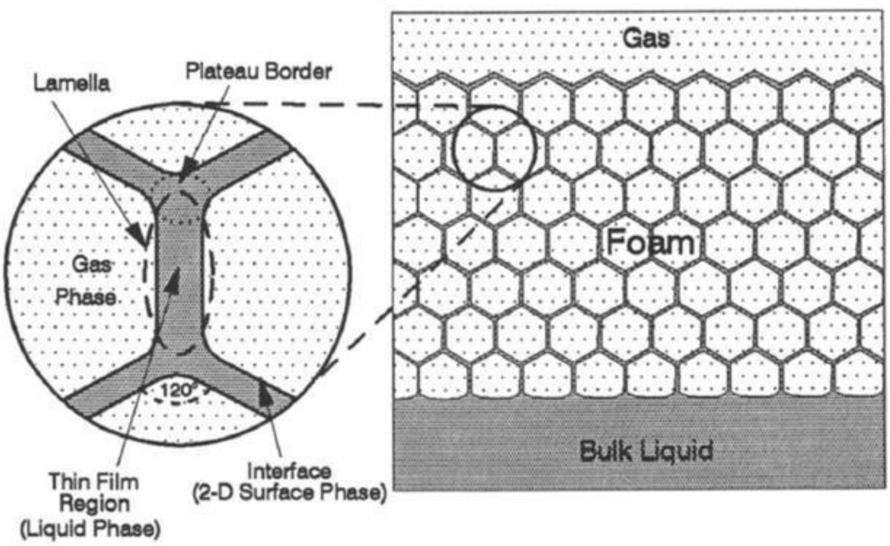

Figure 4.1 Illustration of a two-dimensional foaming system (Schramm & Wassmuth, 1994).

Figure 4.2 shows the difference between the reservoir being swept by free gas on the left causing viscous fingering and gravity override resulting in early gas breakthrough, and on the right showing a stable foam displacement.

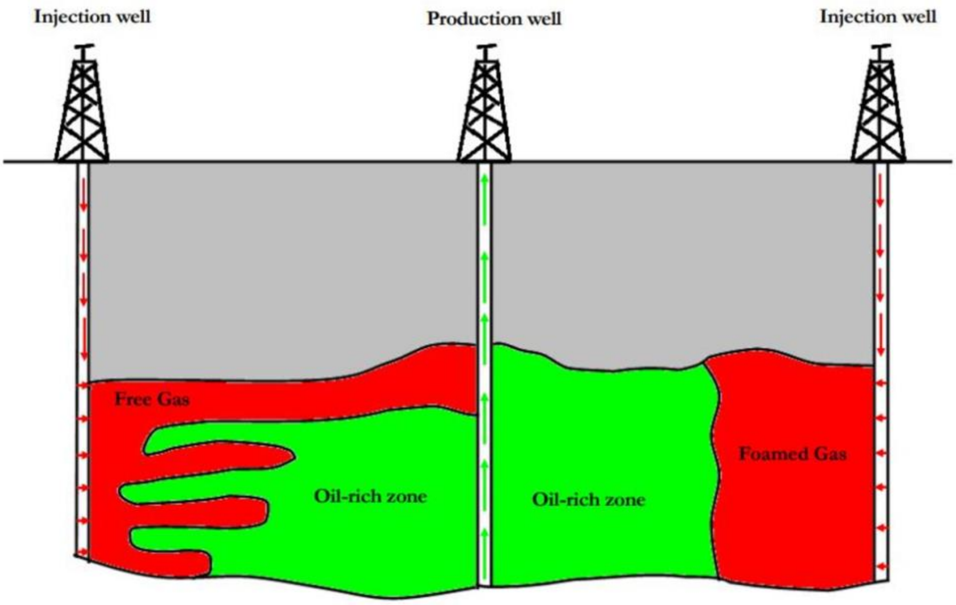

Figure 4.2 On the left: reservoir being swept by free gas causing viscous fingering and gravity override resulting in early gas breakthrough. On the right: a stable foam displacement (Farajzedeh et al., 2010).

4.2 Laboratory Foam Characterization

Foam quality scan (or gas fraction) and rate scan experiments are conducted in the laboratory to characterize foam behavior. Foam quality is the fraction of gas relative to the total of gas and liquid in the foam and can be defined as:

$$f_g = \frac{q_{gas}}{q_{gas}+q_{liquid}} \tag{4.1}$$

Where f_g is the foam quality, q_{gas} is the gas flow rate and q_{liquid} is the flow rate for the liquid (Jones et al., 2016). "High-quality" foam regimes are related to high gas fractions, here foam strength decreases with increasing gas fraction (Boeije & Rossen, 2013).

The foam rate scan experiments with changing injection rates allowed for characterizing shear-thinning behavior of foam and determine the foam strength dependent on different rates. The apparent viscosity of foam as a function of foam quality was used to characterize foam strength and can be described using Darcy's law:

$$\mu_{app} = \frac{K \cdot A \cdot \Delta P}{q_{gas} \cdot L} \tag{4.2}$$

Where K is the absolute permeability of the porous media, A is the cross-sectional area, ΔP is the pressure gradient, q_{gas} is the gas flow rate and L is the length. Gas mobility reduction by foam is described by the apparent viscosity and is an indicator of foam strength. A higher apparent viscosity indicates a stronger foam.

4.3 Foam Generation

Foam is generated through co-injection of surfactant solution and gas or through surfactant-alternating gas injection. When the fluids enter the rock, most liquid separates from the gas. A small amount remains with the gas phase as lamellae. The foam is highly unstable, and the lamellae constantly form and collapse. The main mechanism for generation of foam is leave-behind, snap-off and lamella division (Ransohoff & Radke, 1988). Leave-behind is when the gas enters the pore body from two directions and squeezes the liquid until it forms as a lamella. The foam created by leave-behind is associated with low velocities and are often weak. Figure 4.3 illustrates the mechanism of leave-behind.

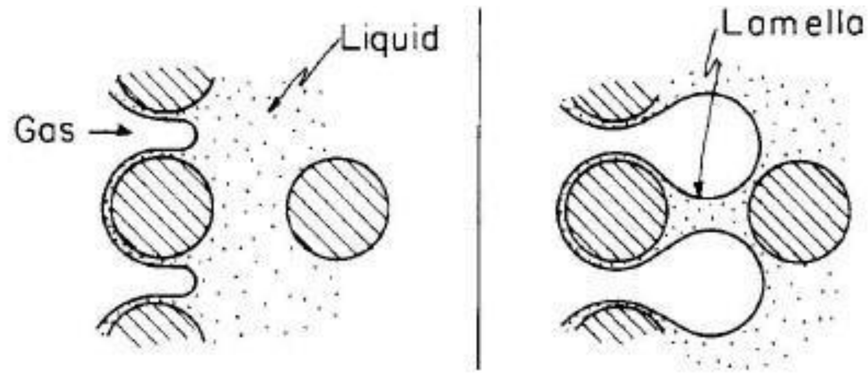

Figure 4.3 Illustration of the foam generating mechanism leave-behind (Ransohoff & Radke, 1988).

Snap-off is the dominating mechanism for foam generation and is illustrated in Figure 4.4. Snap-off occurs by gas fingers entering a fluid-saturated pore through a narrow pore throat, followed by a rapid capillary pressure drop. Because the wetting phase has a strong presence in smaller pores, the gas is separated and significantly reduces the gas mobility (Ransohoff & Radke, 1988).

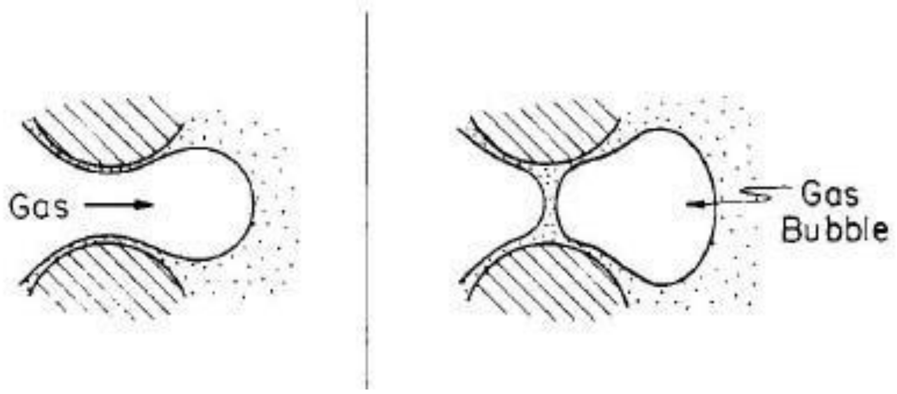

Figure 4.4 Illustration of the foam generating mechanism snap-off (Ransohoff & Radke, 1988).

Lamella division occurs from an existing lamella. When the gas enters a pore with more than one throat, the lamella will divide and create new lamella (Ransohoff & Radke, 1988). Figure 4.5. illustrates lamella division.

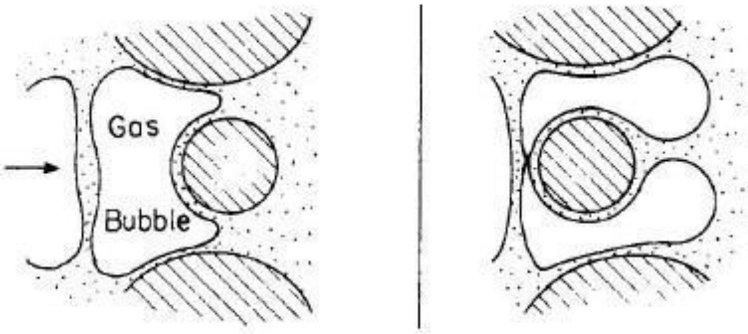

Figure 4.5 Illustration of the foam generating mechanism leave-behind (Ransohoff & Radke, 1988).

4.4 Foam Stability

Foam is thermodynamically unstable and collapses over time (Wasan et al., 1994). Foam stability is described as the ability to withstand collapse of bubbles and depends on several factors including permeability, temperature, pressure, presence of oil and foaming agents.

4.3.1 The Effect of Permeability

The permeability of the reservoir is related to the pressure graduate, where a minimum pressure gradient is required to generate foam. Thus, in heterogeneous reservoir, foam is primarily formed in the high-permeable zones of the reservoir due to low capillary entry pressure (Khatib et al., 1988). Foam flowing into high-permeable zones can result in pore blockage due to lower mobility. Therefore, the foam is diverted into lower permeable layers, increasing recovery by sweeping larger areas of the reservoir (Talebian et al., 2013).

4.3.2 The Effect of Temperature and Pressure

Higher temperatures are an inhibitor for foam generation. The surfactant solubility in the liquid phase is affected by increasing temperatures and leads to less solved surfactant in the gas-liquid interface. Additionally, higher temperatures increase liquid drainage, which destabilize foam. (Sheng, 2013). A higher pressure will stabilize the foam by generating smaller gas bubbles, larger liquid films and slow down the liquid drainage process. The pressure needs to be below the limiting capillary pressure in order to have a stabilizing effect on foam. If the capillary pressure exceeds the limiting capillary pressure it might cause the gas bubbles to break (Sheng, 2013).

4.3.3 The Effect of Oil

It is vital to understand the effect of oil on foam when using foam in EOR applications. The presence of oil has a detrimental effect on the stability of foam in the reservoir. Oil will spontaneously spread on the liquid film and cause it to break and must therefore be below a critical saturation for foam to generate (Ross et al., 1944). The oil may also create an emulsion and sever the stabilizing foam interface (Fried, 1989). In addition, oil can absorb surfactant concentration which is used to stabilize foam (Sheng, 2013).

4.5 Foaming Agent - Surfactants

The presence of foaming agents reduces the interfacial tension between gas and water and are mostly used for stabilization of foam (Sheng, 2013). Surfactants are surface active amphiphilic compounds that consists of a hydrophilic head and hydrophobic tail (Figure 4.6) and occupies the interface between the phases. In the case of foam, occupies the interface between gas and lamellae. Thus, allowing for reduction of IFT between the fluids and increasing foam stability. Surfactants are divided into groups according to the natural charge of the headgroup: Nonionic (no charge), cationic (positive) and anionic (negative).

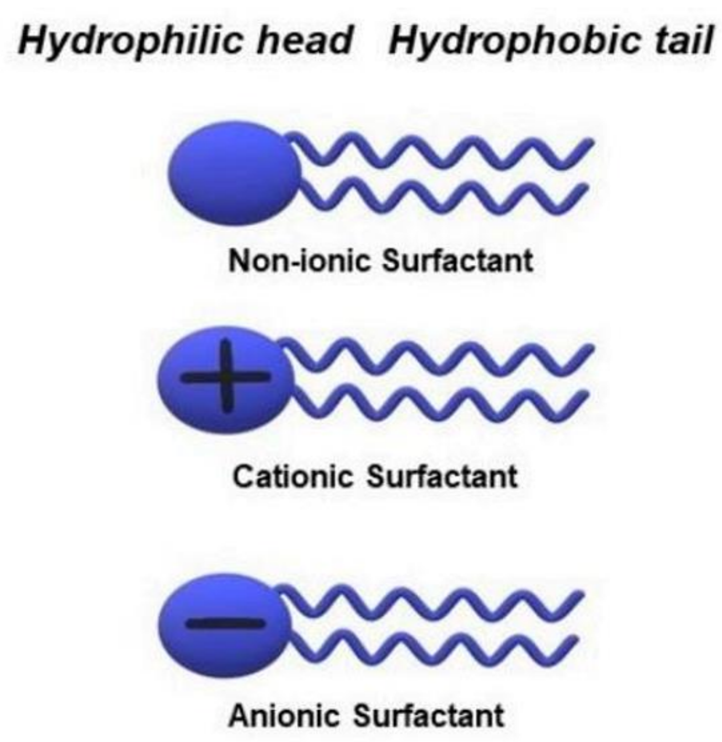

Figure 4.6 Different groups of surfactants depended on surface charge (Soleimani Zohr Shiri et al., 2019).

For field scale application, the surfactant needs to be 1) cost-effective, 2) chemically stable and 3) unaffected by contact with reservoir oil and minerals (Dellinger et al., 1984).

5 Reservoir Simulation

This chapter describes the fundamental principles of reservoir simulation, the governing equations solved for simulation and how to model foam in ECLIPSE.

5.1 Fundamentals Principles of Reservoir Simulation

Reservoir simulation is a form of numerical modeling used to predict fluid flow through porous media. Numerical modeling solves mathematical equations for each phase, in each cell, at each timestep. Reservoir simulation is an important tool for field development and can be used to increase oil and gas recovery. Reservoir simulation is used to forecast field performance for planning both existing and future projects and allows for testing without the economic risk. Figure 5.1 shows an overview of a 3-dimensional reservoir divided into smaller cells.

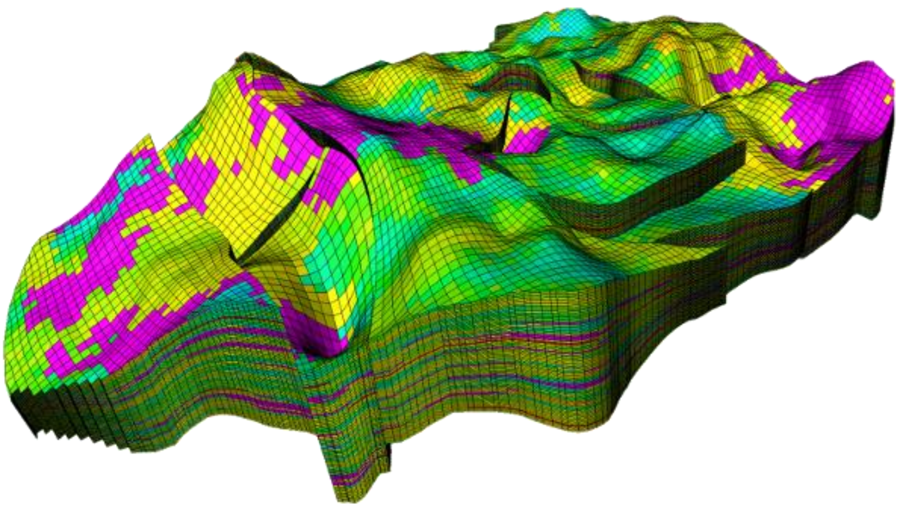

Figure 5.1 Illustration of a 3-dimentional reservoir divided into smaller cells (Correia et al., 2015).

The fundamentals of reservoir simulation consist of dividing the reservoir into smaller grid cells and solving a set of differential equations for modeling the progression of reservoir and fluid properties through time and space (Schlumberger, 2007).

5.2 Governing Equations

Two governing equations that are common for all reservoir simulators are Darcy's Law and the material balance equation (Schlumberger, 2007). Darcy's law describes the volumetric fluid flow in a porous media and assumes laminar flow of incompressible fluid. For a one-dimensional, single-phase flow, Darcy´s law without gravity term is defined as:

$$u = \frac{K}{\mu}\frac{\delta P}{\delta x} \quad (5.1)$$

Where u is the Darcy velocity, K is the absolute permeability, μ is fluid viscosity and P is the fluid pressure.

Material balance equation expresses the mass conservation in the reservoir. Mass flux equals the mass accumulated plus cumulative contribution or loss from injectors or producers (Schlumberger, 2014). The material balance equation can be defined as:

$$-\nabla \cdot M = \frac{\delta}{\delta T}(\rho\phi) + Q \quad (5.2)$$

Where M is the mass flux, ρ is the fluid density, ϕ is the porosity and Q is the volumetric flow. A simulator flow equation that solves each cell at each time step can be described by a combination of Darcy's Law and material balance:

$$\nabla\left[\left(\frac{k_r}{\mu\beta}\right)\left(\nabla P - \rho\frac{g}{g_c}\right)\right] = \frac{\delta}{\delta t}\left(\frac{\phi}{\beta}\right) + \frac{Q}{\rho} \quad (5.3)$$

Where k_r is the relative permeability and β is the volume factor. In order to calculate flow from injection wells to production wells, a well model is required:

$$q_{p,j} = T_{wj}M_{p,j}(P_j - P_w - H_{wj}) \quad (5.4)$$

Where $q_{p,j}$ is the volumetric flow rate of phase p in connection j, T is the transmissibility factor, M is the mobility, P_j is the nodal pressure in grid block containing the connection, P_w is the BHP and H_{wj} is the well pore pressure head. Need to look up the source for this equation.

5.3 Input Data and Syntax in Eclipse

The ECLIPSE compositional simulator (ECLIPSE300) by Schlumberger was used for numerical modeling in this thesis. The parts of the simulation model that tend to influence the flow is (Schlumberger, 2016):

- Flow from one grid block to the next
- Flow from a grid block to the well completion
- Flow within the wells and surface networks

All the parts above are considered in the flow equations solved by Eclipse. The total flow is a product of transmissibility, mobility and potential difference illustrated in figure 5.2 (Schlumberger, 2014).

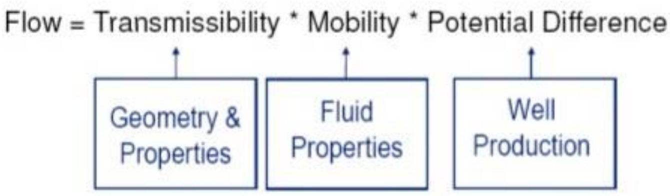

Figure 5.2 Need to fix these figures. Illustration of the flow equation in Eclipse (Schlumberger, 2007).

ECLIPSE runs the model based on an input data file containing a detailed description of the model and simulates the flow in the specific order of the sections in the file. Figure 5.3 shows how the sections in the file are set up:

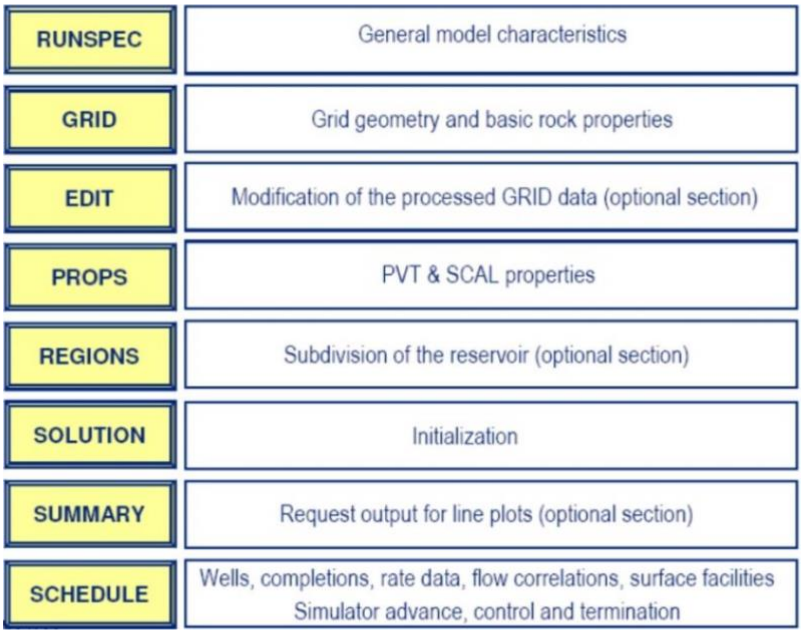

Figure 5.3 Sections in the input data file in ECLIPSE (Schlumberger, 2007).

Figure 5.4 shows the relation between the sections and the flow equation.

Figure 5.4 Illustration of the relation between the flow equation and the section in the input data file (Schlumberger, 2007).

5.4 Foam modeling

Blackoil model (ECLIPSE100) and compositional model (ECLIPSE300) are techniques used for fluid simulation in ECLIPSE. The compositional model was preferred for use in this thesis because of the compositional changes during miscible CO_2 flooding. In the blackoil model, there is not any compositional changes of the fluid with variation in pressure and temperature, however properties are sensitive to the change. In the compositional model, composition changes with varying temperature and pressure. The compositional model requires input of oil and gas components and assumes reservoir fluids can be represented by an Equation of State (EoS) at specific reservoir pressures and temperatures.

Population balance and local equilibrium are the two main approaches to model foam. The population balance explicitly represents the dynamics of lamella creation and destruction, and gas mobility is reduced according to bubble texture. The local equilibrium model implicitly represents the effect of bubble texture by introducing factors for reducing gas mobility (Anderson, 1987). In this thesis, local equilibrium model is used as local equilibrium is assumed at field scale and it offers a simplified approach to reduction of computational effort. Figure 5.5 shows categorization of techniques for modeling the foam. The local equilibrium model assumes instant equilibrium for foam once the gas and liquid meet in the porous media. The model generates foam when pressure and surfactant concentration is sufficient in the respective cells (Schlumberger, 2014).

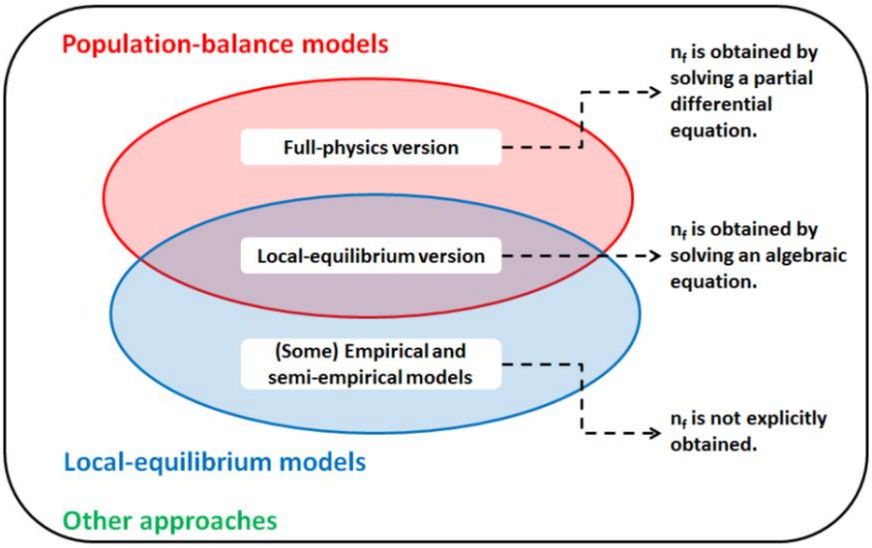

Figure 5.5 Categorization of the techniques used for modeling foam (Anderson, 1987).

The modification of gas relative permeability due to foam ($k_{r,foam}$) was estimated based on relative permeability of CO_2 ($k_{r,g}$) with no foam and the mobility reduction factor (M_{rf}):

$$k_{r,foam} = k_{r,g} \cdot M_{rf} \tag{5.5}$$

The mobility factor is defined as:

$$M_{rf} = \frac{1}{1+(fmmob \cdot F_s \cdot F_w \cdot F_o \cdot F_c)} \tag{5.6}$$

Where $fmmob$ is the reference mobility reduction factor that corresponds to the resistance normalized to flow for minimum bubble size in the absence of factors to increase the bubble size. F_s, F_w, F_o and F_c is the mobility reduction factor cause by surfactant concentration, water saturation, oil saturation and capillary number respectively. All factors can be determined from laboratory experiments.

F_s expresses that lower surfactant concentrations and weaker foams results in a low factor F_s, while higher surfactant concentrations and stronger foams contributes to a higher individual mobility reduction. It is seen from equation (Xx):

$$F_s = \left(\frac{C_s}{C_s^r}\right)^{epsurf} \tag{5.7}$$

Where C_s is effective surfactant concentration, C_s^r is reference surfactant concentration and $epsurf$ indicates rate of change when $C_s = C_s^r$.

The gas mobility reduction due to presence of water is defined as:

$$F_w = 0.5 + \frac{\alpha tan[epdry(S_w - fmdry)]}{\pi} \tag{5.8}$$

Where S_w is the water saturation.

The gas mobility reduction due to presence of oil can be written as:

$$F_o = \left(1 - \frac{S_o}{fmoil}\right)^{epoil} \tag{5.9}$$

Where S_o is the oil saturation.

The gas mobility reduction as a result of the capillary number is defines as:

$$F_c = \begin{cases} (\frac{fmcap}{N_c})^{epcap} & if\ N_c > fmcap \\ 1 & otherwise \end{cases} \tag{5.10}$$

Where N_c is the capillary number that describes the relative effect of capillary and viscous forces.

Foam model parameters that are obtained from laboratory data is the *fmmob*, *fmdry*, *epdry*, *fmcap*, *epcap*, *fmsurf*, *epsurf*, *fmoil* and *epoil*. The equations above are described in greater detail in Schlumberger (2014) and the foam parameters are further described in Sharma (2019).

6 Field Pilot

A CCUS field pilot research program led by the University of Bergen was initiated in 2015 with the aim to optimize and test CO_2 foam for mobility control in heterogeneous reservoirs (Alcorn et al., 2018). The program is an international collaboration between five energy companies and six universities in Norway, USA and the Netherlands.

6.1 East Seminole Field

The CO2 foam pilot was conducted in the East Seminole Field in the Permian Basin of West Texas (Figure 6.1). The field was discovered in the early 1940s and production started in the 1960s with pressure depletion, recovering 12% OOIP. The field was later introduced to water flooding, infill drilling and CO_2 flooding. The latter was initiated in 2013, with an inverted 40 acre 5-spot pattern in the eastern portion of the field. At first the production saw a great increase before taking a turn. The rapid CO_2 breakthrough, high producing gas-oil-ratio and poor sweep efficiency discovered during the CO_2 flooding was likely to be due to an unfavorable mobility ratio and reservoir heterogeneity. The CO_2 foam injection is aiming to mitigate the challenges related to the high CO_2 mobility and reservoir heterogeneity, making the East Seminole Field a good candidate for CO_2 foam injection (Alcorn et al., 2018).

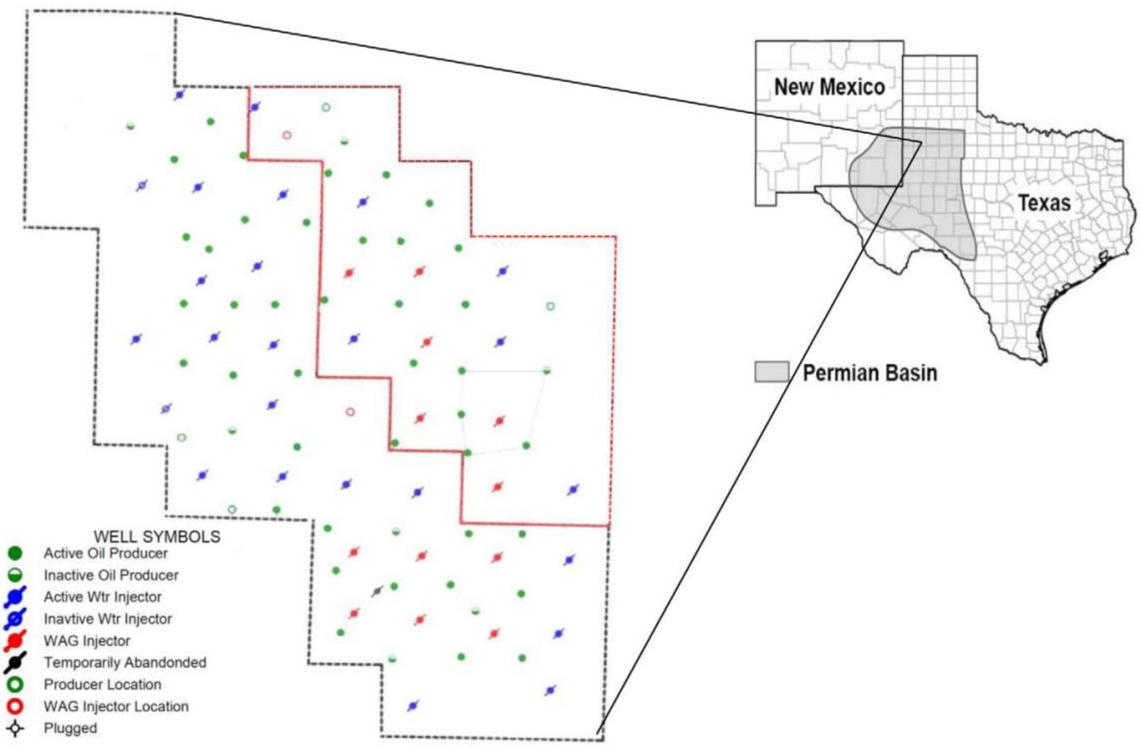

Figure 6.1 Well map of pilot pattern with location of the field in the Permian Basin in West Texas (Alcorn et al., 2018).

6.2 Reservoir Characterization

The East Seminole Field produces from the San Andres formation, that is a heterogeneous carbonate formation in the Permian Basin (Figure 6.2). The San Andres formation is composed of mudstones, wackestones, grainstones, packstones and dolostones (Honarpour et al., 2010). Net pay is 110ft with an average porosity of 13mD, average permeability of 12-15% and thin high permeable zones throughout the pay section with permeabilities up to 300mD. The field has been produced from the main producing zone (MPZ) for over 50 years. Due to a basial tilt and a breach of seal, a deeper residual oil zone (ROZ) was established (Alcorn et al., 2018). The ROZ is located below traditional producing oil-water-contact (OWC). MPZ can be produced using conventional recovery methods, such as pressure depletion and waterflooding. The ROZ contains oil reserves that are only recovered economically feasible by EOR methods (Honarpour et al., 2010). Wells were deepened and completed into ROZ as the tertiary CO_2 floods were initiated in 2013. The reservoir and fluid properties are listed in Table 6.1.

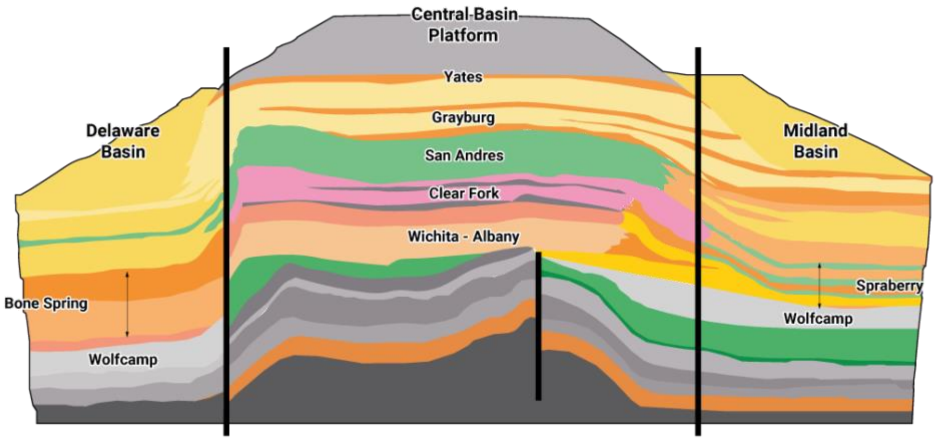

Figure 6.2 San Andres formation in the Permian Basin (Enverus, 2022).

Table 6.1 Reservoir and fluid properties of San Andres formation (Alcorn et al., 2018).

Parameter	Value
Depth	5200 ft
Average Porosity	13 mD
Average Permeability	12-15%
Pay Thickness	110 ft
Reservoir Pressure (Hydrostatic)	2500 psig

Current Reservoir Pressure	3400 psig
Temperature	104° T
Oil Gravity	31° API
Initial Oil Saturation	0.65
Initial Water Saturation	0.35
Oil Viscosity (Reservoir Condition)	1.20 cP
Bubble Point Pressure	1800 psig
Minimum Miscibility Pressure	1500 psig
Average Formation Brine Salinity	70,000 ppm

Part II. Methods

7 Numerical Modeling Methods

This chapter describes the methods used for numerical modeling in this thesis. Foam behavior was investigated in a field-scale radial simulation model for evaluation CO_2 foam mobility reduction. Several sensitivity studies were conducted in order to verify foam generation and improve the model.

7.1 Data Processing, Visualization and Evaluation

Numerical simulations were run in ECLIPSE300, but additional software was used for visualization and data processing, including Petrel, FloViz and Office. Petrel was used for processing and extracting the data needed from the simulation results. Because Petrel is not able to visualize the radial grid, FloViz was an important tool for visualization. Office was used for visualizing the radial grid sliced in 2D.

7.2 Model Description

The radial model is based upon a history-matched (HM) sector model that includes historical water and CO_2 injection from the East Seminole Field. The model was built by Dr. Zachary Paul Alcorn (2018) from University of Bergen and Mohan Sharma (2019) from National IOR Centre of Norway at the University of Stavanger. The sector model (Figure 7.1) covers 1.5 km^2 of the East Seminole Field and includes the pilot five spot well pattern and surrounding wells. The radial model used in this thesis was an area taken out around the foam pilot injector, I1.

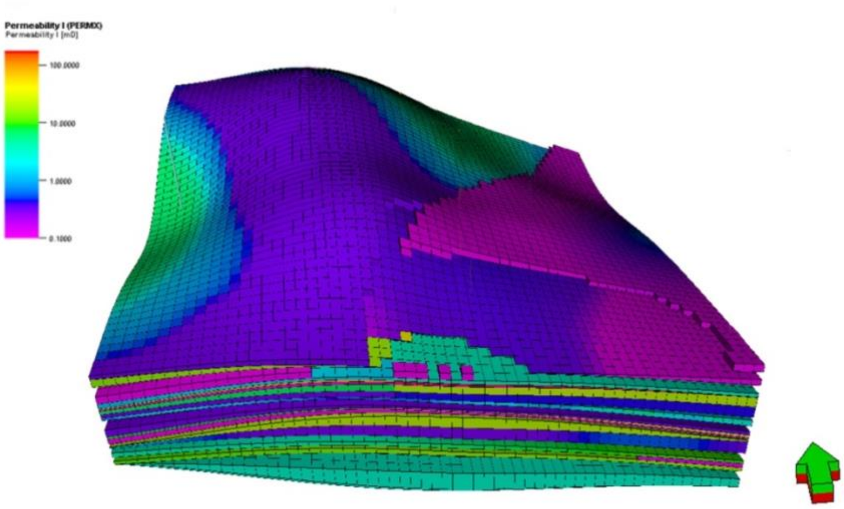

Figure 7.1 The East Seminole field pilot sector model (Alcorn et al., 2017).

7.3 Radial Model Set-up

The model was composed of 560 active grid cells that were divided into 28 layers, centered around an injection well. The grid sizes increased logarithmically from the injector to a total of 700 ft. Figure 7.2 shows the radial model with respect to permeability, with 20 radial grid blocks and 28 vertical grid blocks. The model was used to simulate 11 cycles of SAG injection during the pilot period. The radial model parameters are shown in Table 7.1.

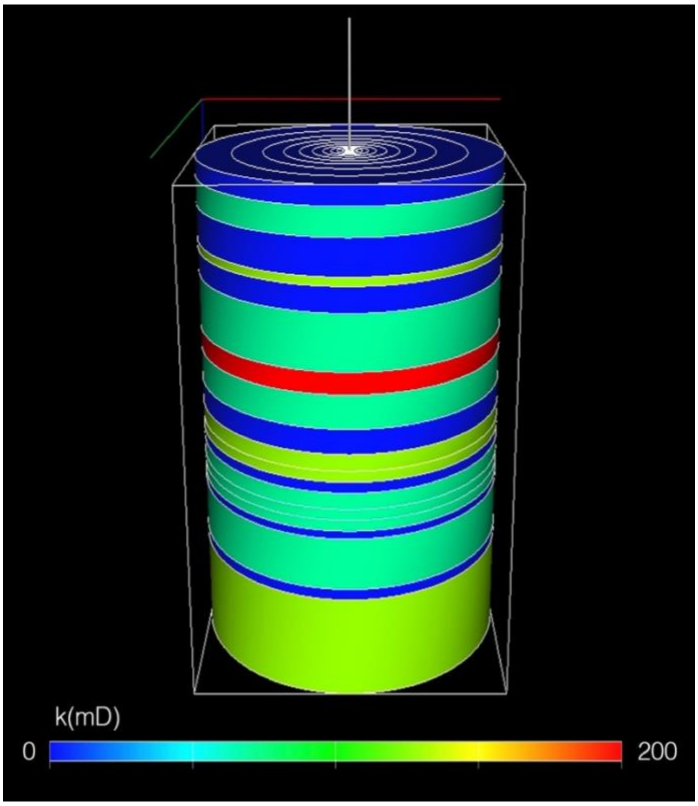

Figure 7.2 Permeability distribution in the radial model.

Table 7.1 Radial model properties (Alcorn et al., 2022).

Parameter	Value
Grid Dimensions (r, θ, z)	20 × 1 × 28
Outer Radius	700 ft
Total Thickness	145 ft
Initial Water saturation	0.50
Initial Reservoir Pressure	3118 psig
Reservoir Temperature	104 °F
Average Permeability	13.5 mD

Average Porosity	0.08

7.4 Fluids and Rock Characterization

A conventional finite-difference compositional model was set up by using Peng-Robinson Equation of State (EoS) for calculating phase behavior. The EoS model was tuned to available PVT data (Figure 7.3) collected from oil samples from MPZ. Two aqueous phases: water and surfactant solution, and six hydrocarbon components, including a separate CO_2 component, was used in the model (Sharma, 2019). Fluid composition measured from MPZ and ROZ are listed in Table 7.2. The fluid model was fit to the available PVT data from differential liberation, swelling and constant compositional expansion (Figure 7.3) (Sharma, 2019).

Table 7.2 Fluid composition measured in the main pay zone (MPZ) and residual oil zone (ROZ) (Sharma, 2019).

Component	Fluid Composition (mol%)	
	MPZ	ROZ
N_2	0.51	0.04
CO_2	2.47	0.02
H_2S	1.96	0
C1	24.65	20.1
C2	9.1	9.07
C3	7.57	6.95
iC4	1.41	0.04
iC5	1.76	0.04
nC5	2.03	2.49
C6	3.54	2.69
C7+	40.97	54.66

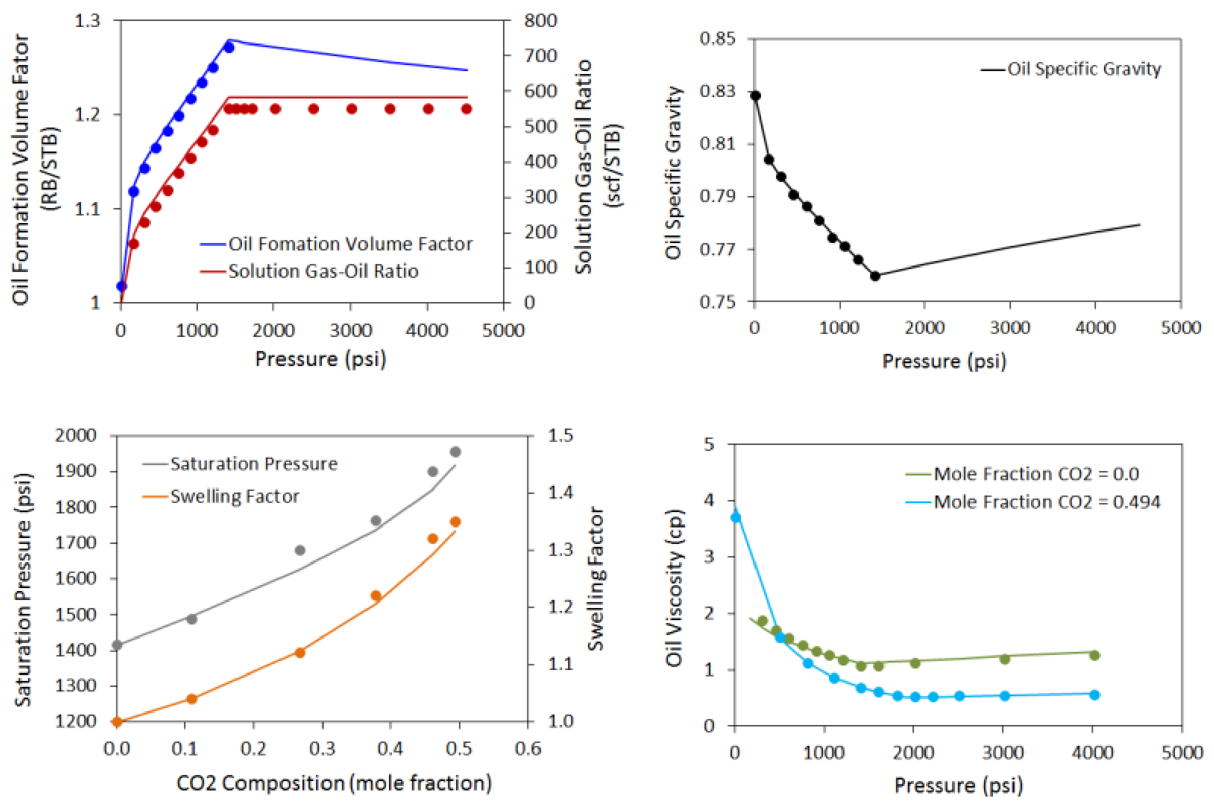

Figure 7.3 The fluid model compared to available pressure, volume and temperature (PVT) data. The dots represent the experimental data and the line represent the tuned equation of state (EoS) in model (Sharma, 2019).

The reservoir was found to have a mixed wettability with a tendency towards oil-wet conditions (Honarpour et al., 2010). The relative permeability curve for two-phase oil-water and gas-oil permeability curves (Figure 7.4) was calculated based on a Modified Brooks-Corey (MBC) model (Brooks and Corey, 1964). The model is dependent on parameters from core flooding experiments.

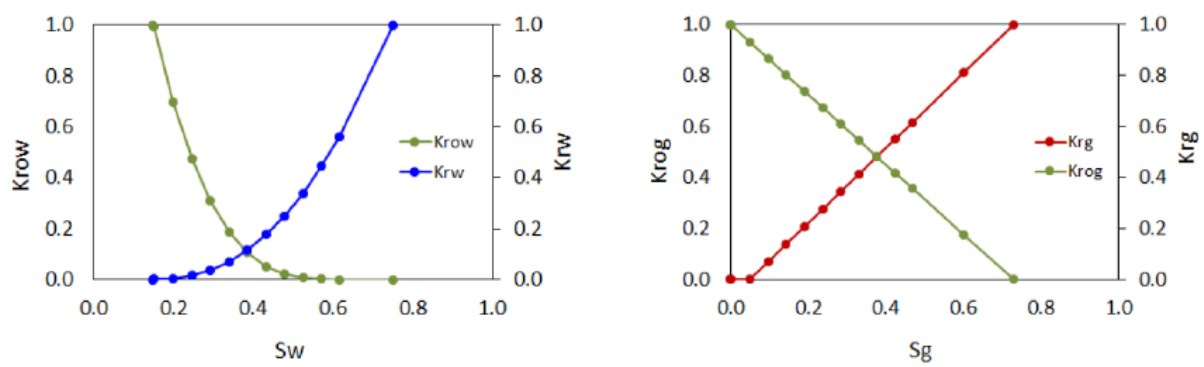

Figure 7.4 Relative permeability curve for water-oil and gas-oil retrieved from core flood experiments and tuned for Modified Brooks-Corey model (Sharma, 2019).

The foam model was simulated with a local-equilibrium model described in chapter 5.4. The foam model parameters were derived from the foam quality and rate scan experiments by curve-fitting regression (Sharma 2019). Figure 7.5 shows regression estimated values for the Base case foam model with foam model parameters from Table 7.3. The surfactant used in the pilot had a low adsorption on the reservoir core material in laboratory (Jian et al., 2016). To avoid a significant increase in runtime, the surfactant adsorption was not excluded from the model (Sharma, 2019).

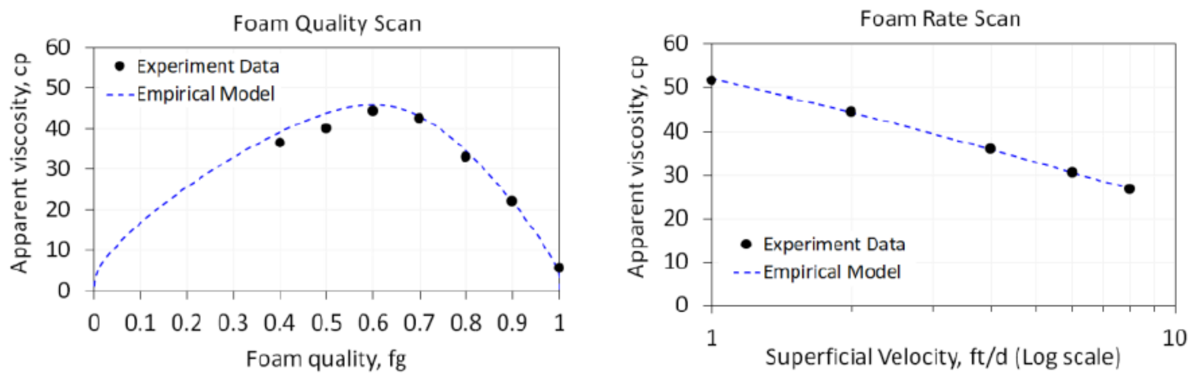

Figure 7.5 Foam quality scan (left) and rate scan (right) was used to create foam model 1 by fitting experimental data (black dots) to an empirical model (blue dotted line) (Sharma, 2019).

Table 7.3 Base foam parameters.

Foam Parameter	Value
fmmob	41.5
fmdry	0.595
epdry	35
fmcap	2.14×10^{-6}
epcap	0.28

7.5 Model Initialization

The injection scheme for the radial model is presented in Figure 7.6, from pilot injection start to post-pilot injection end. The data file is attached in appendix A. The Base SAG injection with 10 days surfactant solution followed by 20 days of CO_2, began in May 2019 and ended in August 2020.

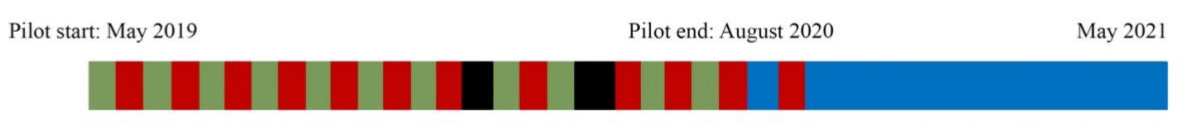

Figure 7.6 Overview of the injection scheme for the radial model in the pilot. Surfactant solution injection (green), CO_2 injection (red), water injection (blue) and no injection (black).

7.6 Foam generation verification

Foam generation and CO_2 mobility reduction were verified in the radial model during SAG injection. Plotting injected bottom hole pressure (BHP) for Base SAG and comparing it to its Baseline WAG without surfactant and calculating average BHP was used to verify foam generation and foam strength. A higher BHP indicated a stronger foam. In addition, CO_2 mobility reduction was verified by a more gradual decline in BHP during the CO_2 slug injection of Base SAG, compared to its Baseline WAG, due to foam generation and increased CO_2 viscosity. CO_2 injectivity was calculated with equation (3.1) and plotted versus CO_2 days injected for Base SAG and Baseline WAG. CO_2 injectivity was used as a measure of CO_2 mobility reduction in presence of foam. A reduction in injectivity index is an indication of CO_2 mobility reduction.

7.7 Sensitivity studies

7.7.1 Foam model parameter sensitivity

The main objective was to evaluate how sensitive the injection BHP was to changes in the local equilibrium foam model parameters. As mentioned previously, injection BHP is used as a measure of foam generation and strength, where a higher BHP corresponds to a stronger foam. The effect of the foam model parameters *fmmob*, *fmdry* and *foamfso* were evaluated and the two first parameters were tuned to achieve a suitable match to the observed BHP from the foam pilot. The different parameters were derived from laboratory data.

- *Fmmob* is the maximum gas mobility reduction factor.
- *Fmdry* is the water saturation at which foam dries out.
- *Foamfso* is the oil saturation which foam ceases to be affected.

Foam model 1 and 3 with foam model parameters listed in Table 7.4-5 was tuned with low, medium and high *fmmob* to evaluate how sensitive the injected BHP was to changes I the parameters.

Table 7.4 Local equilibrium foam parameters for foam model 1 with low, medium and high *fmmob* value.

Parameter	1 (Base)	S1	S2	S3
fmmob	**41.5**	**15**	**60**	**250**
fmdry	0.595	0.595	0.595	0.595

epdry	35	35	35	35
fmcap	2.14×10^{-6}	2.14×10^{-6}	2.14×10^{-6}	2.14×10^{-6}
epcap	0.87	0.87	0.87	0.87
foamfso	0.28	0.28	0.28	0.28

Table 7.5 Local equilibrium foam parameters for foam model 3 with low, medium and high *fmmob* value.

Parameter	3	S4	S5	S6
fmmob	**192**	**10**	**60**	**250**
fmdry	0.4	0.4	0.4	0.4
epdry	84	84	84	84
fmcap	9.0×10^{-7}	9.0×10^{-7}	9.0×10^{-7}	9.0×10^{-7}
epcap	0.59	0.59	0.59	0.59
foamfso	0.28	0.28	0.28	0.28

Sensitivity study of foam model 1 with low *fmmob*, S1, was tuned with low, medium and high *fmdry*. The foam model parameters are seen in Table 7.6.

Table 7.6 Local equilibrium foam parameters for foam model 1 with low *fmmob* and low, medium and high *fmdry* value.

Parameter	S1	S7	S8	S9
fmmob	15	15	15	15
fmdry	**0.595**	**0.2**	**0.4**	**0.6**
epdry	35	35	35	35
fmcap	2.14×10^{-6}	2.14×10^{-6}	2.14×10^{-6}	2.14×10^{-6}
epcap	0.59	0.59	0.59	0.59
foamfso	0.28	0.28	0.28	0.28

Effect of oil on foam was evaluated with sensitivity study S10, S11 and S12 (Table 7.7) for different *foamfso* values.

Table 7.7 Local equilibrium foam parameters for S10, S11 and S12.

Parameter	S10	S11	S12
fmmob	15	15	15

fmdry	0.6	0.6	0.6
epdry	84	35	35
fmcap	9.0×10^{-7}	2.14×10^{-6}	2.14×10^{-6}
epcap	0.59	0.59	0.59
foamfso	**0.28**	**0.15**	**0.40**

7.7.2 Injection Strategies

Four different injection strategies were implemented to evaluate which strategy generated the strongest foam and reduced CO_2 mobility the most. The bottom hole pressure and injectivity index of each strategy was used for comparison. A higher BHP compared to the baseline indicated that foam was generated. Injectivity is a standard way of evaluating how easy it is to inject a fluid at a given pressure. CO_2 injectivity was calculated with equation 3.1 and was used as a measure of CO_2 mobility reduction in presence of foam. A reduction in CO_2 injectivity is an indication of CO_2 mobility reduction. All strategies kept the same cumulative reservoir volume injected, and pre- and post-pilot data was kept the same. The SCHEDULE section of the simulation DATA file was changed for the Base SAG during the pilot period to create a Single cycle SAG, Extended SAG and Co-injection. All strategies were volumetrically sized to target a 60-70% foam quality as determined from laboratory experiments.

Base Case SAG

The Base SAG injection scheme consisted of 11 cycles of 10 days of surfactant injection, followed by 20 days of CO_2 (Figure 7.7). The green periods represent surfactant injection and the red periods represents CO_2 injection.

Figure 7.7 Schematic of the Base surfactant-alternating-gas (SAG) injection strategy. The green periods represent surfactant injection and the red periods represents CO_2 injection.

Single Cycle SAG

Single cycle SAG consisted of one surfactant slug of 110 days, followed by one CO_2 slug of 220 days, for one single cycle (Figure 7.8). The green period represents surfactant injection and the red period represents CO_2 injection.

Figure 7.8 Schematic of Single Cycle surfactant-alternating-gas (SAG) injection strategy. The green period represents surfactant injection and the red period represents CO_2 injection.

Extended SAG

Extended SAG doubled the base case SAG, with 20 days of surfactant injection and 40 days of CO_2 injection, for 5 cycles (Figure 7.9). The green periods represent surfactant injection and the red periods represents CO_2 injection.

Figure 7.9 Schematic of the Extended surfactant-alternating-gas (SAG) injection strategy. The green periods represent surfactant injection and the red periods represents CO_2 injection.

Co-injection

Co-injection of surfactant solution and CO_2 was also implemented. Co-injection lasted for 330 days (Figure 7.10). The green represents surfactant injection and the red represents CO_2 injection.

Figure 7.10 Schematic of the Co-injection injection strategy. The green represents surfactant injection and the red represents CO_2 injection.

7.6.4 Propagation Distance

Propagation distance of the four injectivity strategies were investigated to evaluate how far the foam propagated from the well, into the reservoir. Office was used for visualizing the radial grid sliced in 2D and showed foam concentration in the different layers as a function of time. A snapshot was taken to visualize foam concentration before surfactant injection, mid pilot surfactant injection, end of pilot and end of simulation after waterflooding.

7.8 Capturing Shear Thinning Effect

To account for the shear thinning effect in the model, an extra region was specified in the data file, twenty feet around the injection well, where foam parameters were assigned to represent a no foam region (Table 7.4).

Table 7.4 Local equilibrium foam parameters assigned to the "no foam" region of Base SAG and rest of the reservoir.

Parameter	Rest of reservoir	"No foam" region
fmmob	41.5	0
fmdry	0.595	0.99
epdry	35	1
fmcap	2.14×10^{-6}	7.8×10^{-7}
epcap	0.87	0.65

Fmdry parameter is set to 0.99 in the region where foam is not supposed to form. That is because the foam will dry out at water saturation below 99% and there is not going to be that high water saturations in the that region.

7.9 Grid Resolution

The grid resolution was increased to see if the model was sensitive to grid resolution and could capture the physics better by creating smaller grid cells (i.e., coarser grid cells might oversee important phenomena like the gravity effect if the grids cells are too coarse to visualize how the CO_2 is pushing to the top of the layer). The radial model is initially a 2D model, but the model grid was extended to the theta direction in the data file and became a 3D model (Figure 7.11).

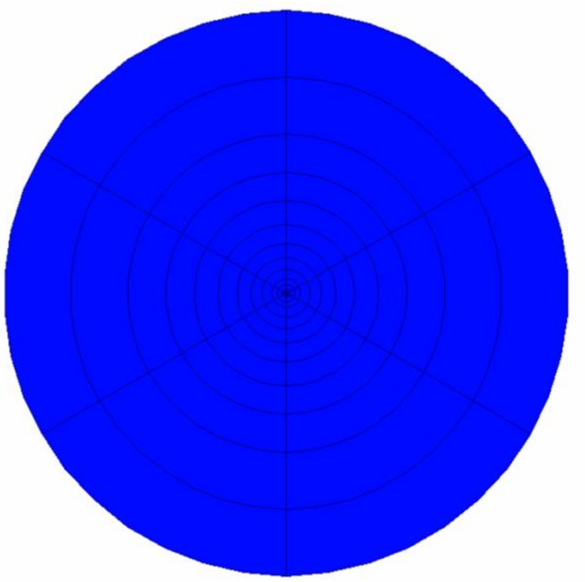

Figure 7.11 2D slice of the radial grid refined in the theta direction.

Part III. Results and Discussion

8 Numerical Modeling

This chapter presents the numerical modeling results of the radial model representing the field pilot in the East Seminole Field. The main objective was to evaluate if foam was generated, how strong it was and how far it propagated from the injection well. In addition, a foam model sensitivity study was conducted to improve the model to fit to the observed data from the pilot. Below foam generation verification, the foam model sensitivity study, grid resolution sensitivity study and the injection strategy sensitivity study are presented.

8.1 Foam Generation Verification

Injection bottom hole pressure (BHP) and CO_2 injectivity index were analyzed to verify foam generation and CO_2 mobility reduction in the radial model during SAG injection. The Base SAG foam model was created based upon experiments in the presence of residual oil to create a realistic condition in the field with core properties representative for most of the reservoir. The Base SAG foam model is described in section 7.4. For comparison and verification of foam generation, a Baseline WAG was also set up, injecting water instead of surfactant solution in the liquid phase. Without a foaming agent present, foam is not expected to generate (Chou, 1991).

8.1.1 Foam Generation

Injection BHP was used to verify that foam was generated by comparing the Baseline WAG to the base SAG. Figure 8.1 shows the BHP as a function of time for baseline WAG (blue curve) and the Base SAG (red curve), and the cycle number is seen in green below the curves. Due to operational reasons that influenced the BHP after the 8^{th} cycle, only the first seven cycles of the pilot were plotted. The average BHP for SAG was 3882 psi, a 12% higher value than for WAG with 3463 psi. Since no foam could be generated during WAG, 3463 psi was set as a foam generation limit in this thesis. The BHP during WAG rose from 3295 psi to 3618 psi in the first CO_2 cycle, which gave an increase of 10%, whereas for SAG, the BHP rose from 3295 psi to 3740 psi, a 14% increase for Cycle 1. In the next cycle, BHP during WAG rose from 3338 psi to 3537 psi, whereas for SAG rose from 3445 psi to 4399 psi. The WAG increased with 6% and SAG increased with 28%, indicating that SAG was influenced by the surfactant injected in the first cycle, generating a stronger foam in Cycle 2.

When only slugs of water and CO_2 were injected during WAG, the BHP of the water slugs showed a steep slope, then stayed almost constant before dropping instantly when injecting CO_2. At reservoir conditions, the water viscosity is much higher than the CO_2 viscosity and therefore the BHP increased after water was injected and dropped instantly when injecting CO_2. Introducing surfactant into the liquid phase, the BHP curve for SAG had a gradual pressure build-up before slowly decreasing when CO_2 was injected. The surfactant increases the viscosity of the injected CO_2, hence reducing the CO_2 mobility, which leads to a more favorable mobility ratio between the injected phases. It is shown on the graph as smoother curve, as seen for the SAG cycles in Figure 8.1. A favorable mobility ratio mitigates poor sweep efficiency with CO_2 injection and delays the breakthrough of gas that will result in increased recovery (Lyons, 2010).

The simulated BHP is always higher than the observed because the simulation is overestimating foam generation. The simulator assumes local equilibrium, and if there is sufficient surfactant concentration and CO_2 in the cell, there is going to be foam. Steady state is assumed for the foam models to extract the parameters needed in the laboratory. The simulator struggles with capturing the shear thinning effect that occurs when rates are high. In reality, there is no equilibrium in the reservoir near the well and rates are so high that the saturation is changing dramatically between the gas and liquid phase.

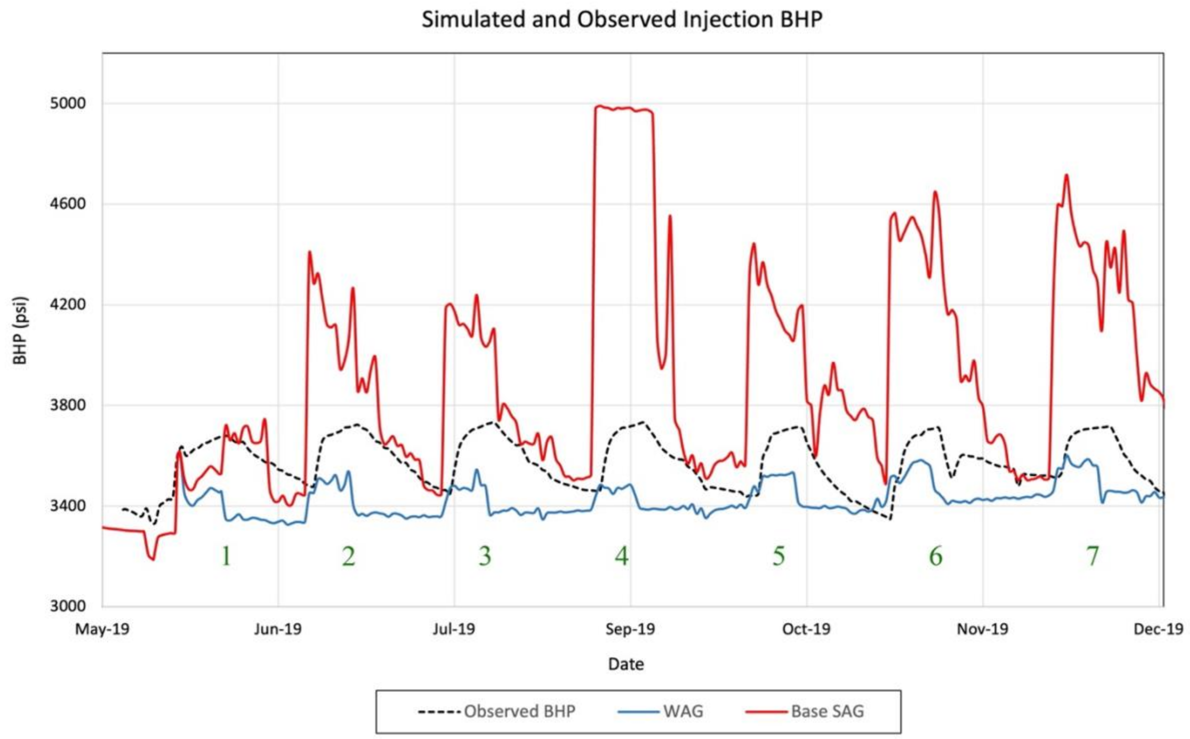

Figure 8.1 Bottom hole pressure (BHP) versus time for water-alternating-gas (WAG) (blue curve) and Base surfactant-alternating-gas (SAG) (red curve) with cycles (green number) below the curves for first 7 cycles.

8.1.2 Injectivity Index

Calculated injectivity index for the injection well was used to verify that foam was being generated to determine the degree of CO_2 mobility reduction. The injectivity index gives information on how easily a fluid is injected at a given pressure. A higher injectivity index value indicates less resistance to flow.

If the foam succeeds in reducing CO_2 mobility, it will show as a lower injectivity index. It is a valuable tool in foam simulation that is influenced by many reservoir-specific parameters including permeability (Tawiah et al., 2020). Figure 8.2 shows the calculated injectivity index as a function of days of CO_2 injection for baseline CO_2 injection period before pilot (black curve) and for the first six CO_2 slugs of baseline WAG. The average injectivity index for the first six CO_2 slugs for WAG was 1.66 $\frac{MSCF}{day}/psi$ and showed a small reduction compared to before the pilot that had an injectivity index of 1.79 $\frac{MSCF}{day}/psi$. The reduction was due to the ability of WAG to reduce CO_2 mobility by reducing CO_2's relative permeability at high water saturations.

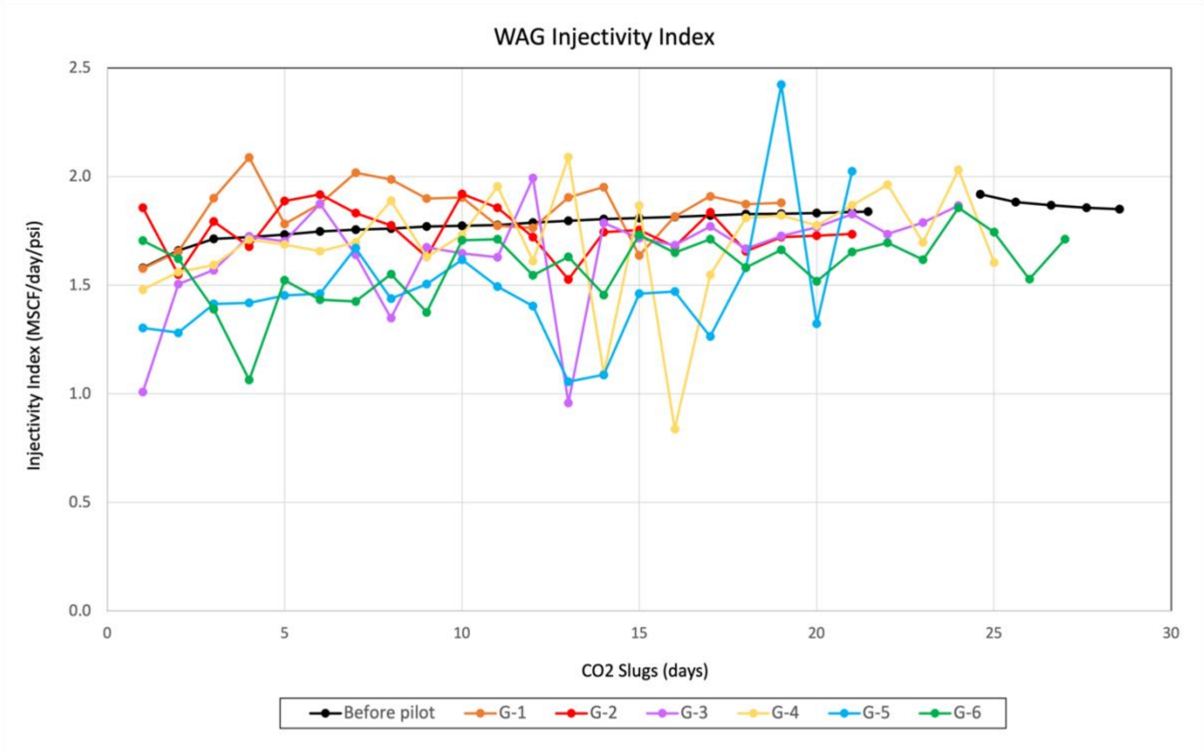

Figure 8.2 Injectivity index versus days of CO_2 injection for baseline water-alternating-gas (WAG). Black curve is before pilot.

Figure 8.3 shows the calculated injectivity index as a function of days of CO_2 injection for Base SAG. The figure shows the baseline CO_2 injectivity before pilot (black curve), the injectivity of the first six CO_2 slugs of SAG and CO_2 injectivity post-pilot (dark blue curve). The average injectivity index for the first six CO_2 slugs for SAG was 1.17 $\frac{MSCF}{day}/psi$, a significantly lower injectivity index than before the pilot, that had an average injectivity index of 1.79 $\frac{MSCF}{day}/psi$. The decrease in injectivity during the first six CO_2 slugs of the SAG, resulted in more resistance to flow and indicated that foam was generated during the pilot.

Comparing Figure 8.2 with Figure 8.3, the average injectivity index for Base SAG was lower than the average injectivity index for Baseline WAG with a 35% decrease. The CO_2 slugs for SAG started at a lower injectivity because CO_2 meets the surfactant that was just injected in the liquid phase and foam was created. The fluids injected do not come together all in equal amounts in the reservoir when it is injected in a surfactant alternating gas mode. First, a section of water and surfactant will fill some pore space, before a section of gas is injected that mixes with the surfactant in some zones and creates foam. As the CO_2 is being injected, the foam front is pushed out in the reservoir away from the well. That leaves more CO_2 around the well and injectivity of CO_2 increases. This behavior was not seen for the WAG as the WAG injectivity was steady and higher. The post-pilot CO_2 injectivity index (dark blue curve in Figure 8.3), showed that the injectivity index was still low after the pilot compared to the injectivity index before the pilot (black curve). It appears that even though the surfactant injection had stopped, foam was still reducing injectivity near the well.

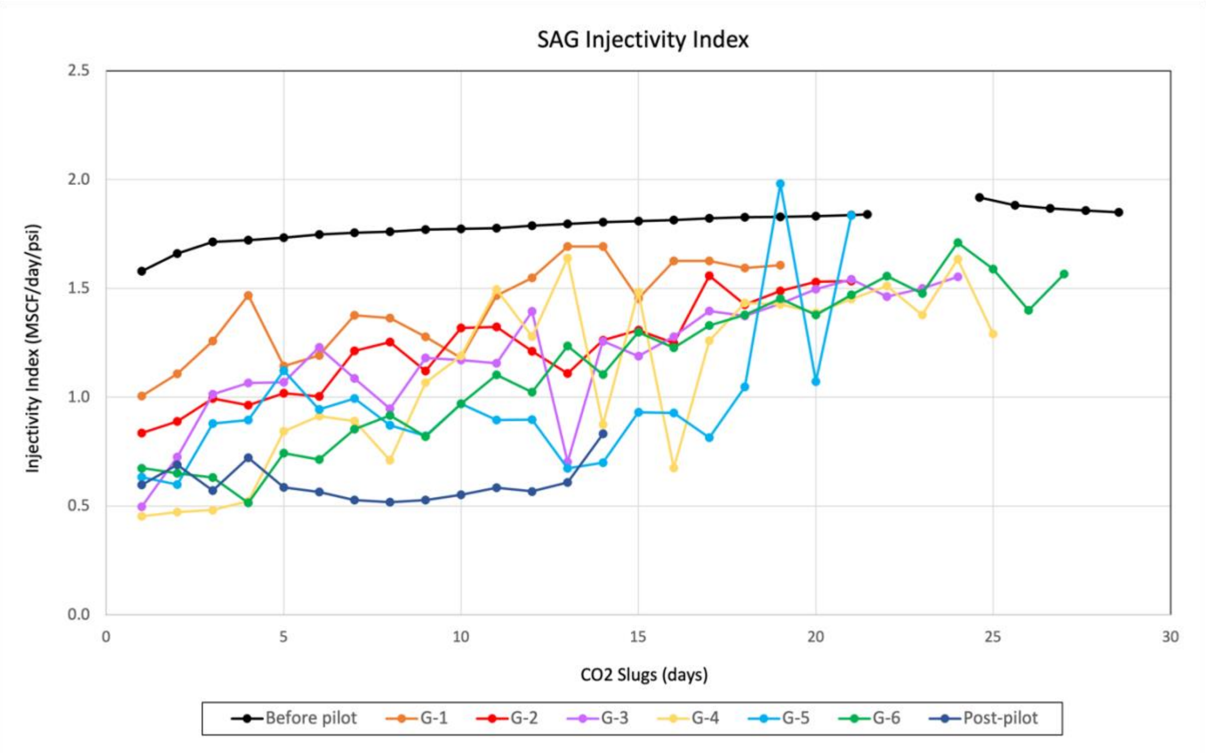

Figure 8.3 Injectivity index versus days of CO_2 injection for Base surfactant-alternating-gas (SAG). Black curve is before pilot.

8.2 Foam Model Sensitivity

This chapter presents the sensitivity study of local equilibrium foam model parameters. The main objective was to evaluate which foam model parameter had the biggest impact on the injected BHP and foam strength. The effect of the foam model parameters *fmmob*, *fmdry* and *foamfso* were evaluated and the two first parameters were tuned to achieve a suitable match to the observed BHP from the foam pilot. Figure 8.4 shows the initial four foam models that were evaluated. All foam model parameters were derived from laboratory data and is described in section 7.7. Base SAG uses foam model 1 in this study. Figure 8.4 shows BHP as a function of time for the four different foam models and the baseline WAG. The blue curve is the baseline WAG with no surfactant, generating no foam at all. The black dotted curve is the observed data from the field pilot and the remaining curves are the models with parameters listed in Table 8.1.

Table 8.1 Local equilibrium foam parameters for foam models derived from laboratory data.

Parameter	1 (Base)	2	3	4
fmmob	41.5	108	192	248
fmdry	0.595	0.27	0.4	0.313
epdry	35	100	84	46.8
fmcap	2.14×10^{-6}	7.80×10^{-7}	9.0×10^{-7}	8.50×10^{-7}
epcap	0.87	0.65	0.59	0.71
foamfso	0.28	0.28	0.28	0.28

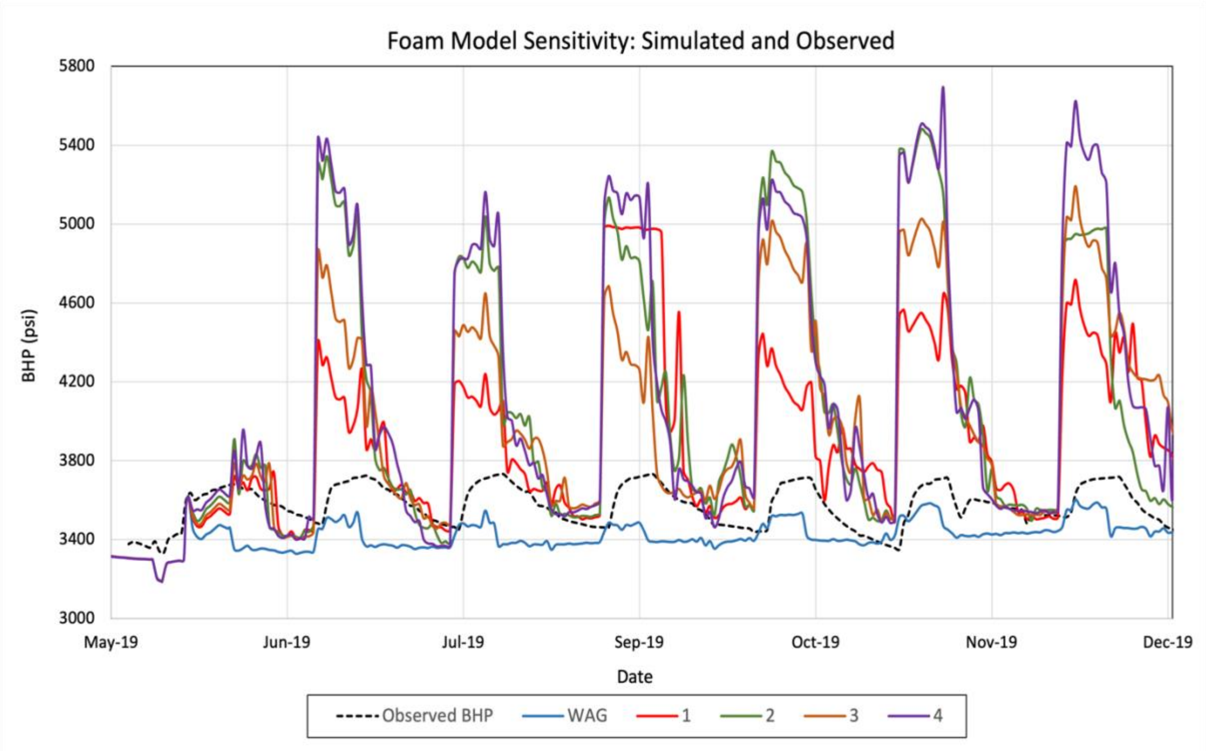

Figure 8.4 Injection bottom hole pressure (BHP) as a function of time for observed (black dotted curve), watrer-alternating-gas (WAG) (blue curve), Base surfactant-alternating-gas (SAG) foam model 1 (red curve), SAG foam model 2 (green curve), SAG foam model 3 (orange curve) and SAG foam model 4 (purple curve).

8.2.1 Effect of fmmob parameter

The *fmmob* foam model parameter is the maximum gas mobility reduction factor. It gives the maximum amount the foam can reduce the CO_2 mobility (i.e., with a *fmmob* value of 10, the foam can reduce the CO_2 mobility by ten times). The values chosen in this study were based on the value range seen in experimental work. It is expected that a higher value of *fmmob* generates a stronger foam That shows on the graph as a higher BHP as seen in Figure 8.4 for foam model 2 (*fmmob*=108) and 4 (*fmmob*=248) with average BHP 4042 psi and 4100 psi respectfully. Foam model 1 and 3 were closer to the observed BHP and was therefore used for further study of the foam parameters sensitivity

***Fmmob* of Foam Model 1 (Base case)**

Figure 8.5 shows BHP as a function of time for WAG (blue curve), observed from the pilot (black dotted curve), foam model 1 (red curve), and foam model 1 with adjusted *fmmob* values. A low (15), medium (60) and high (250) *fmmob* value was used to compare and see how the parameter affects the BHP. Table 8.2 shows the parameter ranges for the *fmmob* sensitivity for foam model 1. From Figure 8.5, S3 (purple curve), gave a higher BHP through all cycles, with an 5% higher average BHP than S1 (green curve). S1 was the graph closest to the observed data and was investigated with a low, medium and high *fmdry* value in the next section. The *fmdry* gives the lowest water saturation where foam is effective.

Table 8.2 Local equilibrium foam parameters for foam model 1 with low, medium and high *fmmob* value.

Parameter	1 (Base)	S1	S2	S3
fmmob	**41.5**	**15**	**60**	**250**
fmdry	0.595	0.595	0.595	0.595
epdry	35	35	35	35
fmcap	2.14×10^{-6}	2.14×10^{-6}	2.14×10^{-6}	2.14×10^{-6}
epcap	0.87	0.87	0.87	0.87
foamfso	0.28	0.28	0.28	0.28

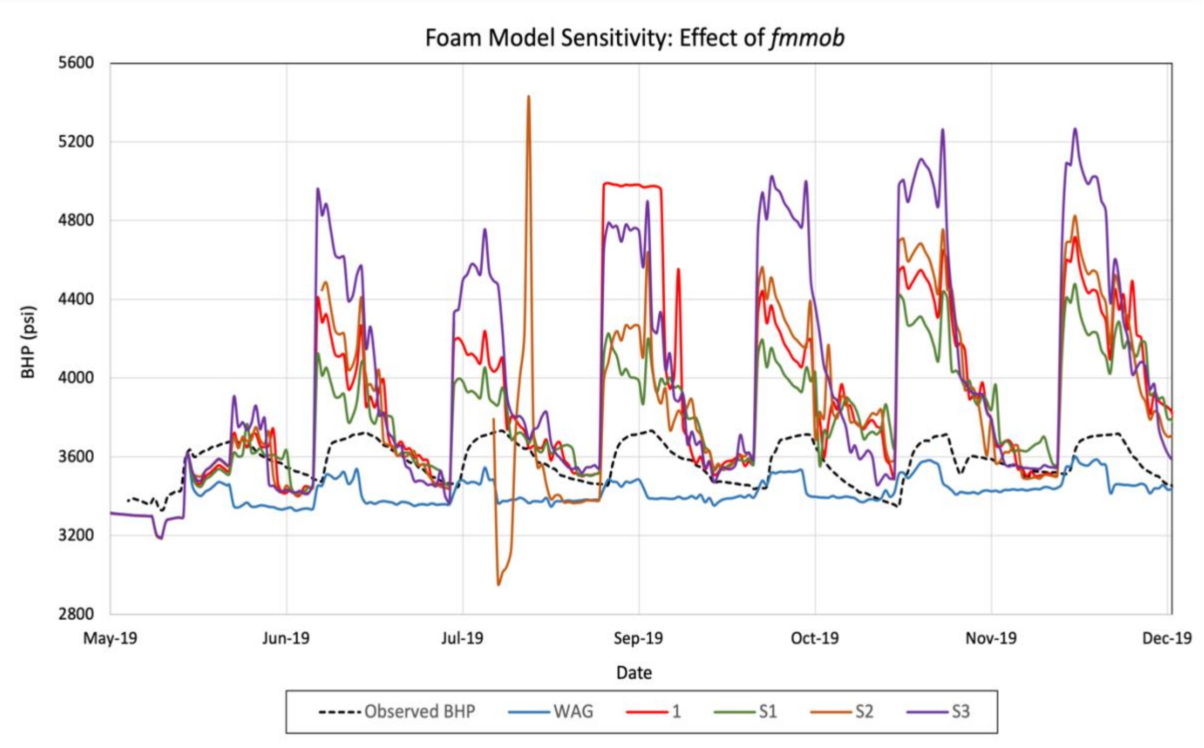

Figure 8.5 Injection bottom hole pressure (BHP) as a function of time for water-alternating-gas (WAG) (blue curve), observed data from pilot (black dotted curve), foam model 1 (red curve), and foam model 1 with low(15), medium(60) and high(250) *fmmob*.

***Fmmob* of Foam Model 3**

Figure 8.6 shows the BHP of baseline WAG (blue curve), foam model 3 (red curve) and foam model 3 with tuned low (10), medium (60) and high (259) *fmmob* values, and the observed BHP from the pilot (black dotted curve). Table 8.3 shows the parameter ranges for the *fmmob* sensitivity for foam model 3. For low *fmmob*, a small change in the value makes a bigger impact on the BHP. Tuning the *fmmob* from 10 to 60, gave a 7% increase in average BHP compared to changing from 60 to 250 which gave a 3% increase. Comparing the regular foam model 3 (192) with high *fmmob* (250), showed only a 0.5% increase in average BHP and indicates that the model is reaching a maximum foam strength for this particular set of parameters. S4 (green curve) had a lower average BHP as assumed because the model's maximum ability to reduce CO_2 mobility was lower. In addition, S4 followed a similar trend with the curve as the observed data, compared to the other models.

Table 8.3 Local equilibrium foam parameters for foam model 3 with low, medium and high *fmmob* value.

Parameter	3	S4	S5	S6
fmmob	**192**	**10**	**60**	**250**
fmdry	0.4	0.4	0.4	0.4

epdry	84	84	84	84
fmcap	9.0×10^{-7}	9.0×10^{-7}	9.0×10^{-7}	9.0×10^{-7}
epcap	0.59	0.59	0.59	0.59
foamfso	0.28	0.28	0.28	0.28

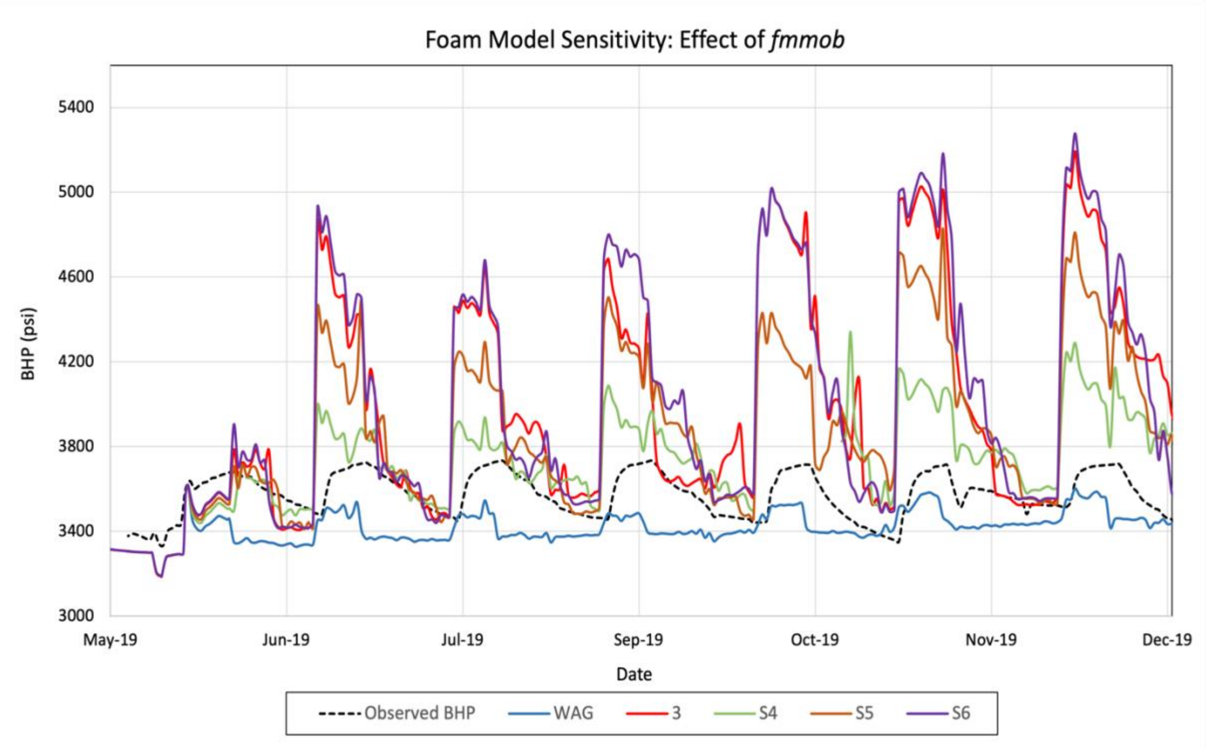

Figure 8.6 Injection bottom hole pressure (BHP) as a function of time for water-alternating-gas (WAG) (blue curve), observed data from pilot (black dotted curve), foam model 3 (red curve), and foam model 3 with low(10), medium(60) and high(250) *fmmob*.

8.2.2 Effect of fmdry parameter

The foam model parameter *fmdry* is the water saturation at which foam dries out and therefore ranges from zero to one. A certain amount of water must be present to stabilize the foam (i.e., a value of 0.5 means that at water saturations below 50%, the foam will dry out). *Fmmob* and *fmdry* are closely related, and a general rule is that a higher *fmmob* value generates a stronger foam and should have lower *fmdry* because it may withstand lower water saturations. Figure 8.7 shows the BHP of baseline WAG (blue curve), foam model 1 low *fmmob* – S1(15) and tuned with low(0.2), medium(0.4) and high(0.6) *fmdry*, and the observed BHP from the pilot (black dotted curve).

Table 8.4 shows the parameter ranges for the *fmdry* sensitivity for S1. The values were chosen based on expected water saturations in the reservoir. A lower value than 0.2 would allow the foam to form everywhere, when in reality, the foam is dependent on an amount of water to be stabilized. A higher value than 0.6 would not be realistic because the reservoir doesn't encounter water saturations that high. A lower *fmdry* will allow foam to form at lower water saturation, which will show on the graph as a higher BHP. The lowest BHP is from the highest *fmdry*, S9 (purple curve) and is the best fit for representing the observed data.

Table 8.4 Local equilibrium foam parameters for foam model 1 with low *fmmob* and low, medium and high *fmdry* value.

Parameter	S1	S7	S8	S9
fmmob	15	15	15	15
fmdry	**0.595**	**0.2**	**0.4**	**0.6**
epdry	35	35	35	35
fmcap	2.14×10^{-6}	2.14×10^{-6}	2.14×10^{-6}	2.14×10^{-6}
epcap	0.59	0.59	0.59	0.59
foamfso	0.28	0.28	0.28	0.28

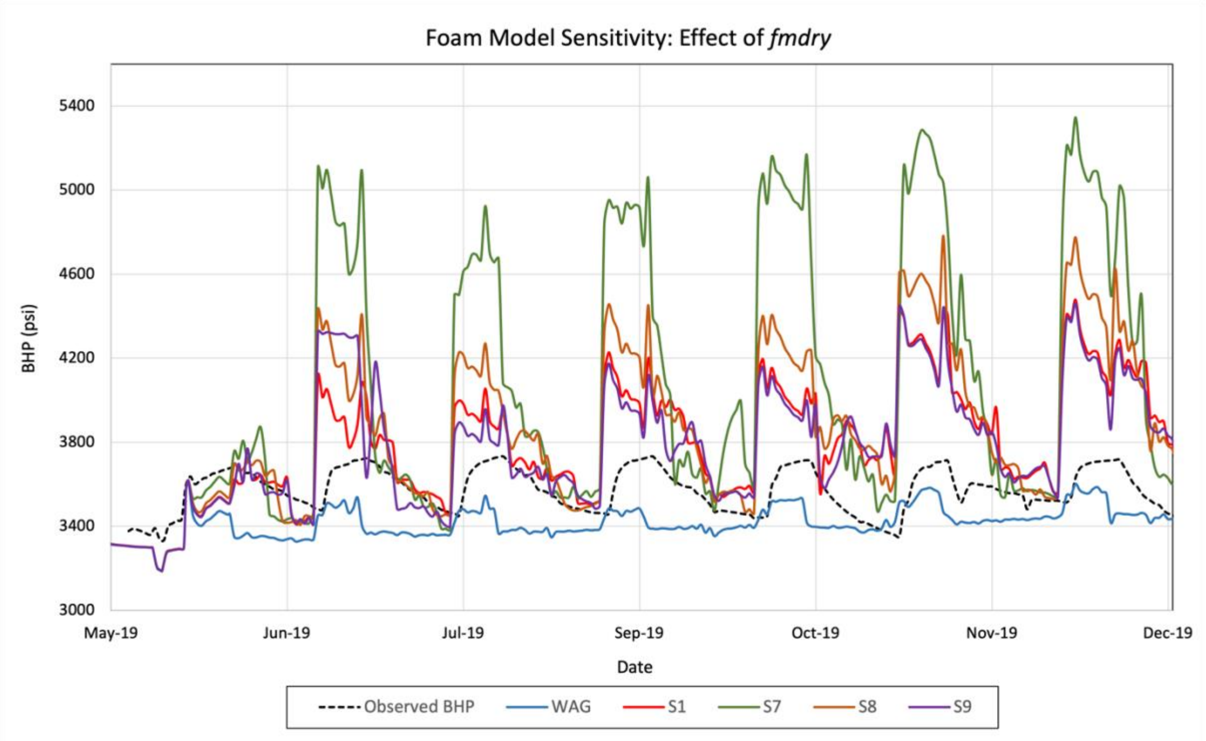

Figure 8.7 Bottom hole pressure (BHP) as a function of time for water-alternating-gas (WAG) (blue curve), observed data from pilot (black dotted curve), foam model 1 with low *fmmob* – S1 (red curve), and S1 with low(10), medium(60) and high(250) *fmmob*.

8.2.3 Effect of oil on foam

Foamfso is the oil saturation which foam ceases to be effective (i.e., foam model 3 has a *foamfso* value of 0.28, meaning an oil saturation above 28%, the foam is no longer effective). Foam model 3 with low *fmmob*(0.15) and high *fmdry*(0.6), which has a *foamfso* of 0.28 was used for effect of oil sensitivity. The *foamfso* values 0.15 and 0.40 was picked to evaluate the effect of oil and Table 8.4 shows the parameter ranges used. The values were selected based on realistic oil saturations seen in the field. The highest *foamfso* value was set at 0.40 to prevent it from exceeding oil saturations realistic for the reservoir. The lower value was set at 0.15. Figure 8.8 shows BHP as a function of time for the Baseline WAG (blue curve), S10 (red curve) and S10 with *foamfso* values of 0.15 (green curve) and 0.40 (purple curve). The observed BHP from the pilot is the black dotted curve.

The highest foamfso, S12, has the highest average BHP of 3681 psi. At higher *foamfso* values, the foam is more stable at higher oil saturations. When the value is lower, foam is less resistant to oil and the foam would be weaker. Comparing S10(0.28) to S12(0.40), the curves are similar where S12 has a 2% increase for average BHP. The small variation indicates that the model is not that sensitive to the effect of oil. That is because the reservoir don't have oil saturations higher than 0.28, thus not effecting the foam strength when the value of foamfso is increased. S11 has an average BHP of 3554 psi and the foam should be weaker in the presence of oil because of the low *foamfso* value of 0.15. The graph is flatter than expected without fluctuating between the injection fluids due to viscosity differences. The S11 is clearly not effective and that is due to the reservoir having oil saturations above 0.15 through the reservoir.

Table 8.5 Local equilibrium foam parameters for S10, S11 and S12.

Parameter	S10	S11	S12
fmmob	15	15	15
fmdry	0.6	0.6	0.6
epdry	84	35	35
fmcap	9.0×10^{-7}	2.14×10^{-6}	2.14×10^{-6}
epcap	0.59	0.59	0.59
foamfso	**0.28**	**0.15**	**0.40**

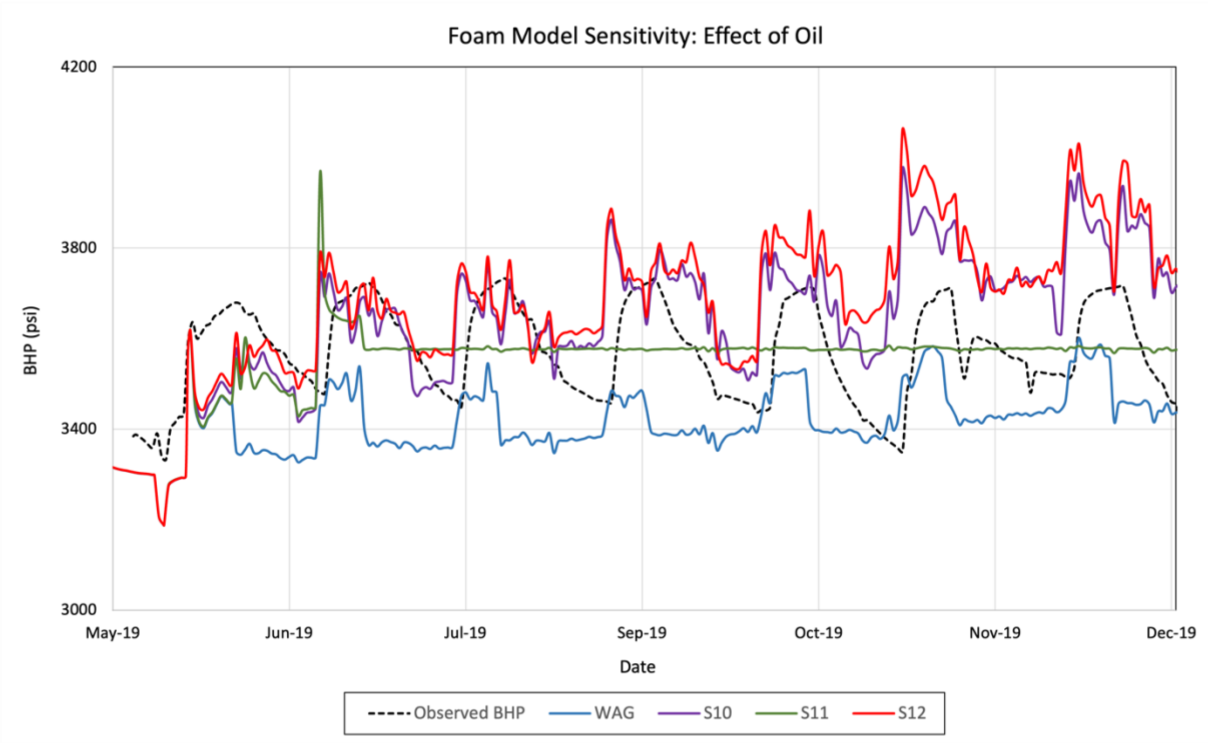

Figure 8.8 Bottom hole pressure (BHP) as a function of time for water-alternating-gas (WAG) (blue curve), observed data from pilot (black dotted curve), S10 (red curve), S11 (green curve) and S12 (purple curve).

8.3 Capturing Shear Thinning Effect

The main objective of this sensitivity study was to account for the shear thinning effect of foam. Conventional reservoir simulators struggle to model foam *dry out* in the near-wellbore region because in the simulator, foam will form everywhere the gas and surfactant solution is sufficient. Therefore, including a region where foam is not allowed to generate near the well may help to capture the physics better. In real life, the injection rates near the injection well are so high that foam may not form and foam is expected to have a low apparent viscosity due to the shear thinning effect. To account for the shear thinning effect in the model, an extra region was specified twenty feet around the injection well, where foam parameters were assigned to represent a no foam region (Table 8.5). *Fmdry* parameter is set to 0.99 in the region where foam is not supposed to form. That is because the foam will dry out at water saturation below 99% and there is not going to be that high water saturations in the that region.

Figure 8.8 shows injection BHP as a function of time for Baseline WAG (blue curve), Base SAG (red curve), Base SAG with “no foam” region (green curve) and observed BHP from pilot (black dotted curve). Base SAG (red curve) has an average BHP of 3883 psi and SAG “no foam” region had an average BHP of 3747 psi. The latter had a more stable curve similar to the observed BHP. Looking at Cycle 2, Base SAG had a 25% increase in BHP when injecting surfactant, whereas the model with “no foam” region had a 7% increase. The SAG “no foam” model seem like a good fit in the first cycles before a higher behavior accurse. It can be because it is generating a foam that is so strong that it causes the high behavior when the next slug of surfactant is generated, while the foam in the field is not as stable. Accounting for the shear-thinning effect with including a region around the well where foam cannot form, improved the model fit.

Table 8.6 Local equilibrium foam parameters assigned to the "no foam" region of base surfactant-alternating-gas (SAG) and rest of the reservoir.

Parameter	Rest of reservoir	"No foam" region
fmmob	41.5	0
fmdry	0.595	0.99
epdry	35	1
fmcap	2.14×10^{-6}	7.8×10^{-7}
epcap	0.87	0.65

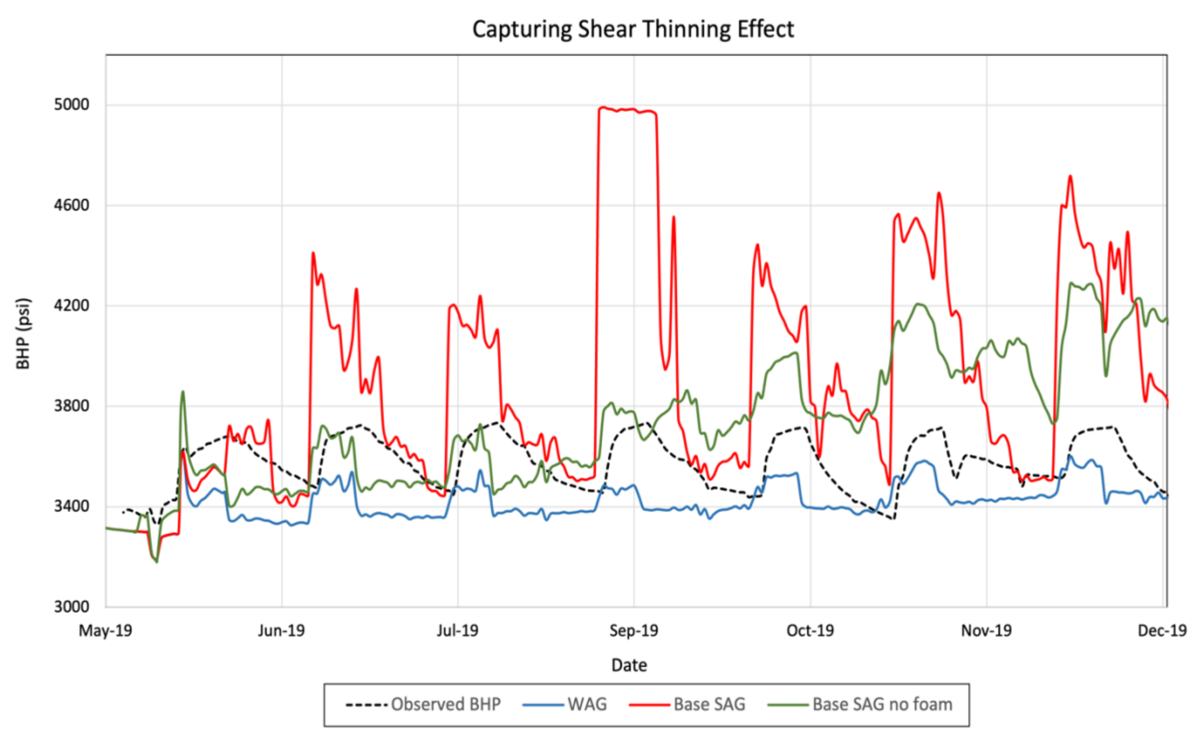

Figure 8.8 shows injection bottom hole pressure (BHP) as a function of time for Baseline water-alternating-gas (WAG) (blue curve), Base surfactant-alternating-gas (SAG) (red curve), Base SAG with "no foam" region (green curve) and observed BHP from pilot (black dotted curve).

8.4 Grid Resolution – Theta Direction

The main objective was to investigate if the model was sensitive to grid resolution. The grid resolution was increased by dividing the grid in the theta direction. See section 7.9 for description of the grid resolution sensitivity study. Implementing the "theta direction" grid cells may help to determine if the model can honor the physics better (i.e., coarser grid cells might oversee important phenomena like the gravity effect if the grids cells are too coarse to visualize how the CO_2 is pushing to the top of the layer) and eliminated some converging problems. The coarser grid cells make it difficult for the simulator to solve the fluid flow equation. The massive cells make the saturation change between one cell to another so large that some of the physics could be missing. By increasing the grid resolution, the saturation change is more gradual, and the simulator can solve the fluid flow equation much easier.

In Figure 8.9 the BHP as a function of time is plotted for observed BHP (black dotted curve), Baseline WAG (blue curve), Baseline WAG Theta (light blue curve), Base SAG (red curve) and Base SAG Theta (orange curve). Comparing the Base SAG with and without theta direction on Figure 8.9, the curves are similar, and the average BHP for Base SAG Theta is only 1.5% higher than Base SAG. However, it looks like the model with theta direction captures the physics (shear thinning effect at high rates near well), better than without theta direction around the fourth slug cycle. The orange curve has the curve expected with surfactant alternating gas, where the BHP gradually decreases when injecting CO_2 because the CO_2 mobility is being reduced by the surfactant. The model is sensitive to grid resolution, but the models with theta direction are more computationally expensive.

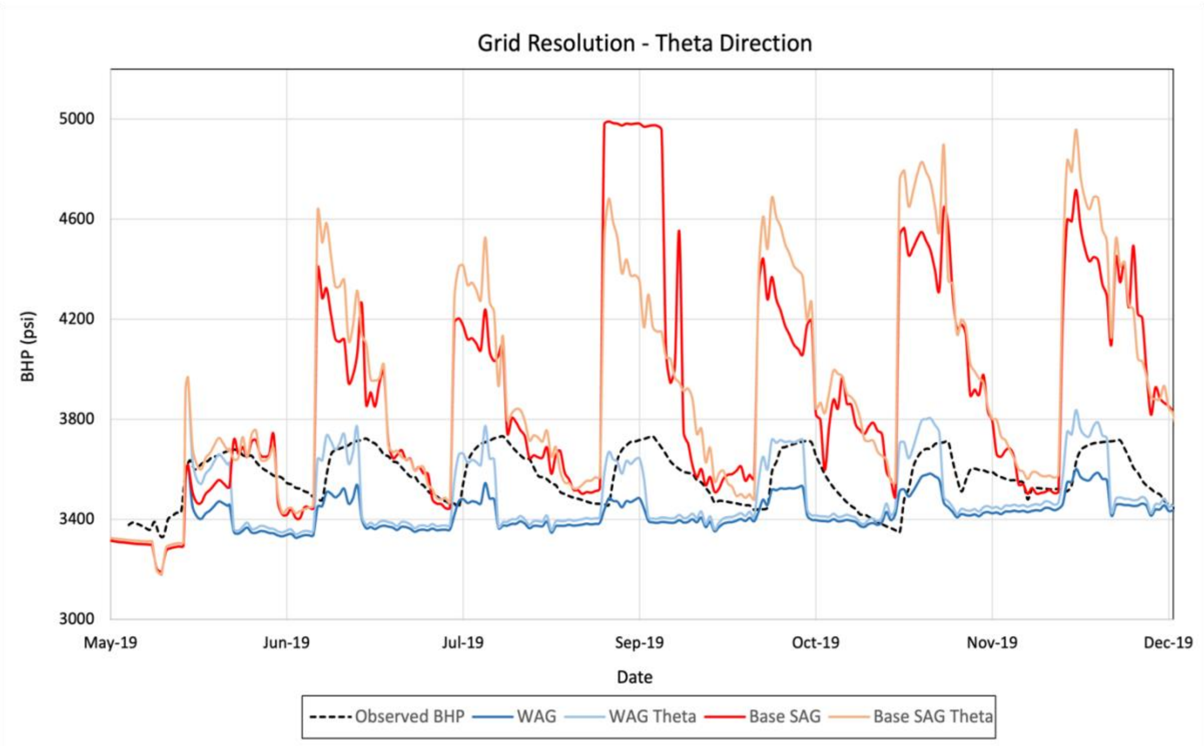

Figure 8.9 shows bottom-hole-pressure (BHP) as a function of time is plotted for observed BHP (black dotted curve), Baseline water-alternating-gas (WAG) (blue curve), Baseline WAG Theta (light blue curve), Base surfactant-alternating-gas (SAG) (red curve) and Base SAG Theta (orange curve).

8.5 Injection Strategy Sensitivity Study

Two main strategies are used for in-situ foam generation in the reservoir: simultaneous injection of CO_2 and surfactants, called co-injection and surfactant-alternating-gas (SAG). The objective of the injection strategy sensitivity study was to evaluate which injection strategy generated the strongest foam and had the largest impact on CO_2 mobility reduction. Co-injection and different types of SAG injection were compared as discussed in section 7.7.2. BHP was used to evaluate the foam strength and CO_2 injectivity was used to compare the degree of CO_2 mobility reduction of the injection strategies.

8.5.1 Foam strength

Injection bottom hole pressure for the injection well was plotted against the hydrocarbon pore volume injected (HCPV) to verify foam strength of different injection strategies. A higher BHP indicates a stronger foam. The Base SAG, Single Cycle SAG, Extended SAG and Co-injection was used for evaluation in this sensitivity study. Figure 8.10 shows BHP versus HCPV injected for Baseline WAG (blue curve) and Base SAG (orange curve) and is discussed in more detail in section 8.1.1. The average BHP of Base SAG was 3882 psi, 12% higher than its baseline WAG. For SAG injections, CO_2 mobility reduction was verified by a more gradual decline during the CO_2 slug injection, compared to its baseline WAG, due to foam generation and increased CO_2 viscosity (Figure 8.10).

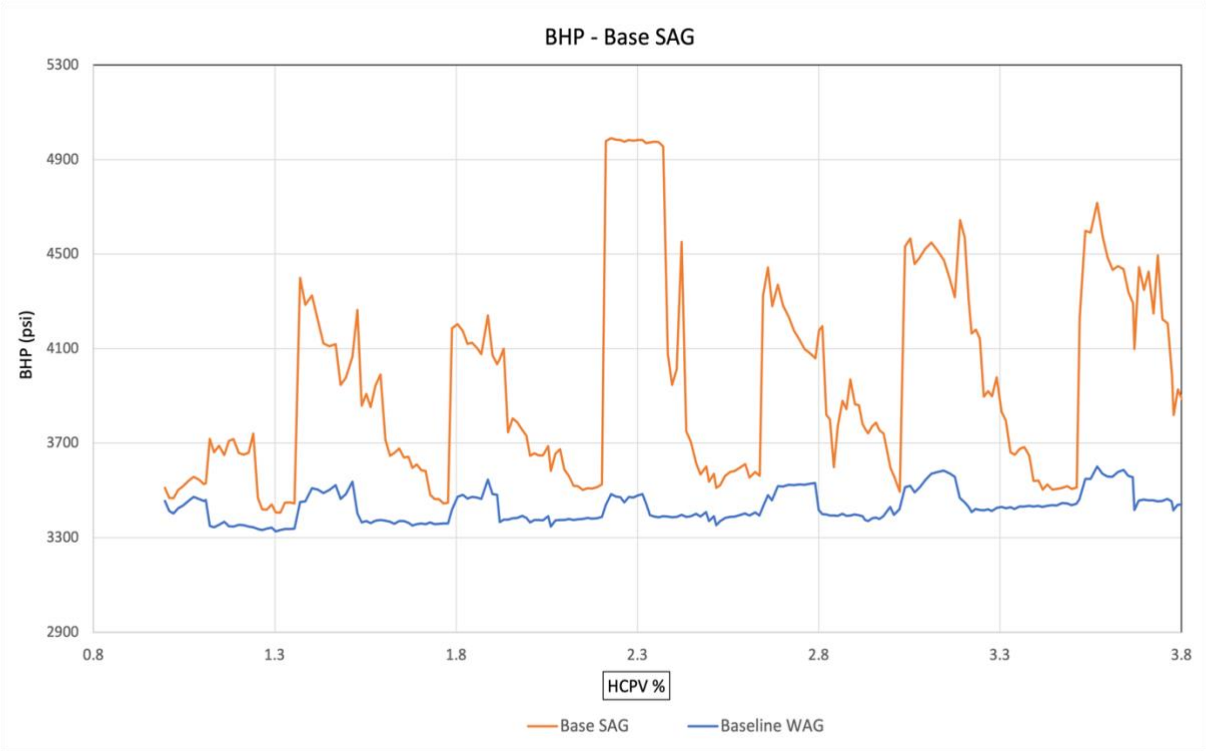

Figure 8.10 Bottom hole pressure (BHP) versus injected hydrocarbon pore volume (HCPV) for Baseline water-alternating-gas (WAG) (blue curve) and Base surfactant-alternating-gas (SAG) (orange curve).

The injection BHP of the single cycle SAG is shown in Figure 8.11. The figure shows BHP versus HCPV injected for Single Cycle WAG (blue curve) and Single Cycle SAG (orange curve). Water or surfactant was injected for the first 2.6 HCPV injected before switching to CO2 injection. Foam generation was seen on for Single Cycle SAG on Figure 8.11 when CO_2 mixed with surfactant solution around 2.6 HCPV injected. The single cycle SAG had a gradual decline in BHP during pure CO2 injection, compared to the Single Cycle WAG. and maintained a higher BHP during the CO_2 injection period. The average BHP for the Single Cycle SAG was 3512 psi, only 1% higher than Single Cycle WAG.

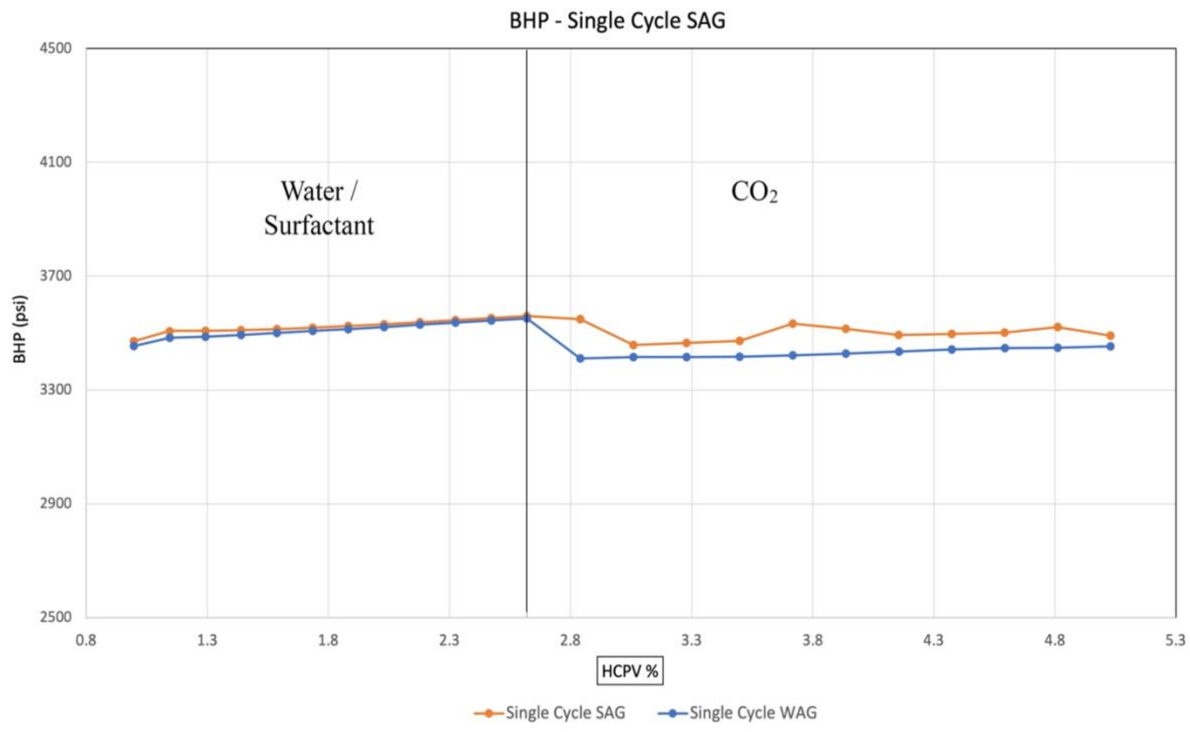

Figure 8.11 Bottom hole pressure (BHP) versus hydrocarbon pore volume (HCPV) for Single Cycle water-alternating-gas (WAG) (blue curve) and Single Cycle surfactant-alternating-gas (SAG) (orange curve).

An extended version of Base SAG with longer slugs of surfactant and CO_2 was set up in Figure 8.12. The figure shows BHP versus HCPV injected for Extended WAG (blue curve) and Extended SAG (orange curve). Average BHP for Extended SAG was 3664, a 6% increase from Extended WAG.

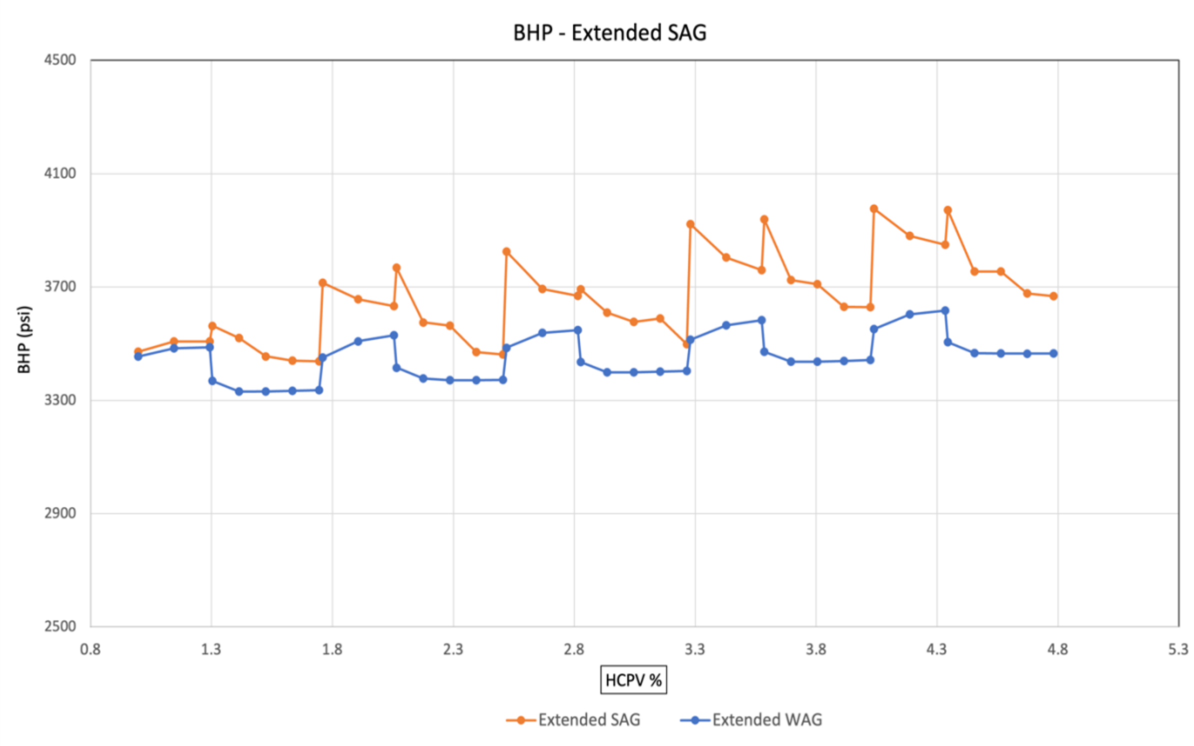

Figure 8.12 Bottom hole pressure (BHP) versus hydrocarbon pore volume (HCPV) for Extended water-alternating-gas (WAG) (blue curve) and Extended surfactant-alternating-gas (SAG) (orange curve).

Co-injection of gas and surfactant were set up in Figure 8.13, showing the BHP versus HCPV injected for Co-injection with water (blue curve) and surfactant (orange curve). Average BHP for Co-injection with surfactant was 8019 psi, 15% higher than with water in the liquid injection phase. The BHP is increasing during injection because surfactant solution is constantly injected and stabilizes the foam.

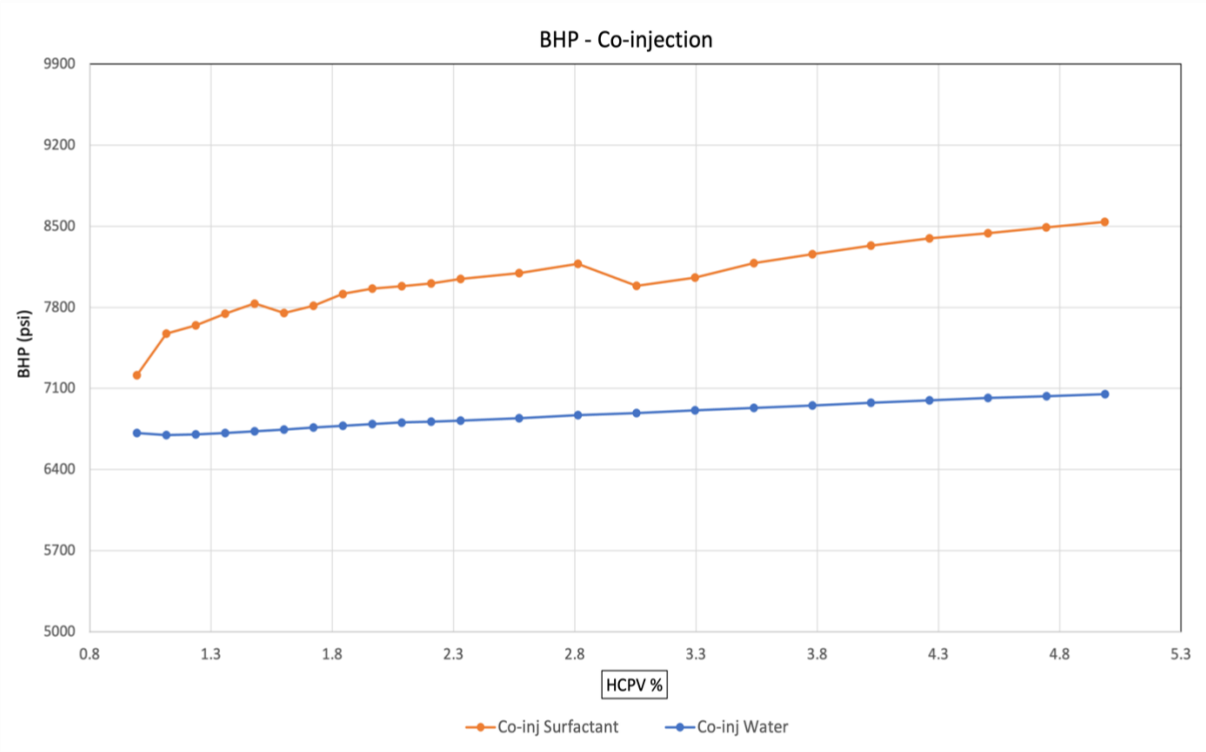

Figure 8.13 Bottom hole pressure (BHP) versus hydrocarbon pore volume (HCPV) for Co-injection water (blue curve) and Co-injection surfactant (orange curve).

Co-injection strategy had the highest average BHP during injection with 8019 psi, followed by Base SAG with 3882 psi, Extended SAG with 3664 psi and Single Cycle SAG with 3512 psi. Co-injection generated stronger foam, but the high BHP and continuous injection of CO_2 can lead to challenges like fractures and downhole corrosion. The average BHP of Co-injection exceeded the formation fracture pressure of 3900 psi (Alcorn et al., 2018) and is therefore not desirable. Thus, base SAG injection was the optimum strategy tested in this thesis.

8.5.2 Injectivity Index

Figure 8.14 shows injectivity index versus days of CO_2 injection for Base SAG. The average injectivity index when CO_2 was injected during the Base SAG was 1.17 $\frac{MSCF}{day}/psi$. Average CO_2 injectivity for

Baseline WAG was 1.66 $\frac{MSCF}{day}/psi$ can be seen in Figure 8.2 in section 8.1.2. The injectivity index for the Base SAG was 35% lower compared to its baseline WAG, indicating reduction of CO_2 mobility with foam. As the injection of CO_2 continued, the injectivity increased because the surfactant is pushed into the reservoir and the foam around the well dries out. That makes it easier to inject and shows a higher injectivity index.

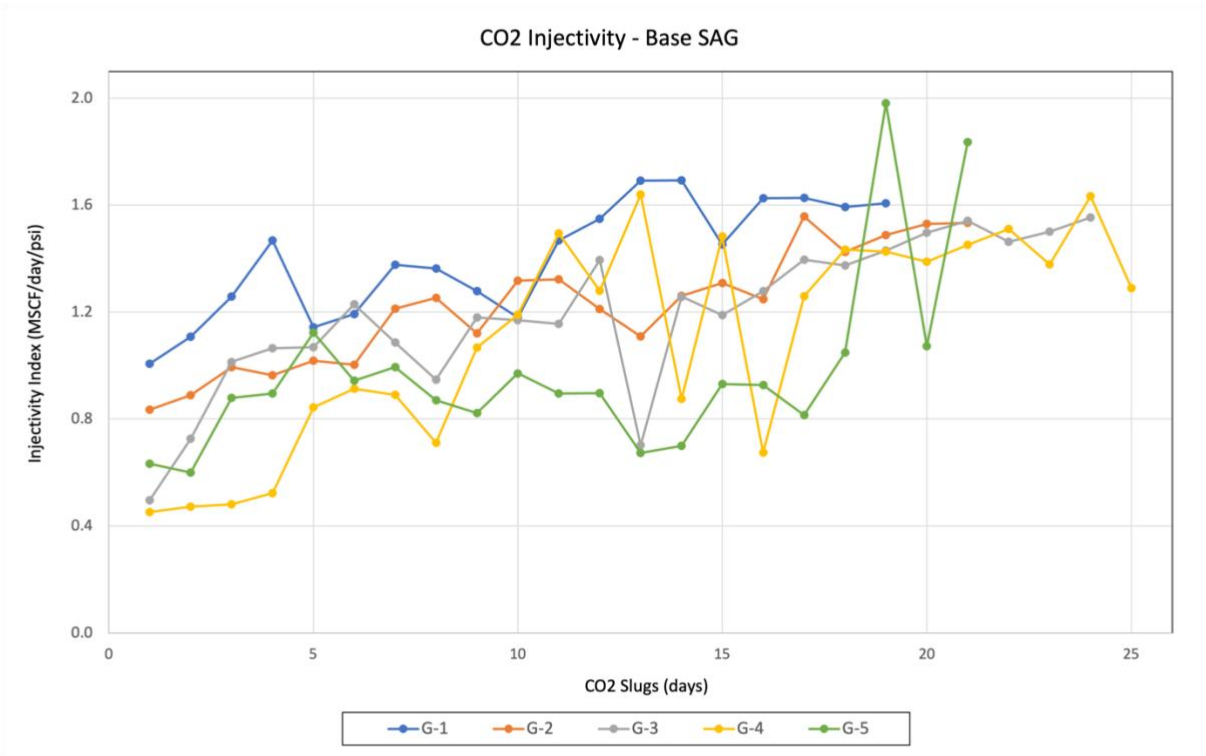

Figure 8.14 Injectivity index versus days of CO_2 injection for Base surfactant-alternating-gas (SAG).

Figure 8.15 shows injectivity index versus days of CO_2 injection for Singe Cycle SAG. The average injectivity index when CO_2 was injected during Single Cycle SAG was 1.28 $\frac{MSCF}{day}/psi$, a 9% decrease from its baseline. Injectivity index versus days of CO_2 injection for Extended Cycle SAG can be seen in Figure 8.16. The average injectivity index when CO_2 was injected during Extended SAG was 1.13 $\frac{MSCF}{day}/psi$, a 9% decrease from its baseline. Lower injectivity index indicates reduction of CO_2 mobility from foam being generated.

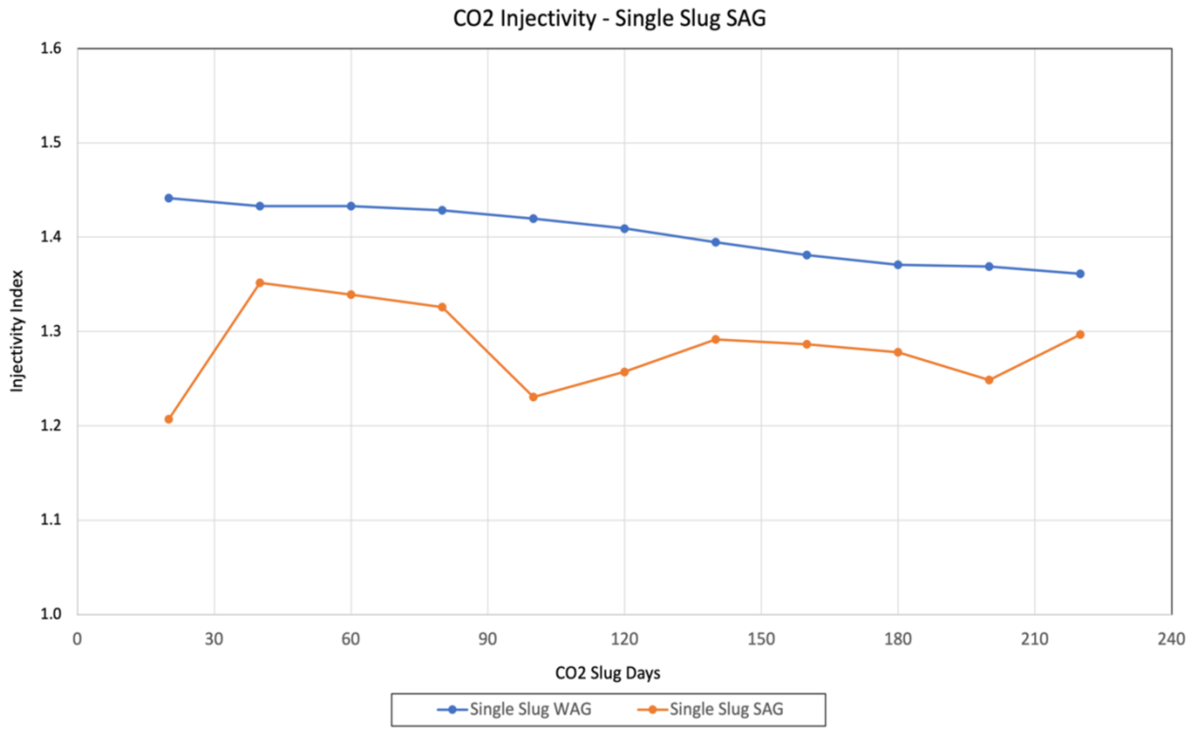

Figure 8.15 Injectivity index versus days of CO_2 injection for Single Cycle water-alternating-gas (WAG) (blue curve) and Single Cycle surfactant-alternating-gas (SAG) (orange curve).

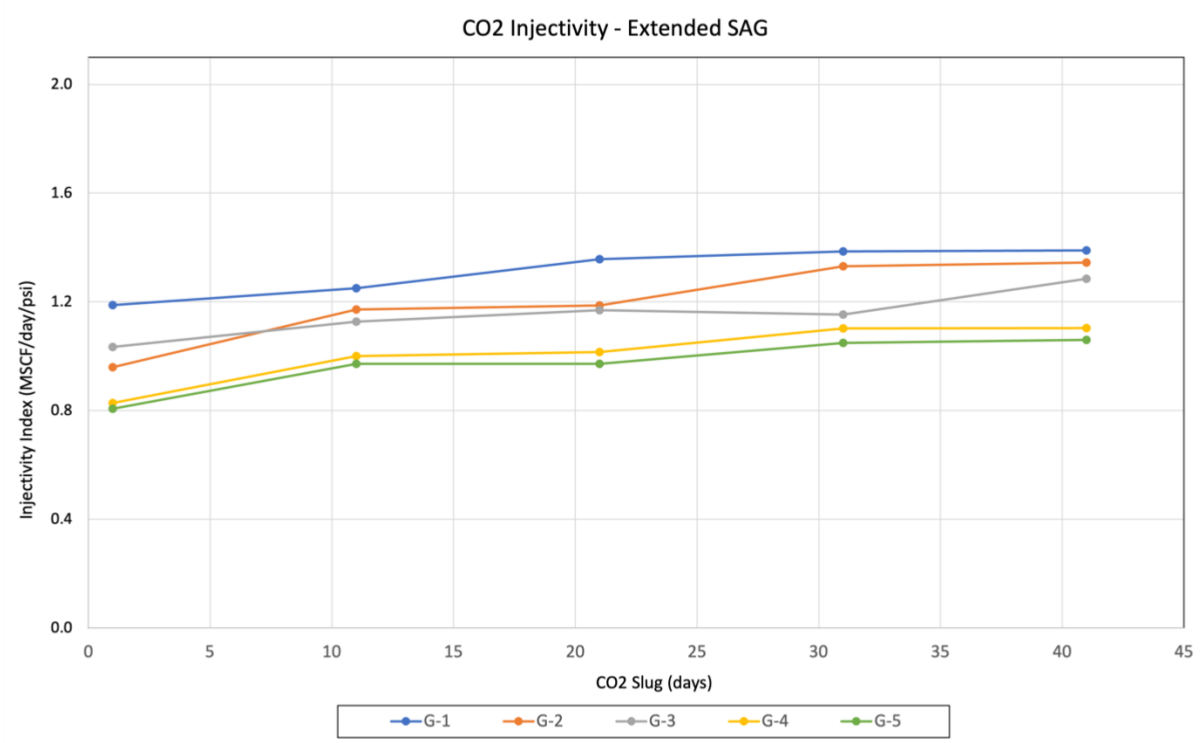

Figure 8.16 Injectivity index versus days of CO_2 injection for Extended surfactant-alternating-gas (SAG).

CO_2 injectivity during co-injection (orange curve, Figure 8.17) declined continuously throughout injection indicating a foam generation that reduces the injectivity. The average injectivity index for Co-injection during simultaneous surfactant and CO_2 injection was 0.55 $\frac{MSCF}{day}/psi$, a 44% decrease from its baseline with water and CO_2. Co-injection significantly reduces injectivity and reduces CO_2 mobility. However, a very low injectivity may not be beneficial on field scale application.

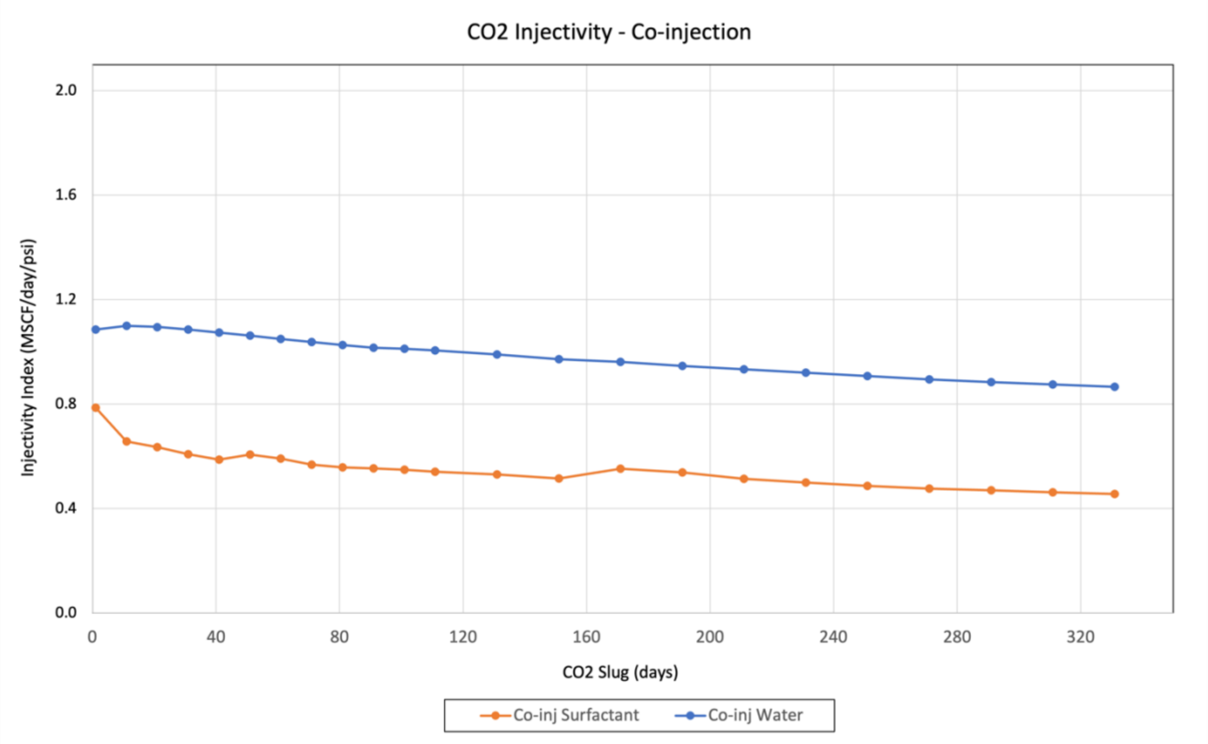

Figure 8.17 Injectivity index versus days of CO_2 injection for Co-injection Water (blue curve) and Co-injection Surfactant (orange curve).

Table 8.7 summarizes the results of CO_2 injectivity for the four different injection strategies. The lowest CO_2 injectivity was calculated for Co-injection with 0.55 $\frac{MSCF}{day}/psi$, followed by Extended SAG with 1.13 $\frac{MSCF}{day}/psi$, Base SAG with 1.17 $\frac{MSCF}{day}/psi$ and Single Cycle SAG with 1.27 $\frac{MSCF}{day}/psi$. Co-injection had the highest CO_2 mobility reduction, but the pressure increase made the strategy not feasible in this field because it exceeds the fracture pressure of 3900 psi.

Table 8.7 Summary of injection strategy average injected bottom hole pressure (BHP) and injectivity index.

Injection strategy	Injectivity Index ($MSCF \cdot psi/day$)
Base SAG	1.17
Single Cycle SAG	1.27
Extended SAG	1.13
Co-injection	0.55

8.6 Foam Propagation

The main objective of investigating foam propagation for different injection strategies was to evaluate how far the foam propagated from the well, into the reservoir. Figures 8.18-8.21 shows the simulated foam concentration for all the injection strategies listed in table 8.4. Before surfactant injection, mid pilot, end pilot and end simulations are shown in a 2D slice (r-z) for each case, with injection from left to right.

Base SAG

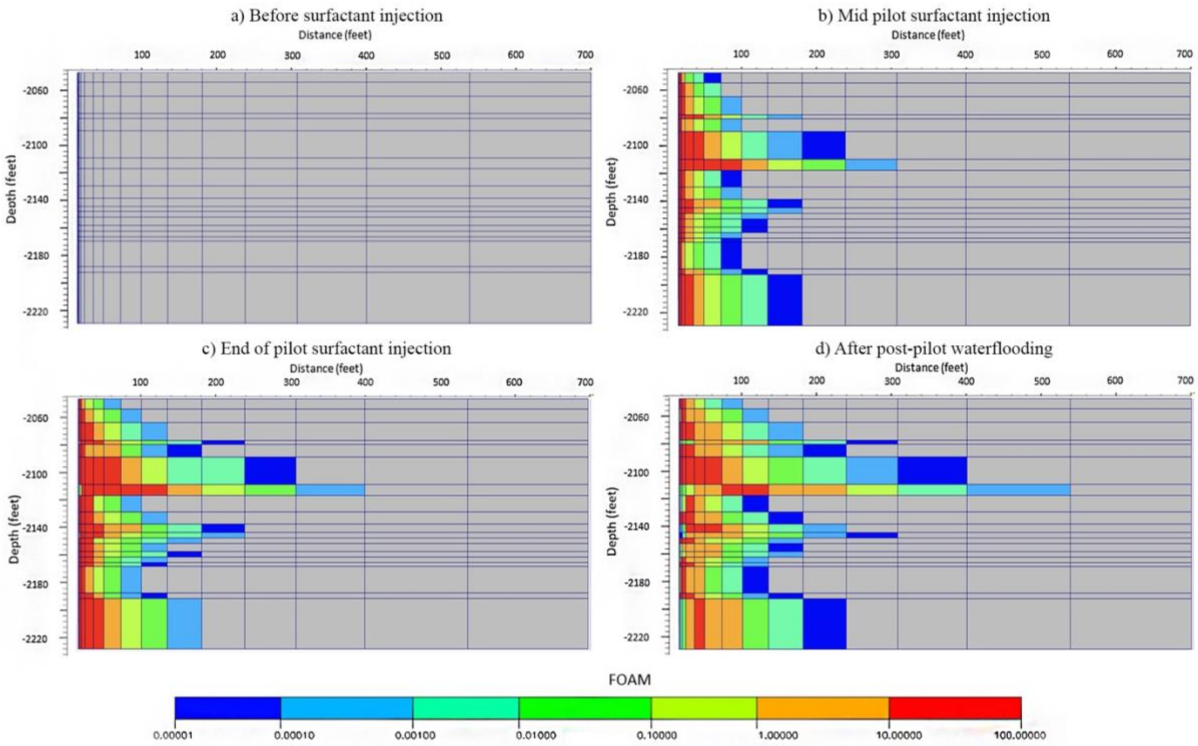

Figure 8.18 Simulated foam concentration for Base surfactant-alternating-gas for a) before surfactant injection, b) mid pilot surfactant injection, c) end pilot surfactant injection and d) after post-pilot waterflood.

Single Cycle SAG:

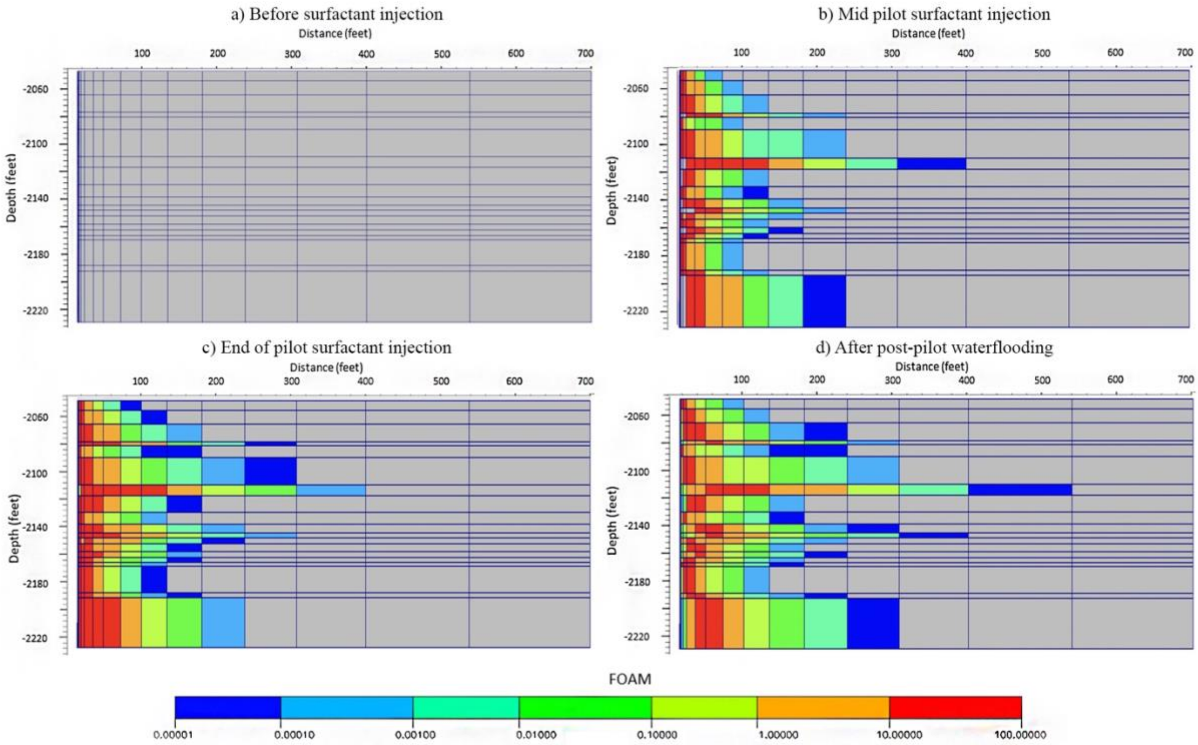

Figure 8.19 Simulated foam concentration for Single Cycle surfactant-alternating-gas for a) before surfactant injection, b) mid pilot surfactant injection, c) end pilot surfactant injection and d) after post-pilot waterflood.

Extended SAG:

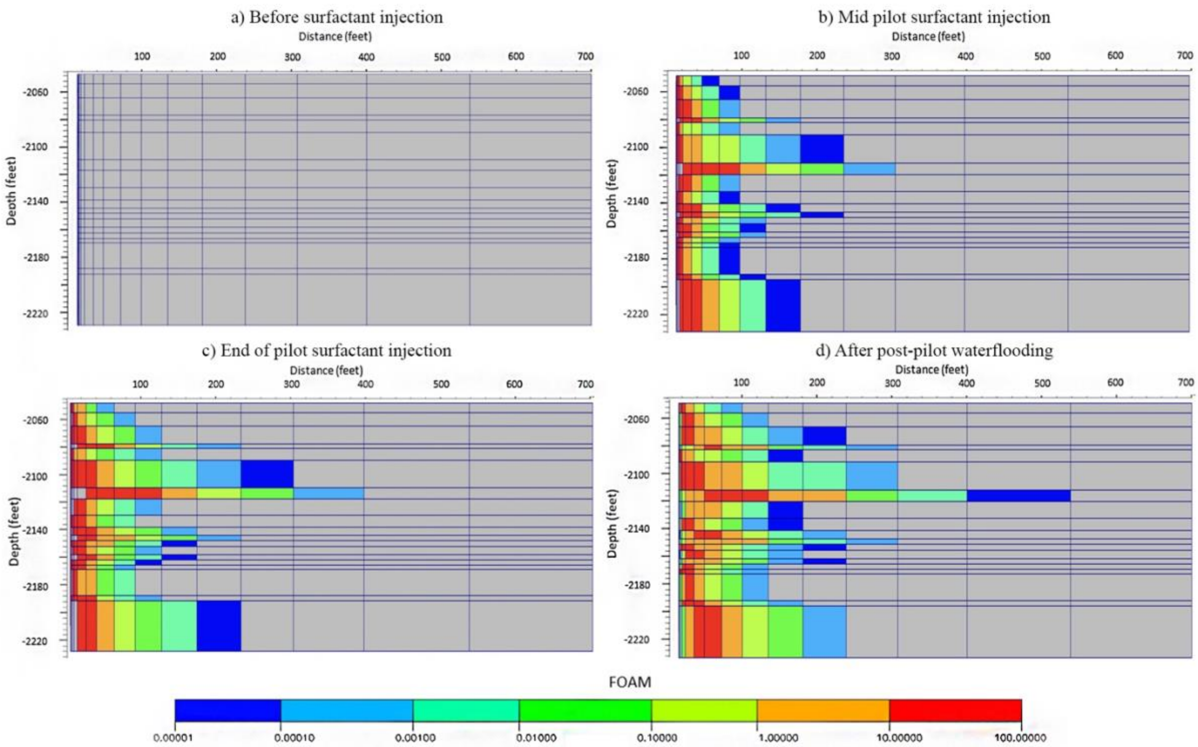

Figure 8.20 Simulated foam concentration for Extended surfactant-alternating-gas for a) before surfactant injection, b) mid pilot surfactant injection, c) end pilot surfactant injection and d) after post-pilot waterflood.

Co-injection:

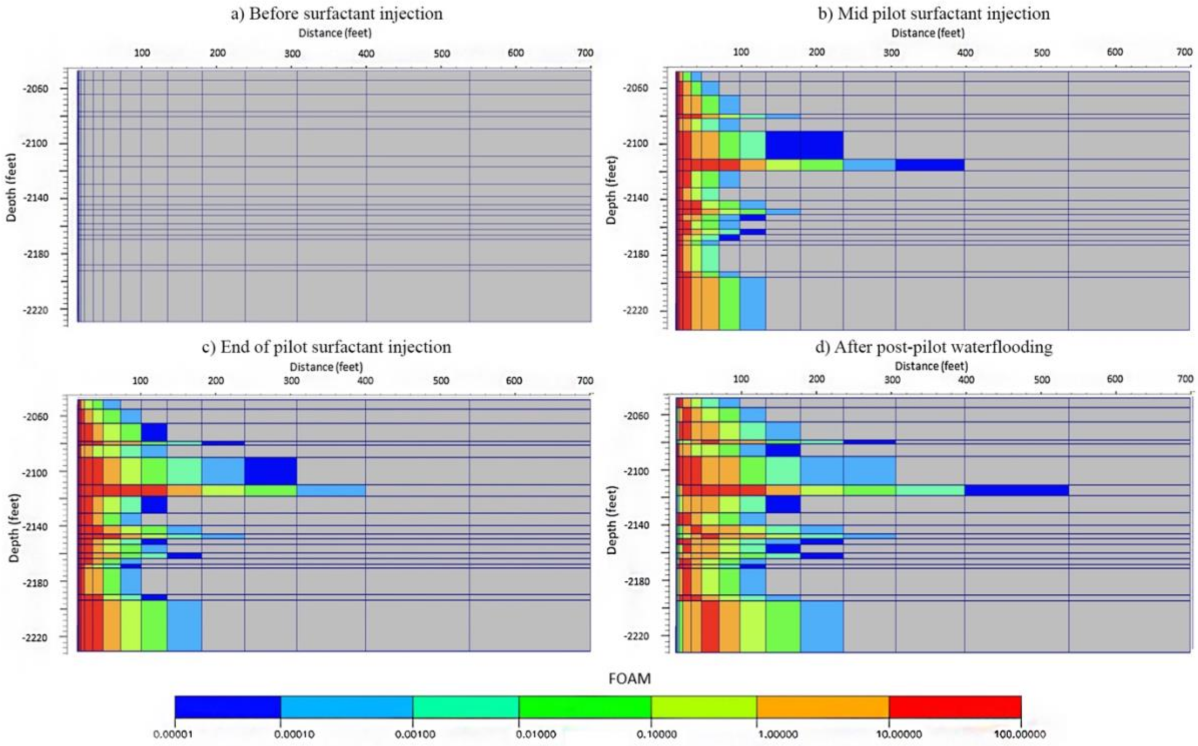

Figure 8.21 Simulated foam concentration Co-injection for a) before surfactant injection, b) mid pilot surfactant injection, c) end pilot surfactant injection and d) after post-pilot waterflood.

All injection strategies propagated foam approximately 200 ft through the high permeable streak. However, Base SAG had the highest concentration of foam with 3.90, followed by Single Cycle with 3.05, Co-injection with 2.36 and Extended SAG with 1.83. After the pilot, water was injected and the foam concentration after post-pilot waterflooding for all the different injection strategies.

Part IV. Conclusion and Future Work

9 Conclusions

This thesis presented a numerical investigation of CO_2 foam for enhanced oil recovery (EOR). Foam generation, foam strength and foam propagation were evaluated in a field-scale radial simulation model representing a completed CO_2 foam field pilot. Foam generation verification, foam model sensitivity study, grid resolution sensitivity study and the injection strategy sensitivity study were presented. The following presents the key conclusion of this thesis:

Overall, the numerical modeling results showed that foam was generated and that foam reduced CO_2 mobility compared to conventional CO_2 injection.

- Foam generation was verified for all simulation cases with surfactant solution present. A higher injected bottom hole pressure (BHP) compared to baselines without surfactant was a critical indication of foam generation. In addition, the BHP of surfactant-alternating-gas (SAG) injection cases had a more gradual decline during CO_2 slug injection compared to water-alternating-gas (WAG), indicating CO_2 mobility reduction by foam.

- Water-alternating-gas (WAG) did not generate any foam as it cannot generate without a foaming agent present.

- CO_2 injectivity was used to determine the degree of CO_2 mobility reduction. The injectivity index of surfactant-alternating-gas (SAG) was lower than water-alternating-gas (WAG) with a 35% decrease. That suggested more resistance to flow due to reduction of CO_2 mobility. Even after stopping surfactant injection, CO2 injectivity was still reduced compared to baseline CO2 injectivity index.

- The foam model parameter *fmmob*, which is the maximum gas mobility reduction factor had a dominating effect when changing the value from low to high. A low *fmmob* was the best fit for observed BHP data for both models used in the sensitivity study. Another foam model parameter, fmdry – the water saturation at which foam dries out, was also tuned to fit the observed data from the pilot.

- The model was not very sensitive to the presence of oil. Foam model parameter *foamfso*, which is the oil saturation which foam ceases to be effective, was evaluated. Changes is the *foamfso* showed small variations in injected bottom hole pressure (BHP), indicating that the oil had a small effect on foam in the model.

- A weakness of the simulator was overestimation of foam generation by generating foam wherever there was sufficient surfactant concentration and CO_2 in the cell. The model included a method to capture the shear-thinning effect that occurs in the near-wellbore region, due to high injection rates. By having a region 20 ft around the well assigned with different foam model parameters than the rest of the reservoir, the model was able to simulate foam dry-out. Accounting for the shear-thinning effect improved the model fit.

- Grid resolution was increased by refining the radial grid in the theta direction to investigate if the model was sensitive to grid resolution. The model with increased resolution honored the physics better (gravity effect etc.) by helping the simulator to solve fluid flow equations more easily. However, the model was more computationally expensive.

- Comparing different injection strategies on foam strength and CO_2 mobility reduction showed that co-injecting generated stronger foam compared to surfactant-alternating-gas injection strategies. However, the co-injection exceeds the formation fracture pressure and is therefore not desirable. Thus, the base SAG with 10 days surfactant and 20 days CO2 injection was the optimal injection strategy tested in this thesis.

- Foam propagated approximately 200 ft through the high permeable streak for all injection strategies in the study. Base surfactant-alternating-gas (SAG) had the highest concentration of foam in the high permeability streak when surfactant injection stopped.

10 Future Work

The numerical work presented in this thesis was a part of an ongoing CO_2 foam field pilot project, led by the Reservoir Physics group at the Department of Physics and Technology at University of Bergen. The work conducted in this thesis was used for improving the understanding of foam generation, strength and propagation, and improvement of the radial model used for numerical modeling.
The following presents suggestions for future work:

- The model struggles with simulating the shear-thinning effect of foam. The foam models in this thesis assume steady-state, but in reality, foam is unsteady in the near-well region. It could be looked further into how far away from the well the foam reaches equilibrium.

- Further improvement of the model could be done by using traditional history matching such as tuning the relative permeability curves.

- The sensitivity study performed in this thesis concluded that the model was not very sensitive to the presence of oil. More sensitivity studies could be conducted on the effect of oil on foam.

Part V. Nomenclature, Abbreviations, References and Appendix

Nomenclature

cP	Centipoise
Epcap	Foam model parameter that captures shear-thinning behavior in the low-quality regime
Epdry	Foam model parameter controlling the abruptness of foam collapse
Epoil	Foam model parameter controlling the effect of oil saturation
Epsurf	Foam model parameter controlling the effect of surfactant concentration
Fmcap	Foam model parameter set to the lowest capillary number expected in the simulation
Fmdry	Foam model parameter at which foam dries out
Fmmob	Foam model parameter maximum gas mobility reduction factor
Fmsurf	Foam model parameter that reference surfactant concentration
Fmoil	Foam model parameter that reference high oil saturation for foam collapse
Foamfso	Foam model parameter at which saturation foam ceases to be effective
ft	Feet
K	Absolute permeability
k_{eff}	Effective permeability
k_r	Relative permeability
L	Length
Mrf	Mobility reduction factor
MSCF	Thousand Standard Cubic feet
Nc	Capillary number
P	Pressure
Pc	Capillary pressure
psi	Pound-force per square inch
psig	Pound-force per square inch Gauge
Q	Flow rate
q	Component flow rate
S_g	Gas saturation

S_o	Oil saturation
S_w	Water saturation
T	Temperature
$wt.\%$	Weight percent
ΔP	Differential pressure
σ	Interfacial tension
ϕ	Total porosity
μ	Viscosity
μ_{app}	Apparent viscosity

Abbreviations

API	The American Petroleum Institute
BHP	Bottom Hole Pressure
CCS	Carbon Capture and Storage
CCUS	Carbon Capture, Utilization and Storage
CO_2	Carbon Dioxide
EOR	Enhanced Oil Recovery
EoS	Equation of State
GHG	Greenhouse gas
HC	Hydrocarbon
HCPV	Hydrocarbon Pore Volume
HM	History matched
IFT	Interfacial Tension
MBC	Modified Brooks-Corey
MMP	Minimum Miscibility Pressure
MPZ	Main Pay Zone
MSCF	Thousand Standard Cubic feet
OOIP	Original Oil In Place
OWC	Oil Water Contact
ppm	Parts per million
PV	Pore volume
PVT	Pressure-Volume-Temperature
ROZ	Residual Oil Zone
SAG	Surfactant Alternating Gas
WAG	Water Alternating Gas

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Appendix

A. Radial Model Data File

```
RUNSPEC

--NOSIM

NOECHO

TITLE
L14 RADIAL

FIELD

OIL
GAS
WATER

COMPS
6 /

COMPW
2 /

START
1 APR 2019 /

DIMENS
20  1  28  /

RADIAL

NONNC

EQLDIMS
 1  100   10    1   20 /

TABDIMS
1 /

REGDIMS
15  1   0   0  /

WELLDIMS
2   28   3   1 /

--NUPCOL
--4 /

--NSTACK
--24 /

MESSAGES
6* 2* 1000000 1000000 /

--UNIFOUT
--UNIFIN

--**********************
GRID

COORDSYS
1 28 COMP /

--  SPECIFY INNER RADIUS OF 1ST GRID BLOCK IN THE RADIAL DIRECTION

INRAD
0.3500 /


--CIRCLE

--  SPECIFY GRID BLOCK DIMENSIONS IN THE R DIRECTION

DRV
   0.35 0.36 0.4 0.5 1 2 5 10 20 50 60 100 120 150 200 250 300 400 600 700 /


-- SPECIFY CELL THICKNESSES ( DZ ), RADIAL PERMEABILITIES ( PERMR )
-- AND POROSITIES ( PORO ) FOR EACH LAYER OF THE GRID. ALSO CELL TOP
-- DEPTHS ( TOPS ) FOR LAYER 1. DTHETA IS SET TO 360 DEGREES FOR EVERY
```

```
-- GRID BLOCK IN THE RESERVOIR.
--  ARRAY    VALUE  ------ BOX ------

EQUALS

DTHETA  360   /  BOX DEFAULTS TO THE WHOLE GRID

DZ   7  1 20  1  1  1  1  /  LAYER 1
PERMR   0.1    /
PORO    0.02 /
TOPS    2047  /

DZ   10  1 20  1  1  2  2  /  LAYER 2
PERMR   1.09  /
PORO    0.07 /

DZ   13  1 20  1  1  3  3  /  LAYER 3
PERMR   0.5   /
PORO    0.03 /

DZ   3  1 20  1  1  4  4  /  LAYER 4
PERMR   37.5   /
PORO    0.19 /

DZ   0  1 20  1  1  5  5  /  LAYER 5
PERMR   3.3    /
PORO    0.08 /

DZ   9  1 20  1  1  6  6  /  LAYER 6
PERMR   0.1 /
PORO    0.02 /

DZ   20   1 20  1  1  7  7  /  LAYER 7
PERMR   3.05   /
PORO    0.08 /

DZ   8   1 20  1  1  8  8  /  LAYER 8
PERMR   181.5    /
PORO    0.134 /

DZ   0  1 20  1  1  9  9  /  LAYER 9
PERMR   0.1   /
PORO    0.03 /

DZ   0  1 20  1  1 10 10  /  LAYER 10
PERMR   18   /
PORO    0.12 /

DZ   12  1 20  1  1 11 11  /  LAYER 11
PERMR   3.84   /
PORO    0.087 /

DZ   0  1 20  1  1 12 12  /  LAYER 12
PERMR   0.4   /
PORO    0.02 /

DZ   0  1 20  1  1 13 13  /  LAYER 13
PERMR   3.45 /
PORO    0.09 /

DZ   9  1 20  1  1 14 14  /  LAYER 14
PERMR   0.15   /
PORO    0.02 /

DZ   6    1 20  1  1 15 15  /  LAYER 15
PERMR   10.96   /
PORO    0.12 /

DZ   4    1 20  1  1 16 16  /  LAYER 16
PERMR   23.67   /
PORO    0.11 /

DZ   4    1 20  1  1 17 17  /  LAYER 17
PERMR   0.1   /
PORO    0.07 /

DZ   6    1 20  1  1 18 18  /  LAYER 18
PERMR   3.54   /
PORO    0.10 /

DZ   4    1 20  1  1 19 19  /  LAYER 19
PERMR   8.73   /
PORO    0.13 /

DZ   4    1 20  1  1 20 20  /  LAYER 20
PERMR   1.06   /
PORO    0.09 /
```

```
DZ   3    1 20  1  1 21 21  /  LAYER 21
PERMR   0.1   /
PORO    0.02 /

DZ   19    1 20  1  1 22 22  /  LAYER 22
PERMR   1.32   /
PORO    0.085 /

DZ   4    1 20  1  1 23 23  /  LAYER 23
PERMR   0.4   /
PORO    0.03 /

DZ   37    1 20  1  1 24 24  /  LAYER 24
PERMR   14   /
PORO    0.11 /

DZ   0    1 20  1  1 25 25  /  LAYER 25
PERMR   0.1   /
PORO    0.025 /

DZ   0    1 20  1  1 26 26  /  LAYER 26
PERMR   1.5   /
PORO    0.04 /

DZ   0    1 20  1  1 27 27  /  LAYER 27
PERMR   0.01   /
PORO    0.02 /

DZ   0    1 20  1  1 28 28  /  LAYER 28
PERMR   1.31   /
PORO    0.08 /
/

--  COPY RADIAL PERMEABILITIES (PERMR) INTO VERTICAL PERMEABILITIES
--  (PERMZ) FOR THE WHOLE GRID, AND THEN MULTIPLY PERMZ.

COPY
'PERMR' 'PERMZ'   /
/

MULTIPLY
PERMZ 0.16  1 20  1 1   1  1 /
PERMZ 0.6   1 20  1 1   2  2 /
PERMZ 0.16  1 20  1 1   3  3 /
PERMZ 0.6   1 20  1 1   4  5 /
PERMZ 0.16  1 20  1 1   6  6 /
PERMZ 0.6   1 20  1 1   7  8 /
PERMZ 0.16  1 20  1 1   9  9 /
PERMZ 0.6   1 20  1 1  10 11 /
PERMZ 0.16  1 20  1 1  12 12 /
PERMZ 0.6   1 20  1 1  13 13 /
PERMZ 0.16  1 20  1 1  14 14 /
PERMZ 0.6   1 20  1 1  15 16 /
PERMZ 0.16  1 20  1 1  17 17 /
PERMZ 0.6   1 20  1 1  18 20 /
PERMZ 0.16  1 20  1 1  21 21 /
PERMZ 0.6   1 20  1 1  22 22 /
PERMZ 0.16  1 20  1 1  23 23 /
PERMZ 0.6   1 20  1 1  24 24 /
PERMZ 0.16  1 20  1 1  25 25 /
PERMZ 0.6   1 20  1 1  26 26 /
PERMZ 0.16  1 20  1 1  27 27 /
PERMZ 0.6   1 20  1 1  28 28 /
/

GRIDFILE
2 1 /

INIT

RPTGRID
DRV DTHETA DZ PORO PORV PERMR DEPTH /

-- ***********************
PROPS

NCOMPS
6 /

EOS
PR /

RTEMP
104 /

STCOND
60   14.696  /
```

```
CNAMES
CO2 N2C1 H2SC2C3 C4C5C6 PC1 PC2 /

TCRIT
547.6 340.6 610.9 827.1 1374.3 1324.7 /

PCRIT
1069.9 663.8 706.3 509.8 323.0 248.9 /

VCRIT
1.506 1.583 2.625 4.719 8.746 19.607 /

MW
44.01 16.29 36.19 70.01 148.24 374.21 /

ACF
0.2250 0.0086 0.1202 0.2278 0.4133 0.9618 /

OMEGAA
6*0.45723553 /

OMEGAB
6*0.077796074 /

SSHIFT
6*0 /

TBOIL
350.5 206.2 395.1 552.2 866.1 1368.1 /

PARACHOR
78.0 76.3 122.3 217.1 416.4 865.8 /

BIC
0.1029
0.1285    0.0029
0.1156    0.0136    0.0040
0.1001    0.0327    0.0164    0.0044
0.1146    0.0685    0.0447    0.0229    0.0075
/

PEDERSEN

PEDTUNER
0.5120    1.1240    0.9456    0.5832    0.01062 /

DENSITY
1* 62.4 1* /

PVTW
3400 1* 1.6E-6 0.75 /

ROCK
3400 10E-6 /

STONE

SWFN
-- W -> O
0.100     0.000     0
0.101     0.000     0
0.200     0.001     0
0.235     0.007     0
0.270     0.028     0
0.305     0.063     0
0.340     0.112     0
0.375     0.175     0
0.410     0.252     0
0.445     0.343     0
0.480     0.448     0
0.515     0.567     0
0.550     0.700     0
1.000     1.000     0 /


SGFN
0.000     0.000     0
0.001     0.000     0
0.050     0.000     0
0.100     0.063     0
0.135     0.106     0
0.170     0.150     0
0.205     0.194     0
0.240     0.238     0
0.275     0.281     0
0.310     0.325     0
0.345     0.369     0
0.380     0.413     0
```

```
0.415          0.456          0
0.450          0.500          0
0.583          0.667          0
0.717          0.833          0
0.850          1.000          0  /


-- SORG=5%
SOF3
0.000          0.000          0.000
0.050          0.000          0.000
0.183          0.000          0.157
0.317          0.000          0.314
0.450          0.000          0.471
0.485          0.0003         0.512
0.520          0.003          0.553
0.555          0.009          0.594
0.590          0.021          0.635
0.625          0.041          0.676
0.660          0.071          0.718
0.695          0.113          0.759
0.730          0.169          0.800
0.765          0.240          0.841
0.800          0.329          0.882
0.899          0.700          0.999
0.900          1.000          1.000  /

--SOR
--0.05 /
--0.05 /

---- 70000 PPM (BASE)
--SALINITY
--1.3 /

-------------------------------------------

WNAMES
WATER SURFACT /

MWW
18.015 1168.7 /

PREFW
3400 3400 /

DREFW
62.4 62.4 /

CREFW
1.6E-6 1.6E-6 /

VREFW
0.75 0.75
0    0     /

CWTYPE
1* SURFF /

FOAMFRM
--FMMOB
41.5 /


FOAMFSW
-- FMDRY EPDRY
0.595 35  /


FOAMFCN
--FMCAP EPCAP
2.14E-06 0.87 /


FOAMFSC
--lb/stb   lb/stb,    Sw*
--0.3   1      0.175    0.20 /
0.175 1 0.035 0.20 /

FOAMFST
--lb/stb,lbf/in.
0     0.0001616
3.54  0.0000418 /


FOAMFSO
0.28 1 /
```

```
--************************
REGIONS
--************************
SOLUTION

PRESSURE
560*3118 /

SWAT
560*0.5 /

SGAS
560*0 /

--INCLUDE
--PREDXMF.GRDECL /

--INCLUDE
--PREDYMF.GRDECL /

ZMF
560*0.0247 560*0.2516 560*0.1863
560*0.1277 560*0.2723 560*0.1374 /

WMF
560*1
560*0
/


-- 5300' FROM GROUND
DATUM
2047 /

RPTRST
FOAM FOAMMOB FOAMCNM FLORES PRESSURE SGAS SOIL SWAT AMF XMF YMF ZMF /

--************************
SUMMARY

RPTONLY

INCLUDE
'SUMMARYFOAM_RAD.INC' /

CGIR
L14G /
/
--************************
SCHEDULE

--TUNING
--1 7 0.1 0.1 2 /
--/
--/

RPTRST
'BASIC=2' FOAM FOAMMOB FOAMCNM  DENG DENO DENW VGAS VOIL VWAT FLORES PRESSURE SGAS SOIL SWAT AMF XMF YMF ZMF /

-- DATUM=5300' FROM GROUND

WELSPECS
L14W   WINJ  1  1 2047  WATER /
L14G   GINJ  1  1 2047  GAS   /
/

COMPDAT
L14W  2*  1  28  OPEN  2*  0.70  1*  0  1*  Z /
L14G  2*  1  28  OPEN  2*  0.70  1*  0  1*  Z /
/

--### WATER INJECTION 1 APRIL TO 23 APR 2019 (23 days) ####--

WCONINJE
L14W  WATER  OPEN  RESV  1*  1050    4000 /
L14G  GAS    SHUT  RESV  1*  0  4000 /
/

WELLSTRE
SOLVENT 1 0 0 0 0 0 /
/

WELLSTRW
WATONLY 1.0 0.0 /
WATSURF 0.995 0.005 / 0.5 WT%
/

WINJGAS
```

```
L14G STREAM SOLVENT /
/

WINJW
L14W STREAM WATONLY /
/

TSTEP
22*1 /

--- CO2 injection 24 APRIL 2019 to 09 MAY 2019
WCONINJE
L14W  WATER  SHUT  RESV  1*  0    4000 /
L14G  GAS    OPEN  RESV  1*  428  4000 /
/

TSTEP
21*1 0.45/

-- SHUT-IN FOR 2.16 days

WCONINJE
L14W  WATER  SHUT  RESV  1*   0    4000 /
L14G  GAS    STOP  RESV  1*   0  4000 /
/


TSTEP
2*1 0.16 /

-- RESTART CO2 INJ on MAY 17

WCONINJE
L14W  WATER  SHUT  RESV  1*   0    4000 /
L14G  GAS    OPEN  RESV  1*   428  4000 /
/

---

TSTEP
4*1 0.93 /

--## 1011 BBL WATER INJECTION BEFORE PILOT 1 DAY ##--

WCONINJH
 L14W  WATER  OPEN  1011  3636 6* RATE /
 L14G  GAS    SHUT   0  4000   6* RATE /
 /

TSTEP
0.5 0.54 /


--#### PILOT SAG OBSERVED DAILY DATA ####---

-- Cycle 1
-- ##### 9.42 DAYS SURF #####

WCONINJH
 L14W  WATER  OPEN  535  3600 6* RATE /
 L14G  GAS    SHUT   0  4000   6* RATE /
 /

WELLSTRE
SOLVENT 1 0 0 0 0 0 /
/

WELLSTRW
WATONLY 1.0 0.0 /
WATSURF 0.995 0.005 / 0.5 WT%
/

WINJGAS
L14G STREAM SOLVENT /
/

WINJW
L14W STREAM WATSURF /
/

TSTEP
1 /

WCONINJH
 L14W  WATER  OPEN  439  3612 6* RATE /
 L14G  GAS    SHUT   0  4000   6* RATE /
 /
```

```
TSTEP
1 /

WCONINJH
 L14W  WATER  OPEN  418  3627 6* RATE /
 L14G  GAS    SHUT   0  4000   6* RATE /
 /

TSTEP
1 /

WCONINJH
 L14W  WATER  OPEN  470  3633 6* RATE /
 L14G  GAS    SHUT   0  4000   6* RATE /
 /

TSTEP
1 /

WCONINJH
 L14W  WATER  OPEN  487  3649 6* RATE /
 L14G  GAS    SHUT   0  4000   6* RATE /
 /

TSTEP
1 /

WCONINJH
 L14W  WATER  OPEN  520  3653 6* RATE /
 L14G  GAS    SHUT   0  4000   6* RATE /
 /

TSTEP
1 /

WCONINJH
 L14W  WATER  OPEN  547  3663 6* RATE /
 L14G  GAS    SHUT   0  4000   6* RATE /
 /

TSTEP
1 /

WCONINJH
 L14W  WATER  OPEN  517  3669 6* RATE /
 L14G  GAS    SHUT   0  4000   6* RATE /
 /

TSTEP
1 /

WCONINJH
 L14W  WATER  OPEN  486  3677 6* RATE /
 L14G  GAS    SHUT   0  4000   6* RATE /
 /

TSTEP
1 /

WCONINJH
 L14W  WATER  OPEN  496  3679 6* RATE /
 L14G  GAS    SHUT   0  4000   6* RATE /
 /

TSTEP
0.42 /

-- ##### 20 DAYS CO2 #####

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1025 3675  6* RATE /
/


TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1065 3657  6* RATE /
/


TSTEP
1 /

WCONINJH
```

```
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1245 3653  6* RATE /
/


TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1394 3654  6* RATE /
/


TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1154 3630  6* RATE /
/


TSTEP
1 /


WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1212 3611  6* RATE /
/


TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1319 3598  6* RATE /
/


TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1296 3588  6* RATE /
/


TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1227 3575  6* RATE /
/


TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1227 3573  6* RATE /
/


TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1128 3564  6* RATE /
/


TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1116 3545  6* RATE /
/


TSTEP
```

```
1 /


WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1216 3540  6* RATE /
/


TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1254 3526  6* RATE /
/


TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1026 3522  6* RATE /
/


TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1147 3512  6* RATE /
/


TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1217 3505  6* RATE /
/


TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1193 3488  6* RATE /
/


TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1198 3482  6* RATE /
/


TSTEP
1 /


--Cycle 2
-- ##### 10 DAYS SURF #####

WCONINJH
L14W  WATER  OPEN  561  3479 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN  532  3579 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN  653  3660 6* RATE /
```

```
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN  610  3678 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN  559  3683 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN  591  3691 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN  634  3697 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN  469  3711 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN  535  3713 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN  660  3718 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

-- ##### 21 DAYS CO2 #####

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1305  3723  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1030  3711  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1201  3703  6* RATE /
/

TSTEP
1 /
```

```
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1110  3684  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1267  3659  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1295  3652  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1230  3632  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1186  3627  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1073  3608  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1288  3589  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1243  3571  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1141  3572  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 993  3545  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1147  3536  6* RATE /
/

TSTEP
1 /
```

```
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1157  3513  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1101  3499  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1218  3492  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1088  3478  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1134  3473  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1140  3463  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1146  3463  6* RATE /
/

TSTEP
1 /


--Cycle 3
-- ##### 10 DAYS SURF #####

WCONINJH
L14W  WATER  OPEN  410  3501 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN  538  3546 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN  527  3629 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN  469  3666 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
```

```
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN  483  3687 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN  467  3702 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN  450  3709 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN  659  3715 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN  463  3729 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
2*1 /

-- ##### 24 DAYS CO2 #####

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 672  3732  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1016  3714  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1060  3692  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1177  3672  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1162  3655  6* RATE /
/

TSTEP
1 /

WCONINJH
```

```
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1298  3642  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1120  3641  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 897  3607  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1129  3574  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1110  3569  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1096  3560  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1378  3544  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 620  3536  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1202  3509  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1158  3502  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1136  3493  6* RATE /
/

TSTEP
1 /

WCONINJH
```

```
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1202  3487  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1126  3483  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1169  3477  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1201  3471  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1248  3466  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1181  3463  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1221  3462  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1282  3460  6* RATE /
/

TSTEP
1 /


--Cycle 4
-- ##### 10 DAYS SURF #####

WCONINJH
L14W  WATER  OPEN  410  3464 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN  524  3562 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN  470  3641 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/
```

```
TSTEP
1 /

WCONINJH
L14W  WATER  OPEN  451  3679 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN  386  3696 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN  460  3710 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN  440  3712 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN  464  3717 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN  467  3722 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN  354  3728 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

-- ##### 25 DAYS CO2 #####

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1028  3732  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1075  3710  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1094  3686  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1180  3659  6* RATE /
```

```
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1163  3631  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1138  3615  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1167  3600  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1317  3590  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1121 3586  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1195 3581  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1370 3557  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1110 3547  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1478 3525  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 732  3502  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1290  3467  6* RATE /
```

```
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 547  3475  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1036  3473  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1236  3470  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1253  3467  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1224  3464  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1299  3460  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1378  3457  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1178  3455  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1435  3437  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1112  3442  6* RATE /
/

TSTEP
1 /


--Cycle 5
-- ##### 11 DAYS SURF #####
```

```
WCONINJH
L14W  WATER  OPEN   356 3441 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN   491 3449 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN   406 3591 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN   572 3630 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN   542 3682 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN   550 3689 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN   533 3696 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN   534 3702 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN   523 3707 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN   531 3711 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN   531 3714 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /
```

```
-- ##### 21 DAYS CO2 #####

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 935  3707  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 896  3654  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 986  3617  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 985  3580  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1008  3551  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1012  3526  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1172  3506  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 996  3486  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1044  3468  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1130  3453  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1038  3441  6* RATE /
/
```

```
TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 969  3420  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 712  3420  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 729  3410  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 997  3399  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1008  3390  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 858  3380  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1090  3372  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1769  3365  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 922  3357  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1458  3350  6* RATE /
/

TSTEP
1 /

--Cycle 6
-- ##### 10 DAYS SURF #####

WCONINJH
L14W  WATER  OPEN  541  3481 6* RATE /
```

```
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN  530  3521 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN  429  3607 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN  485  3649 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN  564  3672 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN  627  3682 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN  623  3683 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN  620  3702 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN  575  3705 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN  528  3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

-- ##### 27 DAYS CO2 #####

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1310 3710  6* RATE /
/

TSTEP
1 /
```

```
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1216 3633  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1015 3562  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 754  3512  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1099  3558  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1028  3599  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1020  3603  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1117  3598  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 981  3596  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1239  3589  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1249  3589  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1120  3576  6* RATE /
/

TSTEP
1 /
```

```
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1187  3569  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1050  3562  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1267  3557  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1207  3557  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1258  3551  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1157  3546  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1222  3480  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1107  3524  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1214  3526  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1250  3524  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1190  3523  6* RATE /
/

TSTEP
1 /
```

```
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1386  3520  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1300  3521  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1127  3521  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1272  3515  6* RATE /
/

TSTEP
1 /

-- RECENT DATA starting at 12/8/2019
--

WCONINJH
L14W  WATER  OPEN  309  3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /


WCONINJH
L14W  WATER  OPEN  567  3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /


WCONINJH
L14W  WATER  OPEN  530  3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /


WCONINJH
L14W  WATER  OPEN  659  3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /


WCONINJH
L14W  WATER  OPEN  536  3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /


WCONINJH
L14W  WATER  OPEN  497  3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /
```

```
WCONINJH
L14W  WATER  OPEN  491  3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /


WCONINJH
L14W  WATER  OPEN  549  3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN  562  3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /


WCONINJH
L14W  WATER  OPEN  481  3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /


WCONINJH
L14W  WATER  OPEN  468  3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

-- CO2
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 373  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1166  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1272  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1206  3515  6* RATE /
/

TSTEP
2*1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1148  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1188  3515  6* RATE /
/
```

```
TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1330  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1124  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 447  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1093  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1062  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1349  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 837  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 967  3515  6* RATE /
/

TSTEP
1 /
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1020  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1023  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1000  3515  6* RATE /
/
```

```
TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1015  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1025  3515  6* RATE /
/

TSTEP
1 /

--- Surf Injection
--
WCONINJH
L14W  WATER  OPEN  535  3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

--
WCONINJH
L14W  WATER  OPEN  533  3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

--
WCONINJH
L14W  WATER  OPEN  541  3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

--
WCONINJH
L14W  WATER  OPEN  489  3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

--
WCONINJH
L14W  WATER  OPEN  560  3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

--
WCONINJH
L14W  WATER  OPEN  522  3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

--
WCONINJH
L14W  WATER  OPEN  606  3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

--
WCONINJH
L14W  WATER  OPEN  601  3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/
```

```
TSTEP
1 /

--
WCONINJH
L14W  WATER  OPEN  610  3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

--
WCONINJH
L14W  WATER  OPEN  628  3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /

-- CO2 INJ

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 829  3515  6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1016  3515  6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1084  3515  6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1051  3515  6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1109  3515  6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1169  3515  6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1109  3515  6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1121  3515  6* RATE /
/

TSTEP
1 /
--
```

```
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 854  3515  6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 955  3515  6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1009  3515  6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1050  3515  6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 828 3515  6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1084  3515  6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 2661  3515  6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1118  3515  6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1225  3515  6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 971  3515  6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1101  3515  6* RATE /
/

TSTEP
1 /
--
```

```
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1312  3515  6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1348  3515  6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1403  3515  6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1294  3515  6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1124  3515  6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1265  3515  6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1196  3515  6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1253  3515  6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1113  3515  6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1104  3515  6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1224  3515  6* RATE /
/

TSTEP
1 /
--
```

```
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1178  3515  6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1171  3515  6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 920  3515  6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 998  3515  6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1161  3515  6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1136  3515  6* RATE /
/

TSTEP
1 /
--
-- **NO INJECTION PERIOD (22 DAYS FROM 22 FEB TO 14 MAR 2020)** --

WCONINJH
L14W  WATER  STOP   0  3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  STOP   0  3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  STOP   0  3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  STOP   0  3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  STOP   0  3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
```

```
1 /
--
WCONINJH
L14W  WATER  STOP   0  3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  STOP   0  3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  STOP   0  3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  STOP   0  3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  STOP   0  3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  STOP   0  3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  STOP   0 3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  STOP   0  3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/
TSTEP
1 /
--
WCONINJH
L14W  WATER  STOP   0  3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  STOP   0  3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  STOP   0  3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /
```

```
--
WCONINJH
L14W  WATER  STOP   0  3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  STOP   0  3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  STOP   0  3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  STOP   0  3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  STOP   0  3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  STOP   0  3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /
--
-- Surf Injection
--
WCONINJH
L14W  WATER  OPEN  362  3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  OPEN  327  3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  OPEN  489  3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  OPEN  420  3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  OPEN  407  3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/
```

```
TSTEP
1 /
--
WCONINJH
L14W  WATER  OPEN  410  3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  OPEN  411  3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  OPEN  382  3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  OPEN  382  3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  OPEN  462  3708 6* RATE /
L14G  GAS    SHUT   0  4000   6* RATE /
/

TSTEP
1 /
--
-- CO2 Injection
--
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 884  3515  6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 639  3515  6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 814  3515  6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 784  3515  6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 768  3515  6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 0  3515  6* RATE /
```

```
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 814  3515  6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 829  3515  6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 840  3515  6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 754  3515  6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 746  3515  6* RATE /
/

TSTEP
1 /
--
WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 800  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 1190 3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 731  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 702  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 631  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 717  3515  6* RATE /
```

```
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 619  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 724  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 637  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 754  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 492  3646 6* RATE /
L14G  GAS    OPEN 883  3515  6* RATE /
/

TSTEP
1 /

--SURF INJECTION

WCONINJH
L14W  WATER  OPEN 420  3646 6* RATE /
L14G  GAS    SHUT 883  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 459  3646 6* RATE /
L14G  GAS    SHUT 883  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 410 3646 6* RATE /
L14G  GAS    SHUT 883  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 400  3646 6* RATE /
L14G  GAS    SHUT 883  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 441  3646 6* RATE /
L14G  GAS    SHUT 883  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
```

```
L14W  WATER  OPEN 404  3646 6* RATE /
L14G  GAS    SHUT 883  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 407  3646 6* RATE /
L14G  GAS    SHUT 883  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 642  3646 6* RATE /
L14G  GAS    SHUT 883  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 970  3646 6* RATE /
L14G  GAS    SHUT 883  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 367  3646 6* RATE /
L14G  GAS    SHUT 883  3515  6* RATE /
/

TSTEP
1 /

--** FIELD SHUT DOWN FOR 59 DAYS FROM 26 APRIL- 23 JUNE 2020 NO INJECTION **--

WCONINJH
L14W  WATER  SHUT   0  3708 6* RATE /
L14G  GAS    STOP   0  4000   6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT   0  3708 6* RATE /
L14G  GAS    STOP   0  4000   6* RATE /
/

TSTEP
1 58*1 /


---RESTART WITH 3 DAYS SURF INJECTION--
WCONINJH
L14W  WATER  OPEN 372  3646 6* RATE /
L14G  GAS    SHUT 883  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 505  3646 6* RATE /
L14G  GAS    SHUT 883  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 468  3646 6* RATE /
L14G  GAS    SHUT 883  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 400  3646 6* RATE /
L14G  GAS    SHUT 883  3515  6* RATE /
/
```

```
TSTEP
1 /

--CO2 INJECTION
WCONINJH
L14W  WATER  SHUT 400  3646 6* RATE /
L14G  GAS    OPEN 1127  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 400  3646 6* RATE /
L14G  GAS    OPEN 1056 3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 400  3646 6* RATE /
L14G  GAS    OPEN 1222  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 400  3646 6* RATE /
L14G  GAS    OPEN 1108  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 400  3646 6* RATE /
L14G  GAS    OPEN 772  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 400  3646 6* RATE /
L14G  GAS    OPEN 900  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 400  3646 6* RATE /
L14G  GAS    OPEN 935  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 400  3646 6* RATE /
L14G  GAS    OPEN 923  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 400  3646 6* RATE /
L14G  GAS    OPEN 870  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 400  3646 6* RATE /
L14G  GAS    OPEN 1199  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 400  3646 6* RATE /
L14G  GAS    OPEN 1362  3515  6* RATE /
/
```

```
TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 400  3646 6* RATE /
L14G  GAS    OPEN 1358  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 400  3646 6* RATE /
L14G  GAS    OPEN 728  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 400  3646 6* RATE /
L14G  GAS    OPEN 879  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 400  3646 6* RATE /
L14G  GAS    OPEN 886  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 400  3646 6* RATE /
L14G  GAS    OPEN 1017  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 400  3646 6* RATE /
L14G  GAS    OPEN 1073  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 400  3646 6* RATE /
L14G  GAS    OPEN 697  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 400  3646 6* RATE /
L14G  GAS    OPEN 771  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 400  3646 6* RATE /
L14G  GAS    OPEN 781  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 400  3646 6* RATE /
L14G  GAS    OPEN 828  3515  6* RATE /
/

TSTEP
1 /

--SURF INJECTION
WCONINJH
L14W  WATER  OPEN 300  3646 6* RATE /
L14G  GAS    SHUT 828  3515  6* RATE /
```

```
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 416  3646 6* RATE /
L14G  GAS    SHUT 828  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 408  3646 6* RATE /
L14G  GAS    SHUT 828  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 419  3646 6* RATE /
L14G  GAS    SHUT 828  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 430  3646 6* RATE /
L14G  GAS    SHUT 828  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 391  3646 6* RATE /
L14G  GAS    SHUT 828  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 128  3646 6* RATE /
L14G  GAS    SHUT 828  3515  6* RATE /
/

TSTEP
1 /

---CO2 INJECTION--
WCONINJH
L14W  WATER  SHUT 128  3646 6* RATE /
L14G  GAS    OPEN 809  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 128  3646 6* RATE /
L14G  GAS    OPEN 931  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 128  3646 6* RATE /
L14G  GAS    OPEN 888  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 128  3646 6* RATE /
L14G  GAS    OPEN 1012  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 128  3646 6* RATE /
```

```
L14G  GAS    OPEN 1214  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 128  3646 6* RATE /
L14G  GAS    OPEN 992  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 128  3646 6* RATE /
L14G  GAS    OPEN 1191  3515  6* RATE /
/

TSTEP
1 /
WCONINJH
L14W  WATER  SHUT 128  3646 6* RATE /
L14G  GAS    OPEN 903  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 128  3646 6* RATE /
L14G  GAS    OPEN 778  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 128  3646 6* RATE /
L14G  GAS    OPEN 1406  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 128  3646 6* RATE /
L14G  GAS    OPEN 979  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 128  3646 6* RATE /
L14G  GAS    OPEN 1023  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 128  3646 6* RATE /
L14G  GAS    OPEN 825  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 128  3646 6* RATE /
L14G  GAS    OPEN 955  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 128  3646 6* RATE /
L14G  GAS    OPEN 886 3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 128  3646 6* RATE /
L14G  GAS    OPEN 1071  3515  6* RATE /
```

```
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 128  3646 6* RATE /
L14G  GAS    OPEN 798  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 128  3646 6* RATE /
L14G  GAS    OPEN 829 3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 128  3646 6* RATE /
L14G  GAS    OPEN 864  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 128  3646 6* RATE /
L14G  GAS    OPEN 874  3515  6* RATE /
/

TSTEP
1 /

--END OF PILOT INJECTION--

--POST PILOT WATER INJECTION OBSERVED

WELLSTRW
WATONLY 1.0 0.0 /
WATSURF 0.995 0.005 / 0.5 WT%
/

WINJW
L14W STREAM WATONLY /
/

WCONINJH
L14W  WATER  OPEN 423  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 384  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 206  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 226  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 215  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
```

```
1 /

WCONINJH
L14W  WATER  OPEN 148  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 352  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /


WCONINJH
L14W  WATER  OPEN 354  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 390  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 383  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 498  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 506  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 452  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 504  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

--POST PILOT CO2 INJECTION

WCONINJH
L14W  WATER  SHUT 128  3646 6* RATE /
L14G  GAS    OPEN 983  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 128  3646 6* RATE /
L14G  GAS    OPEN 1161  3515  6* RATE /
```

```
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 128  3646 6* RATE /
L14G  GAS    OPEN 951  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 128  3646 6* RATE /
L14G  GAS    OPEN 1260  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 128  3646 6* RATE /
L14G  GAS    OPEN 1003  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 128  3646 6* RATE /
L14G  GAS    OPEN 957  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 128  3646 6* RATE /
L14G  GAS    OPEN 876  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 128  3646 6* RATE /
L14G  GAS    OPEN 855  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 128  3646 6* RATE /
L14G  GAS    OPEN 853  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 128  3646 6* RATE /
L14G  GAS    OPEN 925  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 128  3646 6* RATE /
L14G  GAS    OPEN 935  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 128  3646 6* RATE /
L14G  GAS    OPEN 896  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 128  3646 6* RATE /
L14G  GAS    OPEN 958  3515  6* RATE /
```

```
/

TSTEP
1 /

WCONINJH
L14W  WATER  SHUT 128  3646 6* RATE /
L14G  GAS    OPEN 1331  3515  6* RATE /
/

TSTEP
1 /

--POST PILOT WATER INJECTION

WCONINJH
L14W  WATER  OPEN 706  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 459  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 432  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 450  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 417  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 436  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 445  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 449  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 447  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
```

```
L14W  WATER  OPEN 441  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 430  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 484  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 488  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 473  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 636  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 496  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 520  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 492  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 469  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 490  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
```

```
L14W  WATER  OPEN 468  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /


WCONINJH
L14W  WATER  OPEN 451  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 426  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /


WCONINJH
L14W  WATER  OPEN 429  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 452  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /


WCONINJH
L14W  WATER  OPEN 442  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 447  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 451  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 461  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 452  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 447  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
```

```
1 /

WCONINJH
L14W  WATER  OPEN 439  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 442  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 435  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 436  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 440  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 436  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 438  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 453  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 447  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 447  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 403  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
```

```
1 /

WCONINJH
L14W  WATER  OPEN 422  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 382  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 415  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 334  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 381  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 432  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 425  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 431  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 417  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 441  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 427  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
```

```
1 /

WCONINJH
L14W  WATER  OPEN 473  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 451  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 435  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 387  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 406  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 556  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 441  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 414  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 446  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 398  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 427  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
```

```
1 /

WCONINJH
L14W  WATER  OPEN 436  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 437  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 430  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 435  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 441  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 378  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 449  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 436  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 450  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 446  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 435  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
```

```
1 /

WCONINJH
L14W  WATER  OPEN 371  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 424  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 474  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 485  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 481 3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 480  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 486  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 480  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 434  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 410  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 423  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
```

```
1 /

WCONINJH
L14W  WATER  OPEN 441  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 281  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

---shut from 11 DEC 2020 to 13 JAN 2021 due to water line issues

WCONINJH
L14W  WATER  STOP 281  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
30*1  1 1 /


---reopen with water injection on 13 JAN 2021--

WCONINJH
L14W  WATER  OPEN 486  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 826  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 496  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 485  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 134  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 70 3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 121  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
```

```
L14W  WATER  OPEN 160  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 161  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 225  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 386  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 359  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 383  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 415  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 424  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 319  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 336  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 312  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
```

```
L14W  WATER  OPEN 313  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 310  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 314  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 283  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 277  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 283  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 295  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 285  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 328  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 282  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 268  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
```

```
L14W  WATER  OPEN 269  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 272  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 244  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 174  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

---shut 15 FEB 2021 TO 18 MAR 2021

WCONINJH
L14W  WATER  SHUT 174  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
30*1 1 1 /


---REOPEN ON 19 MARCH 2021 WITH WATER INJECTION
WCONINJH
L14W  WATER  OPEN 194  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 458  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 427  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 400  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 417  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 413  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/
```

```
TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 387  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 376  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 380  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 352  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 374  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 369  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 351  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 353  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 355  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 344  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 305  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/
```

```
TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 316  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 339  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 342  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 333  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 339  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 323  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 321  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 322  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 320  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 317  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 306  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/
```

```
TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 324  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 302  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 309  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 309  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 293  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 295  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 291  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 296  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 297  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 323  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 312  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/
```

```
TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 311  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 308  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 280  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 303  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 290  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 325  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 316  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 288  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 311  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 325  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 312  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/
```

```
TSTEP
1 /

WCONINJH
L14W  WATER  OPEN 304  3646 6* RATE /
L14G  GAS    SHUT 874  3515  6* RATE /
/

TSTEP
1 /

---END OF OBS DATA ON 08 MAY 2021

END
```