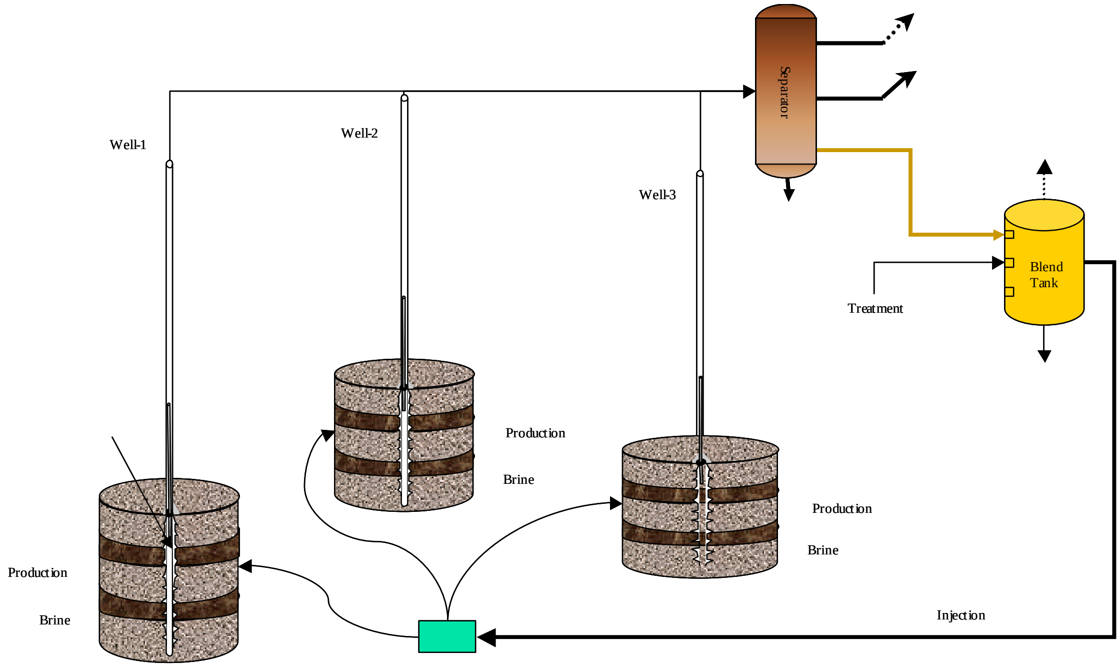
ESP FLOWSHEET SIMULATION

APPLICATION BRIEF

Oil Field Scale Prediction during Brine Re-injection



Aged natural gas wells in northern Mexico are now producing significantly more water than gas. Re-injection of produced water brines is being considered to increase gas production. Additionally, reduction of produced water (an environmental concern) by re-injection is regarded as a potential benefit. However, there is concern that re-injection could increase scale formation and damage the reservoir.

Contents

The Application

Three natural gas wells are producing from three separate production zones. These wells are labeled “Well1”, “Well2” and “Well3”. The production zones are labeled “Zone1”, “Zone2”, and “Zone3” respectively.

Two simulations are presented. The first demonstrates the current situation in which no brine re-injection is performed. The second simulation mixes the three produced brines and re-injects them into the separate formations.

Without Brine Re-injection

The following flow diagram represents the current configuration of the gas field:

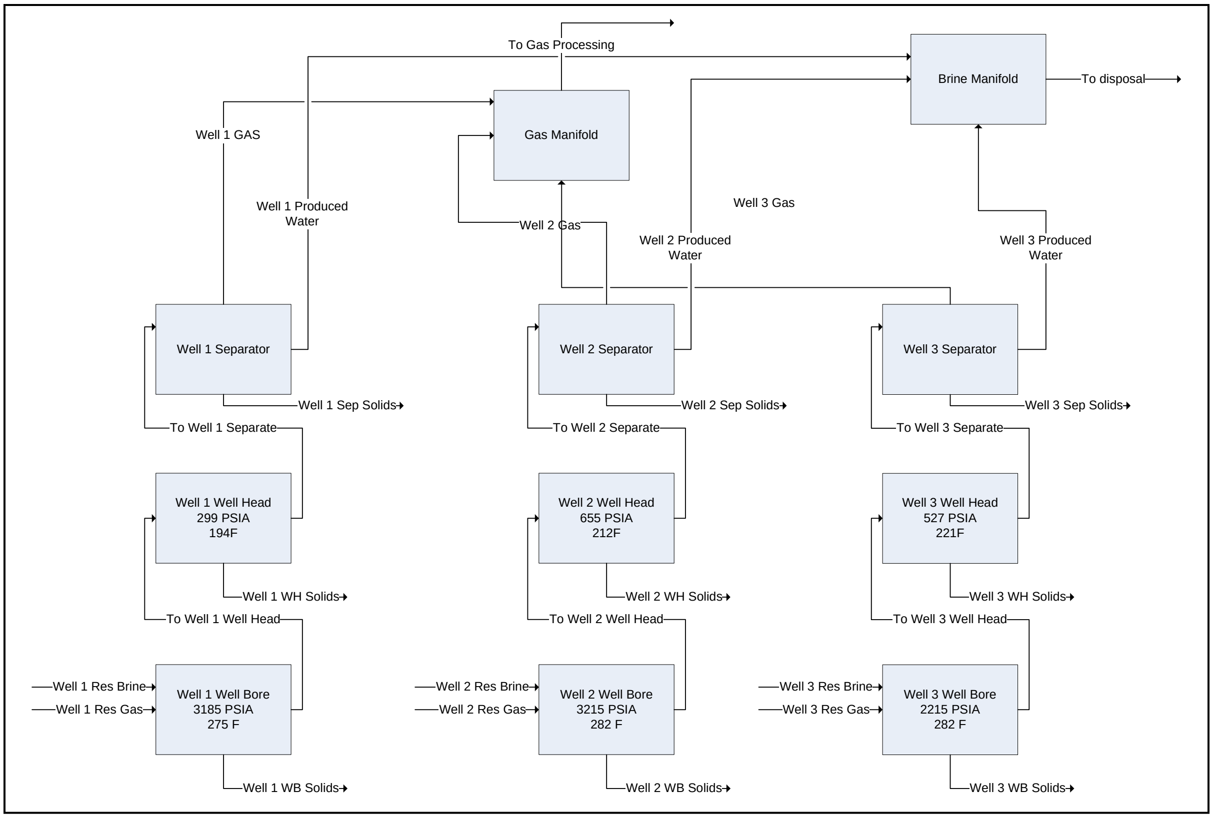


Figure 1 – Without brine re-injection

Conditions and Concentrations

The following table shows the reservoir brine conditions, flow-rate and concentrations:

	Well 1	**Well 2**	**Well 3**
Temperature, ^oF	275	282	282
Pressure, psia	3185	3215	2215
Flow, bbl/day	1538	123	1194
Concentration @77^oF, mg/L			
Na^{+1}	11196	27567	15651
Ca^{+2}	440	856	1680
Mg^{+2}	9.6	38.4	96
Fe^{+2}	0.05	0.74	0.33
Ba^{+2}	0.83	0.2	1.72
Sr^{+2}	31.8	80.0	144
Cl^{-1}	16400	40200	26400
SO_4^{-2}	1475	4800	950
HCO_3^{-1}	659	793	573
CO_3^{-2}	192	0	60
pH @ 77^oF	8.9	7.6	8.2
Density @77^oF, mg/L	1.02	1.05	1.03
Alkalinity, as mg HCO_3/L	1030	766	676

The next table shows the reservoir gas conditions, flow-rate and concentrations:

	Well 1	**Well 2**	**Well 3**
Temperature, ^oF	275	282	282
Pressure, psia	3185	3215	2215
Flow, ft^3/day	9862	44500	28911
Concentration, mole%			
H_2O	2.1	1.7	2.3
CO_2	2.5	2.4	3.1
H_2S	0.8	1.1	1.7
CH_4	94.6	94.8	92.9

The ***Lab Analyzer*** was used to reconcile the three measured brine concentrations for electroneutrality and pH. Alkalinity, not originally reported, was calculated by titrating the reconciled sample to a pH of 4.5 using hydrochloric acid. The water samples were then automatically converted to a molecular basis for use with ESP.

Simulation – Without Brine Re-injection

An ESP simulation was created for the flow diagram shown in Figure 1. The flowsheet calculation order for this simulation is a once-through sequence where each block is executed once only.

The primary concern for this study is the potential for solids to form (scales) in the well bore region as well as in production equipment.

The following table shows the location and amounts of solids that are produced:

Location	Scale, lb/day	Types of scales
Well 1 WB Solids	0.9	$CaCO_3$, trace amounts of $BaSO_4$, and $SrSO_4$
Well 2 WB Solids	10.9	$CaCO_3$, $CaSO_4$, trace amounts of $BaSO_4$, and $SrSO_4$
Well 3 WB Solids	44.0	$CaCO_3$, $CaSO_4$, trace amounts of $BaSO_4$
Well 1 WH Solids	64.0	$CaCO_3$
Well 2 WH Solids	3.9	$CaCO_3$, trace amounts of $BaSO_4$
Well 3 WH Solids	39.1	$CaCO_3$, $BaSO_4$
Well 1 Sep Solids	25.8	$CaCO_3$, trace amounts of $BaSO_4$
Well 2 Sep Solids	17.9	$CaCO_3$
Well 3 Sep Solids	46.2	$CaCO_3$

Notes: WB = Well Bore, WH= Well Head, Sep = Separator

Our initial observation is that calcite ($CaCO_3$) is the dominant scale that will be produced. Well 3 has more solids than the other two wells near the well bore (WB). This is probably due to the lower pressure in this well which allows carbon dioxide (CO_2) to evolve out of solution, raising the pH. The solubility of calcite is a function of pH and a higher pH decreases the solubility and increases the amount of scale formation.

The amount of gas produced, reported in stream “To Gas Process”, is 1.66 MM ft^3/day. The total amount of water produced is 2646 bbl/day.

Brine Re-injection

The following flow diagram shows a proposal for re-injecting the produced brines. The produced brines are mixed at the surface. Next, the mixed brine is filtered to remove any scales that may have formed as a result of mixing. Some gas may be produced and, if so, is vented.

The mixed brine is injected back into the production zones at 157 psia and 206 ^{o}F. These are the conditions that result for an adiabatic mix at the lowest pressure of the produced brines.

The production zones are not of uniform thickness. Therefore, the total injection brine is divided into unequal fractions to approximate the volume of brine displaced in each zone:

Zone 1	20 %
Zone 2	30 %
Zone 3	45 %
Formation Leakage	5 %

Some of the brine does not return to the well bores. This was estimated to be 5% of the total brine that is re-injected.

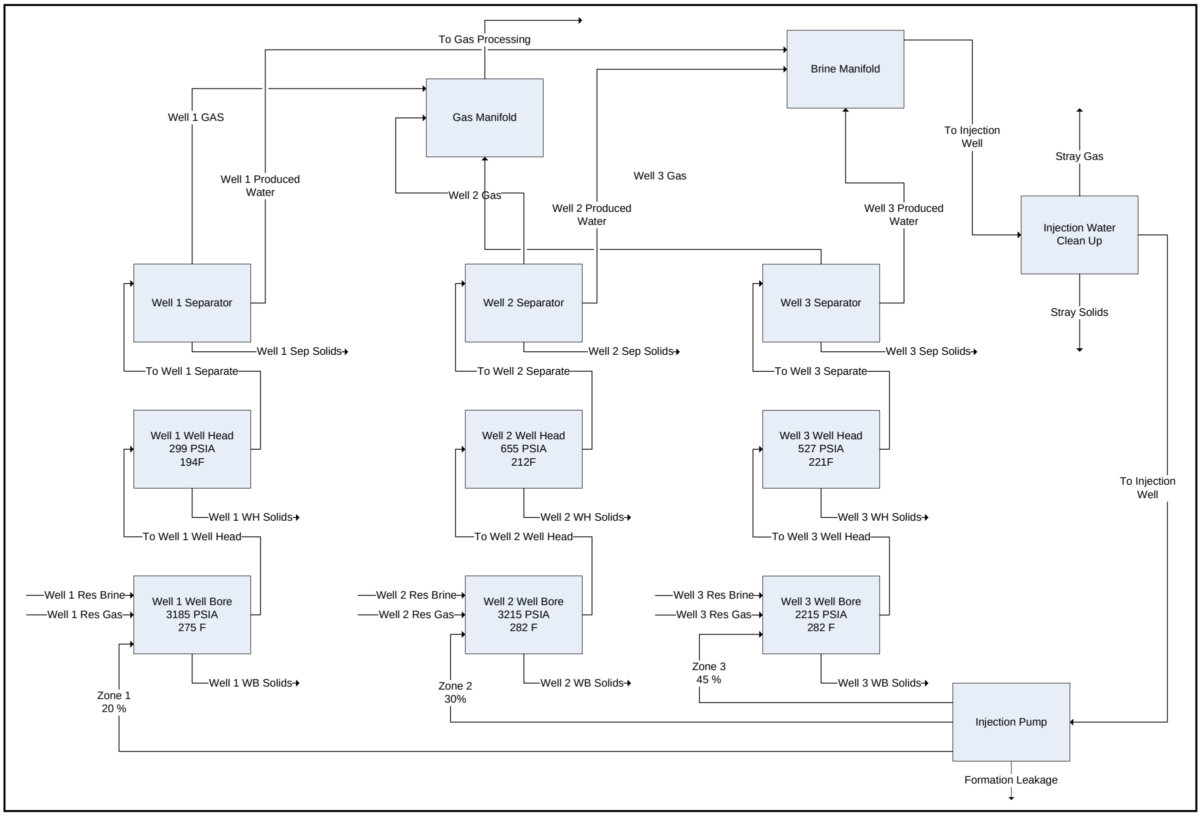


Figure 2 – Brine re-injection

Simulation – Brine Re-injection

An ESP flowsheet was built according to the flow diagram in Figure 2. This flowsheet introduces a recycle stream to the simulation. Values for this recycle loop are unknown at the start of the calculation and must be specified prior to the start of the calculation. This is often referred to as “tearing” a process.

The “tear” stream does not have to be the recycle stream. For this simulation, the stream labeled “To Injection Well” is the selected tear stream. An initial estimate for this stream is:

Stream	**Injection Water**
Temperature, ^oF	206
Pressure, psia	157
Total Flow, lb/day	170 MM
Composition, lb/day	
H_2O	168 MM
CO_2	2200
CH_4	1880
H_2S	2650

Once this stream is specified, the process can be simulated. You will notice that no scale minerals are specified. These will be added automatically as the tear stream converges.

The predicted scale locations are now as follows:

Location	**Scale, lb/day**	**Types of scales**
Well 1 WB Solids	2.2	$CaCO_3$
Well 2 WB Solids	10.3	$SrSO_4$
Well 3 WB Solids	357.0	$CaSO_4$, $BaSO_4$
Well 1 WH Solids	0.2	$CaCO_3$
Well 2 WH Solids	0	No scales predicted
Well 3 WH Solids	0	No scales predicted
Well 1 Sep Solids	0.1	$CaCO_3$
Well 2 Sep Solids	154.0	$CaCO_3$
Well 3 Sep Solids	99.1	$CaCO_3$, $BaSO_4$, and trace FeS

It appears that the well bore region around Well 3 will produce significantly more scale than the case without re-injection (44 lb/day vs. 357 lb/day). There are very few pathways for calcium removal other than by scale formation.

The total amount of gas produced is 1.66 MM ft^3/day. The amount of brine returned to the formation via injection is 50,470 barrels/day. Finally, the amount of brine leaked into the formation is 2520 barrels/day.

Conclusions / Limitations

It would appear that using brine re-injection is not a very good method of increasing the gas production without increasing the amount of scale formation. There are several issues here. First, when there is no brine re-injection, 2646 barrels/day of produce water are discharged. In the brine re-injection case, the amount that is being recycled is 50,470 barrels/day. This is a 20 fold increase and would require similar increases in production equipment sizes and costs. Only a fraction of the produced brines are returned to the formation because of this increase in volume.

One limitation of this analysis is that we have used steady-state simulation to model the two scenarios. Generally, as a gas well ages due to production, the gas/water ratio decreases. This means that, at some point, more water than gas will be produced. However, away from the well bore, there may be non-depleted areas where the gas/water ratio is still high. Brine re-injection can push these high ratio areas towards the depleted zone close to the well bore. Steady-state simulations cannot account for this effect.