PROCEEDINGS, 50th Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, February 10-12, 2025
SGP-TR-229

Risk Assessment of Shallow Oil and Gas Well to Geothermal Well Conversion

Alex McSheridan, Catalin Teodoriu, Khizar Abid

100 Boyd St, Norman, OK 73019

Alex.N.Mcsheridan-1@ou.edu

Keywords: Geothermal, Retrofitting, Risk Analysis, Integrity

ABSTRACT

With the world targeting a net zero carbon emission, oil and gas will begin to decline leaving behind thousands of abandoned wells to handle. Pawnee Nation has taken the initiative in handling this vast inventory by converting old oil and gas wells into geothermal wells. By giving new life to these old wells, there are significant cost savings due to not needing to be drilled, and furthermore there does typically not need to be an extensive completion design to make these wells suitable for geothermal. However, before repurposing these wells, there needs to be a risk assessment to avoid well integrity issues, aquifer contamination and surface contamination. A way to identify these risks is by utilizing a Feature, Event and Processes (FEP), this can show us various elements that could create a catastrophic failure. Once these elements are identified, an interaction matrix is then used to show how each element will react with another. After that, an incident potential matrix will be done by a field expert to assess the risk level of each interaction and quantify said risk. Finally, a cause and effect diagram is used to show the mean value and visually shows which elements are the most critical to the system. Once the most critical pieces of the system have been identified, steps can be taken to ensure a safe and reliable system. The Pawnee Nation is at the forefront of these conversions and are solidifying their involvement in the green future.

1. INTRODUCTION

1.1 Background

With the ever changing and increasing energy demands of today's world, there is a need to find alternative sources to heat our buildings. The heat beneath our feet, aka geothermal heat can be an excellent source of heat to keep buildings and greenhouses at optimal temperatures during the cold winter months.

The Rural Energy Pilot Program (REPP) is a 2.6-million-dollar grant from the United States Department of Agriculture to help transform the energy landscape of Pawnee Nation for a cleaner, more sustainable future. Pawnee Nation is partnering with Pawnee Nation College, Pawnee Nation Housing Authority, Indian Electric Cooperative, University of Oklahoma, and Tribuquent. Through this coalition, the Pawnee Nation will be changing the energy landscape of Pawnee in multiple ways. One of these ways is by converting old oil and gas wells into geothermal wells, giving new life to idle and orphan wells.

Typically, the life cycle of the oil and gas well starts with drilling and ends when the well is deemed to be no longer economically viable. Initially, the well is drilled and cased to protect freshwater aquifers. Some formations need to be stimulated as well, or other tools need to be used in the well, this is called completing the well. Once there is access to the hydrocarbons, the well is then put on production and it can begin producing the fluids and gases in the reservoir. Once the operator has recovered all the oil and gas possible and re-stimulating won't produce enough hydrocarbons to make financial sense, the well is then idled for future use, plugged and abandoned (P&A), or if the operator goes out of business and does not have the means to P&A the well, orphaned.

Instead of permanently abandoning these wells, it is possible to give them a new lease on life by converting them to geothermal wells. Pawnee has 4 idled/orphaned wells near their greenhouse and administrative buildings that would be great candidates to heat these buildings during the winter by storing heat in the formation during the summer and extracting it during winter. This paper will focus on a single well system, utilizing the well closest to the greenhouse and administrative buildings.

Figure 1 explains the single wellbore, showing heated fluid being pumped down the annulus in order to heat the formation. Then this heated fluid will be stored until it is needed and then produced via the tubing and ESP.

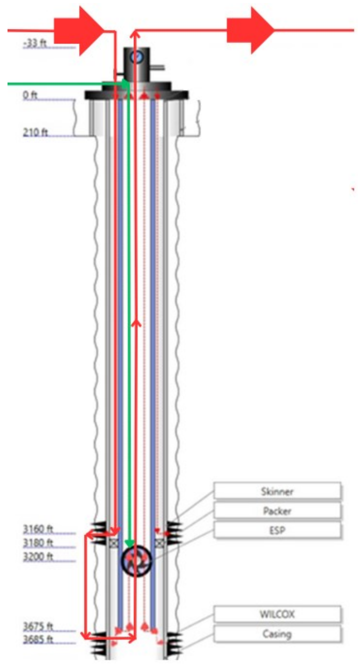

Figure 1: Single wellbore design

1.2 Statement of Problem

The main problem when converting orphaned oil and gas wells into geothermal wells is not understanding the risks associated with the conversion. Also, because these wells are already drilled, cased, perforated and completed it is necessary to design around these constraints.

1.3 Objectives

The objective of this paper is to identify the critical elements of the well for converting old wells into geothermal systems to ensure that those areas that are more susceptible to catastrophic failure can be strengthened. The proposal will include a Feature, Events and Processes (FEP), Interaction Matrix (IM), and a cause-and-effect plot diagram to identify the critical components of the system.

Comprehensive risk analysis is also proposed to understand the viability and environmental safety aspect of the candidates. This will be done by using a modified FEP method, translated into a geothermal application

1.4 Methodology

Critical elements within the well system will be identified via the FEP, then placed in the IM to assess the effect of one element on another. The Incident Potential Matrix (IPM) assigns a risk value based on severity and probability, as determined by experts in the field. After the risk values are established in the IM, a cause-effect calculation generates a plot that indicates which elements are critical and have the potential to compromise well integrity and cause catastrophic events. This risk assessment exercise enables the implementation of remedial measures in advance, ensuring the well is suitable for retrofitting into geothermal applications.

1.5 Significance

The significance of the project will give an outline for assessing risk when converting oil wells into geothermal wells. When a well stops being economically productive, instead of plugging and abandoning it, it is possible to use the already drilled wellbore to produce heat and electricity, saving on drilling costs and turning carbon producing resource into a green powerhouse. By understanding risk, and forces acting within a system it is then possible to proceed with a completion design knowing that all risks have been mitigated or taken into account, and that the chances of catastrophic failures have been minimized.

2. METHODOLOGY

2.1 Features, Events and Processes

The FEP used in this proposal for converting old oil and gas wells into geothermal wells was taken from Quintessa (2013). This FEP is specific to Carbon Capture Storage wells. Geothermal and CCS wells are very different, it is still practical to use this approach to show the critical elements in these old wells that are to be repurposed for geothermal purposes because it still gives an idea of which elements and interactions are needed for the interaction matrix,

2.2 Interaction Matrix

The interaction matrix takes the qualitative aspect of the FEP and turns it into semi-quantitative. This matrix is a square that shows the interaction of different elements within the system. It shows the interaction that A has on B, and that B has on A. This system can help identify the most critical component in the system we are trying to do a risk assessment on.

Table 1: Interaction matrix of 3x3 (Abid et al., 2024)

Element A	*Interaction of A to B* →	*Interaction of A to C*
Interaction of B to A ↑	***Element B***	*Interaction of B to C* ↓
Interaction of C to A	*Interaction of C to B* ←	***Element C***

2.3 Incident Potential Matrix

The Incident Potential Matrix (IPM) is used to assess the risk when qualitative analysis is used. The risk is defined as the product of probability and severity.

In an IPM, the x-axis represents the severity of an incident, and the y-axis represents the probability of exposure to the incident. An expert can give their input on the severity of the interaction and the probability, and from that we can give the interaction a number to show where it places in terms of severity and probability. After each interaction is analyzed, it is possible to identify where the weak points in the system are. A color code also helps to distinguish between severity levels. It is important to note that these ratings are based off of experts' opinions and therefore can differ from person to person.

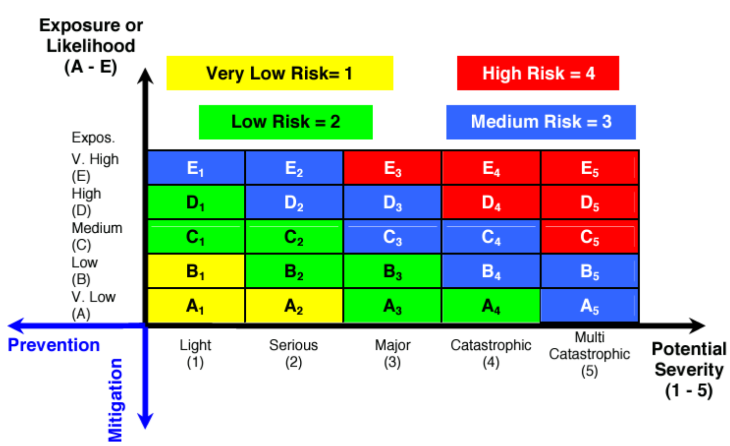

Figure 2: Interaction Potential Matrix (Condor and Asghari, 2009)

Table 2: Color code for Risk Evaluation Matrix (Condor and Asghari, 2009)

Priority		Description
No	Risk	
0	Nil	No identified risk
1	Very Low	Present Interaction – cannot be considered in the initial evaluation, but it has the potential of affecting the system. Little influence in other parts of the system
2	Low	Important Interaction – part of the initial evaluation. Limited or uncertain influence through this interaction to other parts of the system.
3	Medium	Very Important Interaction – part of the initial evaluation. They have influence in other part of the system.
4	High	Critic Interaction – Part of the initial evaluation. High probability of influencing other parts of the system.

2.4 Cause & Effect Plot

The Cause & Effect plot can be made once the interaction matrix is complete, and the risks have been ranked. The cause is given by the sum of the horizontal row, and effect is the sum of vertical row. These sums will then be plotted for each element, along with the mean of the cause and effect to show which elements are more critical. The elements above the mean line are critical elements, and the ones below are less critical elements in the system. Table 3, Table 4 and Figure 3 are examples of this cause and effect.

Table 3: Interaction Matrix with Risk Assessment Value (Abid et al., 2024)

Effect ↓ / Cause →			
Element A *(1,1)*	Interaction of A to B E4 4	Interaction of A to C B4 3	*7*
Interaction of B to A C2 2	*Element B* *(2,2)*	Interaction of B to C A1 1	*3*
Interaction of C to A A2 1	Interaction of C to B D4 4	*Element C* *(3,3)*	*5*
3	*8*	*4*	

Table 4: Values of Cause and Effect (Abid et al., 2024)

Element	Cause	Effect
Element A [1,1]	7	3
Element B [2,2]	3	8
Element C [3,3]	5	4
Mean	5	5

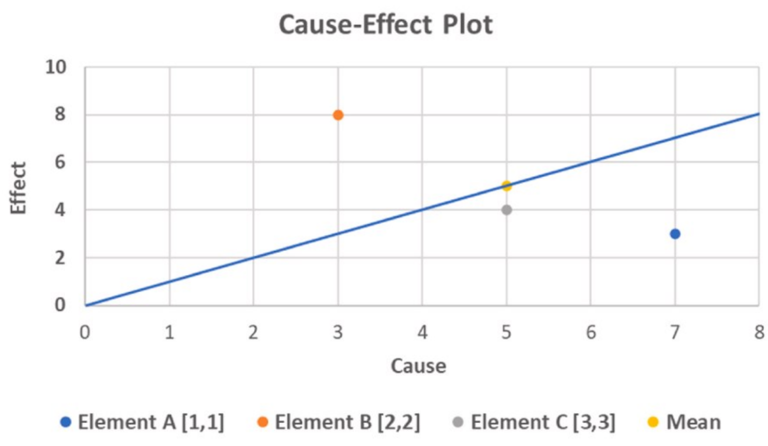

Figure 3: Cause & Effect plot (Abid et al., 2024)

It is clear to see that element B is the most critical element on this example system.

2.5 Workflow

Figure 4 shows the workflow of this type of risk assessment. First the FEP elements that are relevant to these wells need to be identified. Then select the elements for the geothermal wells, put those elements into an interaction matrix and rank those elements. After that comes the cause-and-effect plot where it is easy to identify the critical components

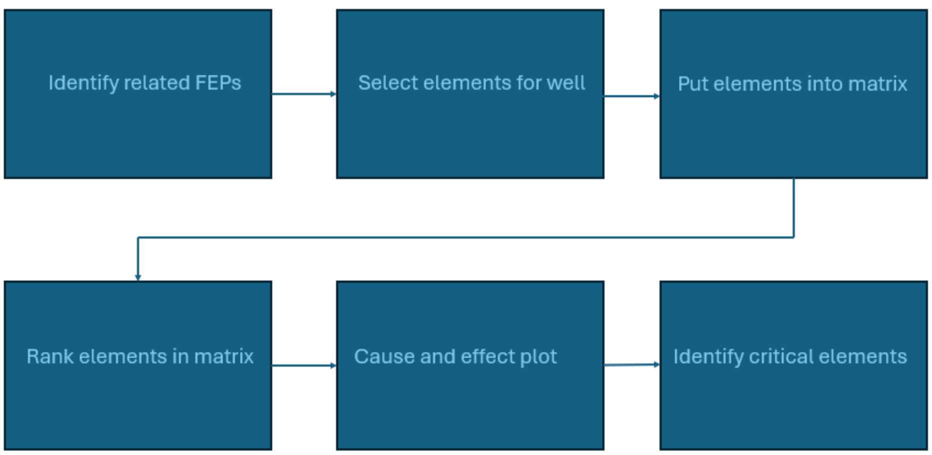

Figure 4: Risk assessment workflow

RESULTS

3.1 Single Well Risk Assessment

This section will cover the assumptions, IM, IPM, and Cause and Effect plot for the single well of both the wellbore and surface. Forewarning, there will be repeats in the ratings sections due to similar effects happening on surface and the wellbore.

3.2 Assumptions for Single Well

The following assumptions are assumed for the risk assessment of the single wellbore proposal:

Well Age = 10 years
Well type = Suspended
Suspended age = 4 years
Reservoir Temperature = 110 °F -190 °F
Packer Depth = 3,250 feet
Total Depth =3,791 feet
Well trajectory = Vertical
Working fluid = Water
Dominant phase = Liquid

Thermal cyclic loading = Caused by huff and puff and closure of the well for workover if required.
Cement bond data = limited
Casing = Carbon steel (5.5" 15.5 #/ft J-55)
Production = Through tubing
Injection = Through casing

3.3 Single Well Wellbore Proposal

Six elements were considered for the proposal for the single wellbore. A) Casing (production casing and intermediate). B) Cement (cement sheath around casing strings). C) Fluid (water composition that will be found within the wellbore). D) Temperature (natural heat from both formation and solar heaters). E) Wellhead (Christmas tree, connections on surface tubing spools, valve etc.). F) Downhole Equipment (Tubing, packer and ESP). The interaction matrix size will be 6x6. It is important to note that these ratings are subjective and can be different based on a person's experiences.

Table 5: Interaction matrix of wellbore for single well proposal

[1,1] **Casing**	[2,1] A) Expansion and Contraction B) Creation of new residual stresses C) Debonding and micro annulus	[3,1] A) Sorption	[4,1] A) Heat Loss	[5,1] A) Thermal expansion shifting wellhead	[6,1] A) Fishing problem due to size restriction of final casing
[1,2] A) Compression Failure B) Corrosion	**[2,2]** **Cement**	[3,2] A) Chemical equilibrium	[4,2] A) Heat loss	[5,2] A) Annular pressure B) Thermal stresses	[6,2] N/A
[1,3] A) Corrosion B) Erosion C) Scale	[2,3] A) Carbonation and bi-carbonation B) Change in transfer properties C) Degradation	**[3,3]** **Fluid**	[4,3] A) Heat loss	[5,3] A) Corrosion B) Erosion C) Scale	[6,3] A)Corrosion B) Erosion C) Scale
[1,4] A) Expansion and contraction B) Affects burst and collapse pressure C)Thread Jumping	[2,4] A) Axial and circumferential cracking B) Thermal stresses	[3,4] A) Precipitation	**[4,4]** **Temperature**	[5,4] A) Displacement B) Thermal stresses	[6,4] A) Thread jumping B) Change in burst and collapse pressure C) Thermal effect on cable/ESP performance
[1,5] A) Outside forces changing stress	[2,5] A) Debonding and microannuli	[3,5] A) Sorption B) Phase change	[4,5] A) Heat loss	**[5,5]** **Wellhead**	[6,5] A) Tensile stresses B) Thread jumping C) Change in burst and collapse pressure
[1,6] A) Casing contact damage via vibrations B) Packer slip damage from packer	[2,6] N/A	[3,6] A) Sorption	[4,6] A) Heat Loss	[5,6] A) Thermal stresses	**[6,6]** **Downhole Equipment**

Table 6: Interaction matrix with values of the wellbore for single well proposal

	1	2	3	4	5	6	Cause
1	**[1,1]** **Casing**	[2,1] E5 4	[3,1] B1 1	[4,1] E1 3	[5,1] C4 3	[6,1] A4 2	13
2	[1,2] E5 4	**[2,2]** **Cement**	[3,2] B1 1	[4,2] E1 3	[5,2] D4 4	[6,2] 0 0	12
3	[1,3] E5 4	[2,3] B5 3	**[3,3]** **Fluid**	[4,3] E1 3	[5,3] E4 4	[6,3] E3 4	18
4	[1,4] E5 4	[2,4] E5 4	[3,4] D1 2	**[4,4]** **Temperature**	[5,4] E4 4	[6,4] E3 4	18
5	[1,5] A5 3	[2,5] A5 3	[3,5] A1 1	[4,5] E1 3	**[5,5]** **Wellhead**	[6,5] D3 3	13
6	[1,6] B5 3	[2,6] 0 0	[3,6] B1 1	[4,6] E1 3	[5,6] E4 4	**[6,6]** **Downhole Equipment**	11
	18	14	6	15	19	13	Effect

Table 7: Cause and effect values for single well wellbore

Element	Cause	Effect
Casing [1,1]	13	18
Cement [2,2]	12	14
Fluid [3,3]	18	6
Temperature [4,4]	18	15
Wellhead [5,5]	13	19
Downhole Equipment [6,6]	11	13
Mean	14.2	14.2

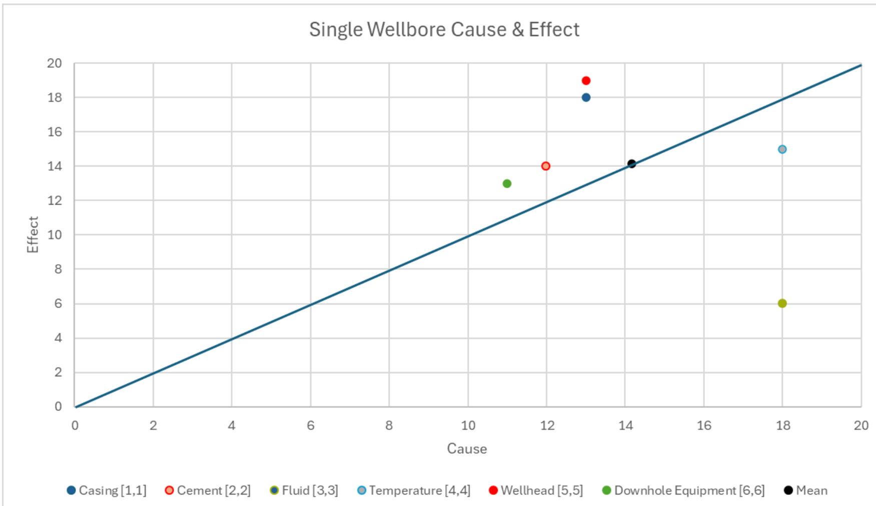

Figure 5: Cause & Effect Plot for single wellbore proposal

3.4 Single Well Wellbore Rating Discussion

This section will go into detail for each rating for each interaction. These are worst case scenarios for each interaction with the exposure to each interaction. It is important to note that some important data is missing, such as casing quality, fluid quality and cement bond quality to name a few.

[2,1] Casing on Cement - 4, E5 – Albawi (2013) states that "Heating and cooling make the steel casing expand and contract as a result of thermal expansion. This volumetric change can influence downhole well barriers, e.g. annular cement sheaths leading them to fail. Failure of annular cement sheaths can introduce well integrity issues and subsequent well leakages of downhole formation fluids". This is also backed up by an experimental study done by Vrålstad et al., (2015) in which the applied a thermal cyclic load to cement with sandstone as the formation, they observed that when mulitple cycles occurred, it was debonded from the formation, small cracks formed, and grew with thermal cycles and thus created a path for fluids to flow. Because formation fluid leakages can be catastrophic and this casing's temperature will be cycled many times, the exposure is high and so is the potential severity of this cycling. If the cement fails, then the following consequences could be catastrophic. Also, near perforation the impact could cause debonding and travel up the wellbore.

These wells are perforated, and cyclic thermal expansion and contraction won't make these impact points better. Because it is unknown the condition of the cement sheath, it is necessary to assume it is not perfect and therefore subject to these forces. The exposure to thermal cycling is high, and there are perforations, and the severity of cement failing is catastrophic.

[3,1] Casing on Fluid – 1, B1– Sorption is the solid absorbing the fluid. While this is possible with our casing, it won't affect fluid that much. Organic substances from oily wastewater can adhere to porous sorption media. In the case of Ogunbiyi et al. (2023), they are talking about how to clean up an oil spill. But most surfaces have pores. "adsorption refers to the gathering of the impurities at the liquid/solid interface, while absorption involves the penetration of the sorbate into the sorbent material". That is why this is the lowest possible severity and second lowest exposure as well.

[4,1] Casing on Temperature –3, E1- Casing will affect temperature due to the geothermal gradient present in the earth. There will be heat loss associated with this. Every time fluid moves, the temperature will be impacted. Kujawa et al., (2006) showed that running insulated tubing helps reduce heat loss in geothermal wells. Because our temperatures are not extreme, this will not be a severe interaction. But because this happens in every single well in the world, the exposure is high, but severity is not.

[5,1] Casing on Wellhead – 3, C4- With thermal expansion a known phenomenon, the casing expands or contracts dependent on temperature. With this movement, the wellhead could be put in unintended stress, along with connections and pipes leading off it that could cause potential leaking. Febriansyah et al. (2023) shows through finite element method that this growth and contraction can be predicted and accounted for. While this expansion and contraction via casing can cause problems, the exposure is not extremely high, but on the chance that it does there could be a surface leak via the pipe's fittings, or on the wellhead itself. These wells are dead, so a major blowout is very unlikely. However, if someone is injecting fluid somewhere else, that could increase formation pressure and cause a blowout.

[6,1] Casing on Downhole Equipment- 2, A4- Casing ID plays a large role in how large the tubing, ESP, and packer can be. Issues can arise when the ESP power cable falls down in the well, and needs to be fished out. If complications arise while fishing, it might become more economical to just abandon the well than to continue getting the fish out. DeGeare (2003) states that "Fishing can be thought of as a risk management strategy. When used successfully, it can save a well.". It can also kill a well. That is why this risk is A4, there is a small chance that this well will have to be fished on, and while it is costly or could be abandoned due to the fish, the likelihood of that happening is small.

[1,2] Cement on Casing -4, E5- If CO_2 is present, it will mix with the formation fluid and create carbonic acid. Zhou et al., (2016) Carbonic acid is a relatively strong corrosion medium, resulting in a higher corrosion frequency and a larger corrosion rate for metals and alloys. Along with the possibility for corrosion, cement will also expand and contract with the temperature changes, causing a change in axial and radial stresses. Because the amount of CO_2 is unknown in the formation fluid, we have to assume that there will be some carbonic acid forming and corroding the formation. When corrosion of the casing happens, this can be catastrophic.

[3,2] Cement on Fluid-1, B1- Cement does have the possibility to change the pH of the fluid. In Galon et al. (2021) the pH of cement was as high as 13.3. Because the volume of water is so large compared to the volume of cement, the pH of the water will not be affected greatly. Also, fluid and cement will not be mixing much due to casing. That is why it has received a rating of 1, B1.

[4,2] Cement on Temperature – 3, E1- Cement will affect temperature due to the geothermal gradient present in the earth. There will be heat loss associated with this. Every time fluid moves, the temperature will be impacted. Kujawa et al., (2006) showed that running insulated tubing helps reduce heat loss in geothermal wells. Because our temperatures are not extreme, this will not be a severe interaction. But because this happens in every single well in the world, the exposure is high, but severity is not.

[5,2] Cement on Wellhead – 4, D4- With thermal expansion a known phenomenon, the cement will expand or contract dependent on temperature. This expansion could stress the casing, which in turn could stress the wellhead. If the wellhead is stressed in unforeseen ways, then leaks could occur on the surface. Early detection is a must, and if left alone a small leak could become a major problem down the line. Also, Zhang et al., (2017) stated that "The calculated thermal expansion annulus pressure with field data is less than 8.0%". This change in annular pressure could affect the seal on the tubing spool causing a leak. The exposure to thermal cycling is high, and the effects of failure would be catastrophic.

[6,2] Cement on Downhole Equipment-0- The cement has no direct impact on downhole equipment.

[1,3] Fluid on Casing-4, E5- Scale, corrosion and erosion can be quite the issue in geothermal wells. "Mineral deposition or scale is the main problem faced in geothermal energy management activities that occur in wells and in production facilities that cause a decrease in power plants' capacity. Scales are formed naturally and cannot be prevented because they are associated with the reservoir (Kushonggo et al. 2021). Scale can cause restrictions in pipes, reducing flow, break off and cause clogs, and wreak havoc on any system and cause corrosion. The scales that are formed from the formations utilized in this project are barium scale from the Red Fork Zone, and sulfate coming from the Mississippi Formation. These can be combated via scale inhibitors, but this is not the perfect solution and will not get rid of all scale. Fluid speed can also cause erosion, 3m/s is the industry standard to avoid erosion, and in Zadeh et al. (2020) going from 5m/s to 16m/s erosion increase 4 to 6 times depending on microstructure. Corrosion is a major concern, if the casing corrodes, then all that is left is cement and fluid migration will occur. Differing salinity and pH levels of fluid can affect corrosion rates.

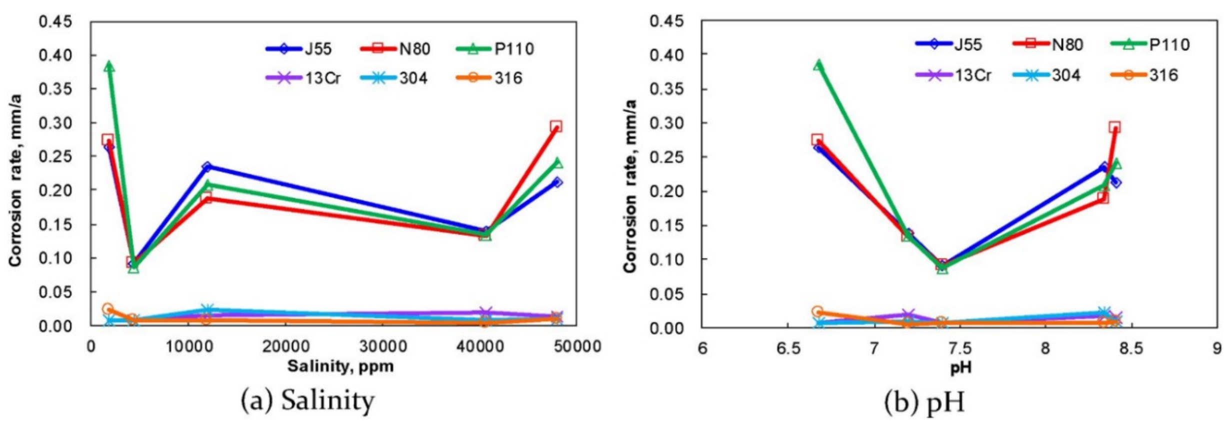

Figure 6: Effect of salinity and ph on corrosion (Zhang et al., 2021)

Temperature and CO_2 pressure also affect corrosion.

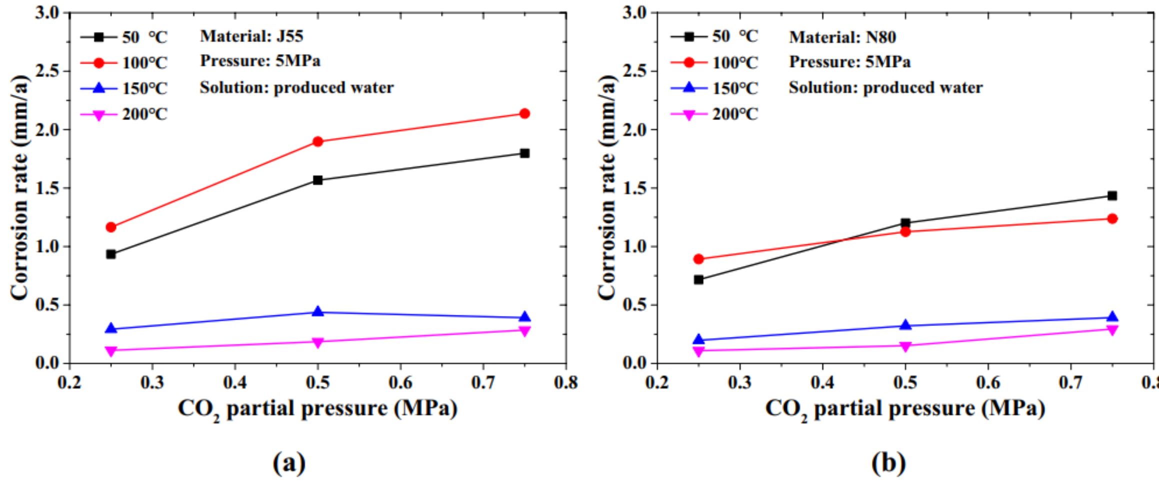

Figure 7: CO2 on corrosion (Cui et al., 2020)

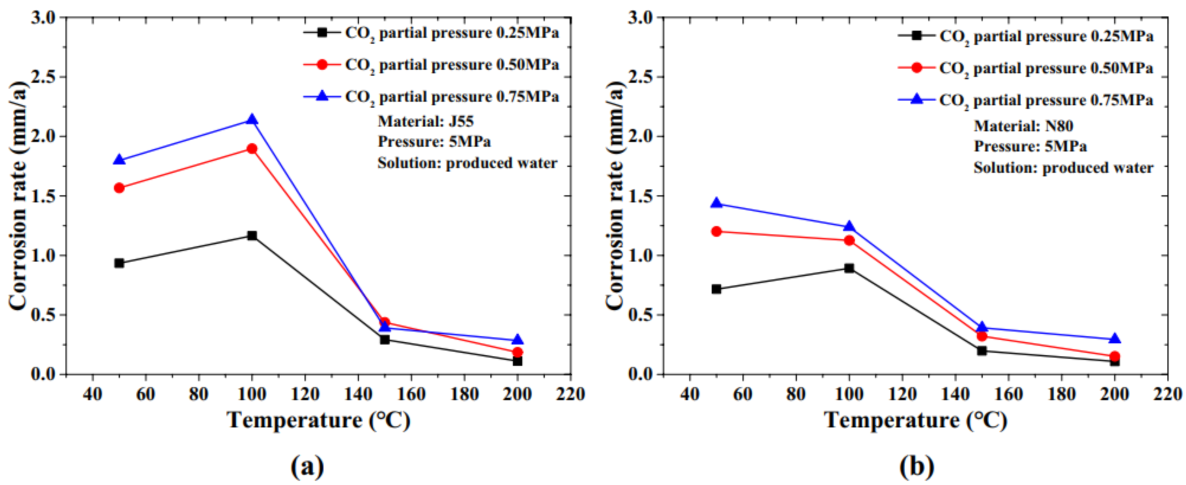

Figure 8: Temperature on Corrosion (Cui et al., 2020)

There are inhibitors that can be pumped to reduce corrosion by up to 99% (Sarkar et al. (2021). Because the fluid interacts on the casing all the time, the exposure is very high. Also, the potential to reduce flow, reduce structural integrity of the wellbore, and cause fluid migration means that this interaction could be extremely catastrophic.

[2,3] Fluid on Cement-3, B5- Wellbore fluid can degrade cement, just like it can degrade casing depending on certain chemical reactions. If there is CO_2 in the wellbore, this can speed up the degradation process. According to Chen et al. (2023) the "cement sheath is susceptible to corrosion and its corrosion degree is not easy to observe in acid gas wells and geological storage wells containing carbon dioxide (CO_2).". While the exposure of formation fluid to cement is low, the severity of that interaction can be catastrophic.

[4,3] Fluid on Temperature-3, E1- Fluid will affect temperature because it is the main carrier of heat in and out of the system. There will be heat loss associated with this. Every time fluid moves, the temperature will be impacted. Kujawa et al., (2006) showed that running insulated tubing helps reduce heat loss in geothermal wells. Because our temperatures are not extreme, this will not be a severe interaction. But because this happens in every single well in the world, the exposure is high, but severity is not.

[5,3] Fluid on Wellhead-4, E4- Scale, corrosion and erosion can be quite the issue in geothermal wells. "Mineral deposition or scale is the main problem faced in geothermal energy management activities that occur in wells and in production facilities that cause a decrease in power plants' capacity. Scales are formed naturally and cannot be prevented because they are associated with the reservoir (Kushonggo et al. 2021). Scale can cause restrictions in pipes, reducing flow, break off and cause clogs, and wreak havoc on any system and cause corrosion. The scales that are formed from the formations utilized in this project are barium scale from the Red Fork Zone, and sulfate coming from the Mississippi Formation. These can be combated via scale inhibitors, but this is not the perfect solution and will not get rid of all scale. Fluid speed can also cause erosion, 3m/s is the industry standard to avoid erosion, and in Zadeh et al. (2020) going from

5m/s to 16m/s erosion increases 4 to 6 times depending on microstructure. Corrosion is a major concern, if the casing corrodes, then all that is left is cement and fluid migration will occur. Differing salinity and pH levels of fluid can affect corrosion rates (Figure 21). Temperature and CO_2 can have impacts on corrosion as well (Figure 22 &23).

There are inhibitors that can be pumped to reduce corrosion by up to 99% (Sarkar et al. (2021). Because the fluid interacts on the wellhead all the time, the exposure is very high. Also, the potential to reduce flow, reduce structural integrity of the wellhead, and cause surface leaks means that this interaction could be catastrophic.

[6,3] Fluid on Downhole Equipment-4, E3- Scale, corrosion and erosion can be quite the issue in geothermal wells. "Mineral deposition or scale is the main problem faced in geothermal energy management activities that occur in wells and in production facilities that cause a decrease in power plants' capacity. Scales are formed naturally and cannot be prevented because they are associated with the reservoir (Kushonggo et al. 2021). Scale can cause restrictions in pipes, reducing flow, break off and cause clogs, and wreak havoc on any system and cause corrosion. The scales that are formed from the formations utilized in this project are barium scale from the Red Fork Zone, and sulfate coming from the Mississippi Formation. These can be combated via scale inhibitors, but this is not the perfect solution and will not get rid of all scale. Fluid speed can also cause erosion, 3m/s is the industry standard to avoid erosion, and in Zadeh et al. (2020) going from 5m/s to 16m/s erosion increase 4 to 6 times depending on microstructure. Corrosion is a major concern, if the casing corrodes, then all that is left is cement and fluid migration will occur. Differing salinity and pH levels of fluid can affect corrosion rates (Figure 21). Temperature and CO_2 can have impacts on corrosion as well (Figure 22 &23).

There are inhibitors that can be pumped to reduce corrosion by up to 99% (Sarkar et al. (2021). Because fluid interacts with the downhole equipment all the time the exposure is very high. Also, the potential to reduce flow, reduce structural integrity of the tubing, and cause leaks within from the tubing to the casing means that this interaction could be a major severity event.

[1,4] Temperature on Casing-4, E5- Temperature causes the casing to expand and contract. This can lead to a catastrophic failure due to stresses on cement changing and causing micro annuli allowing fluid migration. This can also put more stress on the wellhead and connections to it. Steel expands by 0.06–0.07% in length for every 100°F increase in temperature, and this system will be around that temperature change. This could mean 26' over the change of the entire wellbore. Another issue is with the expansion and contraction, the burst and collapse pressure of that casing will be reduced as well. Thread jumping is also a cause for concern. Thread jumping is when the casing or tubing threads are affected by compressive and tensile loads. This thread jumping weakens the threads, which weakens the casing. Because the temperature in the wellbore is changing, the exposure is high, and the results of that exposure can be catastrophic.

[2,4] Temperature on Cement-4, E5- Thermal stresses from cement expanding and contracting can cause cracking as described by Vrålstad et al., (2015). These stresses can cause cracking, cement debonding and allow for fluid migration. Because the cement is exposure to thermal cycling, and the results of this cycling are catastrophic, this is given an E5.

[3,4] Temperature on Fluid-2, D1- The temperature a fluid is can drastically change what it precipitates out. Typically, the higher the temperature, the more salts can dissolve within the fluid.

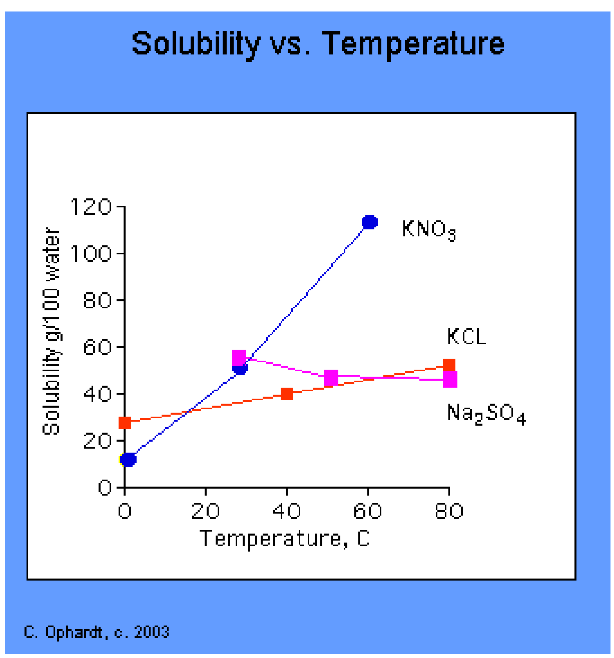

Figure 9: Solubility vs. Temperature (Ophardt 2023)

Because the exposure to temperature changes are somewhat high, but the severity of salts precipitating out are low, this is rated D1.

[5,4] Temperature on Wellhead-4, E4- Temperature causes the wellhead to expand and contract. This puts more stress on the wellhead and connections to it and can affect the burst and collapse pressures. Steel expands by 0.06–0.07% in length for every 100°F increase in temperature, and this system will be around that temperature change. With the casing expanding, and the wellhead potentially shifting due to thermal expansion, it could put stress on pipes on the surface. Thread jumping is also a cause for concern. Thread jumping is when the casing or tubing threads are affected by the compressive and tensile loads. This thread jumping weakens the threads, which weakens the wellhead fittings. Because the temperature in the wellhead is changing, the exposure is high, and the results of that exposure can be catastrophic.

[6,4] Temperature on Downhole Equipment-4, E3- Temperature causes the downhole equipment such as tubing to expand and contract. This puts more stress on the tubing, connections and packer. It can also affect the burst and collapse pressure of that tubing. Steel expands by 0.06–0.07% in length for every 100°F increase in temperature, and this system will be around that in terms of temperature change. Thread jumping is also a cause for concern. This thread jumping weakens the threads, which weakens the wellhead fittings. Another concern is because this system is injecting high temperature fluid in the annulus, it is running right along the power cable for the ESP and this can cause damage. Because the temperature of the downhole equipment is constantly changing, the exposure is high, and the results of that exposure can be serious and cause failures in the system.

[1,5] Wellhead on Casing-3, A5-The wellhead can be impacted by an external event such as a vehicle hitting it. If this happens there is the possibility that the wellhead/ upper section of casing will leak due to change in stresses and weakening of the connection. The chances of this happening are small, but if it does happen the consequences will be catastrophic.

[2,5] Wellhead on Cement-3, A5- the same as described above, if the wellhead gets hit by a vehicle or another object that can affect the stresses it can change the stresses in the cement and cause debonding and micro annuli. This type of event can have severe repercussions such as allowing fluid to migrate to surface.

[3,5] Wellhead on Fluid-1, A1 Sorption is the solid absorbing the fluid. While this is possible with our casing, it won't affect fluid that much. Organic substances from oily wastewater can adhere to porous sorption media. In the case of Ogunbiyi et al. (2023), they are talking about how to clean up an oil spill. But most surfaces have pores. "adsorption refers to the gathering of the impurities at the liquid/solid interface, while absorption involves the penetration of the sorbate into the sorbent material". Phase change is also a possibility, but with our working pressure and temperatures staying below boiling point of water, the likelihood and severity of any this happening is small.

[4,5] Wellhead on Temperature-3, E1- Wellhead will have a small effect on temperature via heat loss. Every time fluid moves, the temperature will be impacted. Kujawa et al., (2006) showed that running insulated tubing helps reduce heat loss in geothermal wells. It is also possible to insulate the wellhead to avoid heat loss. Because our temperature loss is not extreme, this will not be a severe interaction. But because this happens in every single well in the world, the exposure is high, but severity is not.

[6,5] Wellhead on Downhole Equipment-3, D3- The wellhead will be receiving external forces from casing and cement, this will cause stresses on the tubing and packer. Potentially, this can unseat the packer, or it could cause thread jumping. While these are serious issues, they're not catastrophic and thus rated this as high in likelihood due to the change stresses, but not catastrophic.

[1,6] Downhole Equipment on Casing-3, B5- Vibrations from pumps can wear or damage the casing reducing burst and collapse pressure. The internal surface of tubing can be changed by sandblasting or rubbing with sucker rods can alter the corrosion rates. While this system does not use sucker rods, the vibrations from ESP could assist corrosion by wearing down certain parts of the casing. Packer slip is also a concern. If the tubing expands or puts too much compressional force on the packer, it could slip and gouge the tubing. The chances of this are low, but the severity could be catastrophic due to a puncture in the casing.

[2,6] Downhole Equipment on Cement-0- The downhole equipment does not have any negative effect on cement in the wellbore.

[3,6] Downhole Equipment on Fluid-1, B1- Sorption is the solid absorbing the fluid. While this is possible with our tubing, it won't affect fluid that much. Organic substances from oily wastewater can adhere to porous sorption media. In the case of Ogunbiyi et al. (2023), they are talking about how to clean up an oil spill. But most surfaces have pores. "adsorption refers to the gathering of the impurities at the liquid/solid interface, while absorption involves the penetration of the sorbate into the sorbent material". That is why this is the lowest possible severity and second lowest exposure as well.

[4,6] Downhole Equipment on Temperature-3, E1- Tubing will affect temperature due to the geothermal gradient present in the earth. There will be heat loss associated with this. Every time fluid moves, the temperature will be impacted. Kujawa et al., (2006) showed that running insulated tubing helps reduce heat loss in geothermal wells. Because our temperatures are not extreme, this will not be a severe interaction. But because this happens in every single well in the world, the exposure is high, but severity is not.

[5,6] Downhole Equipment on Wellhead – 4, E4- With thermal expansion a known phenomenon, the tubing will expand or contract dependent on temperature. This added stress can negatively impact the wellhead, potentially causing it to leaking. Febriansyah et al. (2023) shows through finite element method that this growth and contraction can be predicted. For their system, it was crucial that they account for growth during high temperature times. This is rated as 4 because the wellhead will experience forces from the tubing constantly. If caught early, it won't be extremely severe, but the exposure to forces from tubing is constant and if the wellhead fails it would be catastrophic.

CONCLUSIONS

This research shows an extensive and dedicated investigation into assessing the risk of converting old oil and gas wells into geothermal wells utilizing J-55 tubing.

The following conclusions can be drawn:

- A comprehensive risk analysis of a single wellbore proposal with J-55 tubing has been done. It has shown which elements are the most critical within each system, and which elements affect and are affected the most.

- Performing a proper risk assessment using an Interaction Matrix can assist in identifying critical components of a system that are prone to failure and cause catastrophic events ie. blowouts, contamination of aquifers, and complete abandonment of the well.

- As expected, wellbore fluid and temperature had the largest cause (18) and wellhead and casing were the most effected for the wellbore section (19 & 18 respectively). This is due to scale, corrosion and erosion that can cause holes within the casing which could potentially lead to unwanted fluid migration leading to a contamination of an aquifer or surface contamination.

ACKNOWLEDGMENTS

We'd like to thank the United States Department of Agriculture for giving us the opportunity to be a part of this project. Also, thank you to Pawnee Nation for being open minded and taking the initiative to try out new technologies that empowers their people. Lastly, thank you to Tribuquent for getting all these groups together and making this happen.

REFERENCES

Abid, K., Baena Velasquez, A. F., Sharma, A., McSherdian, A. N., Srivastava, S., & Teodoriu, C. (2024). Risk assessment through feature, event, and process for repurposing suspended wells for geothermal purposes. Renewable energy 237 (2024): 121720. Web.

Albawi, Ali. "Influence of Thermal Cycling on Cement Sheath Integrity." Institutt for petroleumsteknologi og anvendt geofysikk, 2013. Print.

Chen, Rongyao, Jianjian Song, Mingbiao Xu, Xiaoliang Wang, Zhong Yin, Tianqi Liu, Nian Luo, Prediction of the corrosion depth of oil well cement corroded by carbon dioxide using GA-BP neural network, Construction and Building Materials, Volume 394, 2023, 132127, ISSN 0950-0618, https://doi.org/10.1016/j.conbuildmat.2023.132127.

Cui, L., Kang, W., You, H. et al. Experimental Study on Corrosion of J55 Casing Steel and N80 Tubing Steel in High Pressure and High Temperature Solution Containing CO2 and NaCl. J Bio Tribo Corros 7, 13 (2021). https://doi.org/10.1007/s40735-020-00449-5.

DeGeare, Joe. Chapter 1 - Conventional Fishing, Editor(s): Joe DeGeare, In Gulf Drilling Guides, The Guide to Oilwell Fishing Operations (Second Edition), Gulf Professional Publishing, 2003, Pages 1-2, ISBN 9780124200043, https://doi.org/10.1016/B978-0-12-420004-3.00001-0.

Febriansyah, Dwijaya, Endra Dwi Purnomo, Budi Nofiyantoro Fadjrin, Rudias Harmadi, Cuk Supriyadi Ali Nandar; Thermal growth prediction on 4 MW steam turbine casing using finite element method. AIP Conf. Proc. 27 April 2023; 2646 (1): 050069. https://doi-org.ezproxy.lib.ou.edu/10.1063/5.0113778.

Condor, Jose, Koorosh Asghari, An Alternative Theoretical Methodology for Monitoring the Risks of CO2 Leakage from Wellbores, Energy Procedia, Volume 1, Issue 1, 2009, Pages 2599-2605, ISSN 1876-6102, https://doi.org/10.1016/j.egypro.2009.02.026.

Kujawa, Tomasz, Władysław Nowak, Aleksander A. Stachel, Utilization of existing deep geological wells for acquisitions of geothermal energy, Energy, Volume 31, Issue 5, 2006, Pages 650-664, ISSN 0360-5442, https://doi.org/10.1016/j.energy.2005.05.002.

Kushonggo, Luhung, Heru Berian Pratama, Sutopo and Anton Supriyono, 2022 IOP Conf. Ser.: Earth Environ. Sci. 1014 012013 DOI 10.1088/1755-1315/1014/1/012013.

Ogunbiyi, Oluwaseun, Radee Al-Rewaily, Jayaprakash Saththasivam, Jenny Lawler, Zhaoyang Liu, Oil spill management to prevent desalination plant shutdown from the perspectives of offshore cleanup, seawater intake and onshore pretreatment, Desalination, Volume 564, 2023, 116780, ISSN 0011-9164, https://doi.org/10.1016/j.desal.2023.116780.

Ophardt, Charles. "Temperature Effects on Solubility." LibreTexts, 30 Jan. 2023, https://chem.libretexts.org/Bookshelves/Physical_and_Theoretical_Chemistry_Textbook_Maps/Supplemental_Modules_(Physical_and_Theoretical_Chemistry)/Equilibria/Solubilty/Temperature_Effects_on_Solubility.

Sarkar, Tarun Kanti et al. "Mitigation of Corrosion in Petroleum Oil Well/Tubing Steel Using Pyrimidines as Efficient Corrosion Inhibitor: Experimental and Theoretical Investigation." Materials today communications 26 (2021): 101862. Web.

Vrålstad, Torbjørn, Ragnhild Skorpa, and Nils Opedal. 2015. "Effect of Thermal Cycling on Cement Sheath Integrity: Realistic Experimental Tests and Simulation of Resulting Leakages." SPE Thermal Well Integrity and Design Symposium. Banff: SPE.

Zadeh, Sajjad Akramian, Pourya Rashidi, The effect of fluid velocity and microstructure on erosion corrosion of two-phase CK45 steel, Results in Materials, Volume 6, 2020, 100077, ISSN 2590-048X, https://doi.org/10.1016/j.rinma.2020.100077.

Zhang, Zhi, Han Wang, Effect of thermal expansion annulus pressure on cement sheath mechanical integrity in HPHT gas wells, Applied Thermal Engineering, Volume 118, 2017, Pages 600-611, ISSN 1359-4311, https://doi.org/10.1016/j.applthermaleng.2017.02.075.

Zhou, Yong, Fuan Yan, The Relation between Intergranular Corrosion and Electrochemical Characteristic of Carbon Steel in Carbonic Acid and Sodium Nitrite Solutions, International Journal of Electrochemical Science, Volume 11, Issue 5, 2016, Pages 3976-3986, ISSN 1452-3981, https://doi.org/10.1016/S1452-3981(23)17452-9.