COUPLED GEOTHERMAL PROCESS AND RESERVOIR MANAGEMENT

Mohamed Dabbour[1], Wei Yu[1], Rosalind Archer[2], Brent Young[1]

[1]Department of Chemical and Materials Engineering, University of Auckland, New Zealand

[2]Department of Engineering Science, University of Auckland, New Zealand

mdab002@aucklanduni.ac.nz

w.yu@auckland.ac.nz

r.archer@auckland.ac.nz

b.young@auckland.ac.nz

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ABSTRACT

Currently, New Zealand generates around 18% of its total electrical capacity using geothermal sources and could benefit significantly from simulation for optimization (Ministry of Business, Innovation & Employment, 2017). Current geothermal process and reservoir simulations are conducted separately with data manually parsed between the different simulators. Delays in the modelling process and the inability to efficiently model effects that reservoir changes over the assets lifetime have on the plant. Coupling both process and reservoir simulators would enable accurate prediction of both reservoir and plant issues. In this paper, a proof of concept is developed. The reservoir simulator AUTOUGH is coupled with the process simulator VMGSim using Python and PyTOUGH. A demonstration geothermal model was built using 2 simulated production and injection wells in which data is exchanged with an Organic Rankine Cycle (ORC) geothermal plant. The aim of this study is to demonstrate and compare the effects of coupled and un-coupled models have on a both the process and reservoir of the geothermal industry.

Geothermal fluid mass, pressure and temperature data is passed between AUTOUGH and VMGSim where both the wellbore and plant is simulated. Brine injection data is passed back to AUTOUGH. This cycle is run until either a simulated plant failure occurs or the simulation is terminated. In an ORC plant, typical failures relate to temperature drops in the geothermal fluid that lead to the inability to vaporize the working fluid used to power the turbines. As a result plant changes are required to maintain production, which could reduce power generation or require drilling an additional production well.

Coupling models adds additional benefits to the modelling process that support the optimization of both reservoir and surface related activity. Reservoir production rate in relation to reservoir model size determines the impact that coupled models on forecasting. Addition of fouling has shown significant changes to reinjection temperatures and when incorporated into a coupled model will increase the benefit of coupling.

1. INTRODUCTION

The aim of this study is to demonstrate the ability to couple both surface with subsurface models for more accurate simulation. As the temperature of geothermal fluid decreases dissolved silica comes out of phase as a result forming scale. Scaling which occurs throughout the plant, reduces both flow and heat transfer coefficient, and as a result a decrease in both power output and efficiency can be observed (Zarrouk, Woodhurst, & Morris, 2014). A study conducted on the Wairakei binary plant in New Zealand, shows a reduction of power generation over a fouling life cycle of 6 months.

Typically during forecasting or future prediction runs, injection rates and temperatures are kept constant. As a result temperature and flow changes due to both fouling and natural decline are not accurately represented.

Coupling both simulators allows for constantly updated injection parameters as both the reservoir and plant change over time.

Previous work on a coupled geothermal model (Nandanwar & Anderson, 2014) does not accurately model the process plant, and as a result only benefits on the reservoir side are seen. Issues that may occur due to fouling cannot be modeled.

An advanced coupled software called Matatauria developed by Mercury New Zealand (Franz, 2016), allows for sophisticated coupled models. Matatauria is private and thus does not allow for open use of the software. Matatauria also requires process models to be recreated within the software and which leads to added time when trying to migrate existing models which sometimes can be very complex.

2. SIMULATION TOOLS

2.1 AUTOUGH

AUTOUGH is a geothermal simulator based on a modified version of TOUGH2 by the University of Auckland. PyTOUGH (Croucher, 2011) is a python script used to both generate a subsurface geothermal model and run AUTOUGH. In this paper a model is run constantly until simulated plant failure as a result of depleting reservoir temperature. The effect of fouling is also displayed over several years which is a proof of ability to model changes in injection temperature as a result of reduced heat transfer.

2.2 VMGSim

VMGSim is a process simulator developed by Virtual Materials Group, which allows for state-state and dynamic process simulation with integrated flowsheet design. VMGSim is used for simulating an Organic Rankine Cycle geothermal power plant as shown on Figure 1. A material and energy balance is conducted in steady state to obtain information such as power generated, temperature of brine leaving the plant and parasitic load on the plant. Input data for the process model is obtained from the coupler and results are exported back.

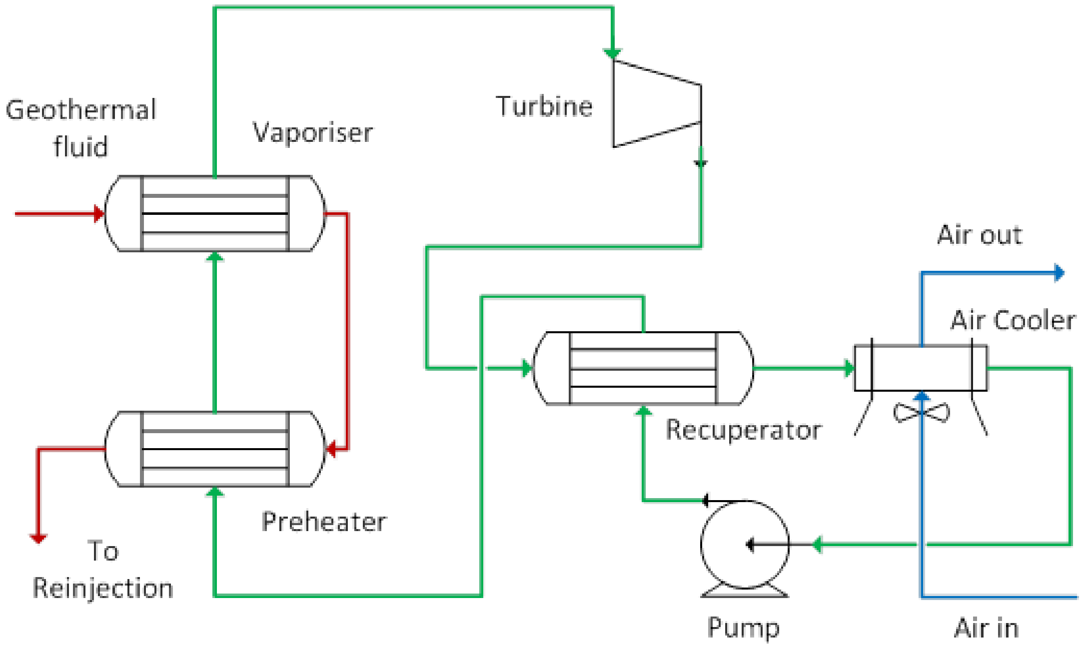

Figure 1: Process flow diagram of a geothermal Organic Rankine Cycle

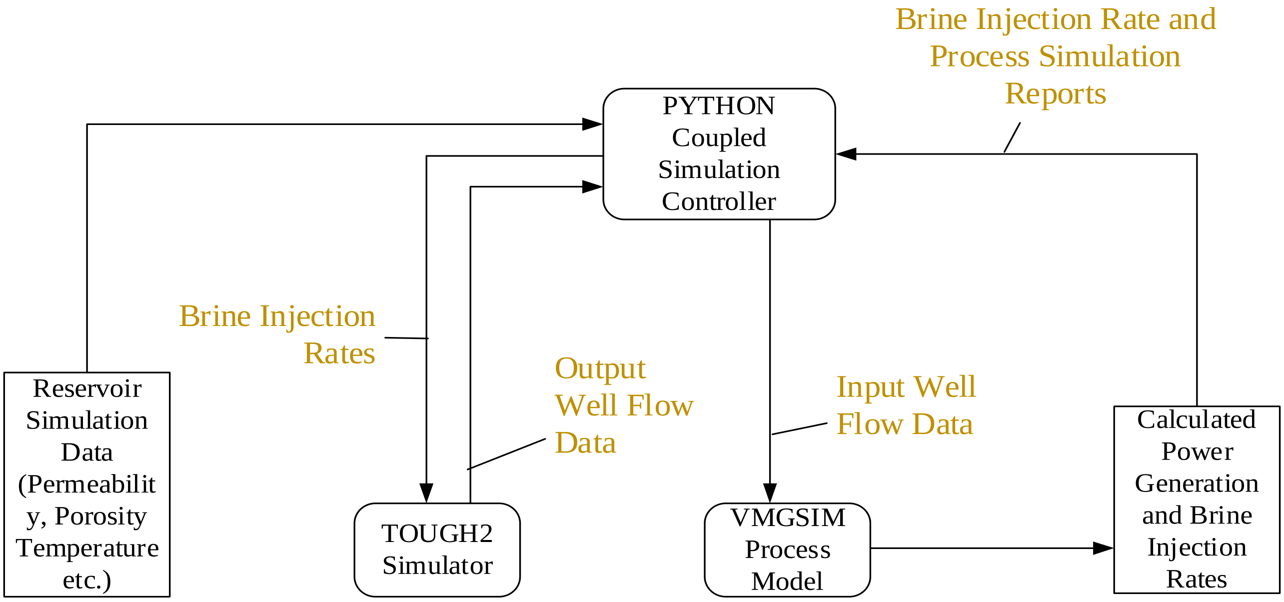

Figure 2: Data flow of coupled model

2.3 COUPLER

The coupler built in python interacts with both PyTOUGH and VMGSim. The reservoir model is initially run for 6 simulated months. Bottomhole fluid flow and properties are parsed to VMGSim. The wellbore is then simulated to determine changes in temperature, pressure and vapor fraction of incoming fluid. The geothermal process plant is then simulated and injection temperatures and pressures at the bottomhole are calculated. This information is parsed back to AUTOUGH and injection information in the reservoir model is updated. The above cycle is repeated until either the model stops at the user selected finish time or an issue/failure occurs in the plant that does not allow for the process simulation to complete.

3. COUPLED MODEL

3.1 Reservoir Model

A demonstration model was built as an example to test the coupling capabilities. The model included 2 production and 2 injection wells. The model parameters are shown in Table 1. Two reservoir models were run, both starting with an initial injection temperature of 100.3°C which was obtained from the process simulation. The first model is not coupled and continues to inject at the above temperature. The second model which is coupled to VMGSim obtains injection temperatures from the process model in which it cycles through every 90 days.

Table 1: Reservoir model properties

Model Dimensions(X,Y,Z)	10x12x15 Grid Blocks
Porosity	10%
Grid Block Length	100 m
Initial Reservoir Pressure	118 Bar
Reservoir Temperature	227°C
Production Rate per Well	72000 Kg/hr
Composition	Water

The accuracy of the model depends on how often data is parsed between the reservoir and process model. Reducing the time between cycles increases run time. In the base case geothermal model, an injection rate of 2.1% (631000 Tons/year) per year of total volume is used.

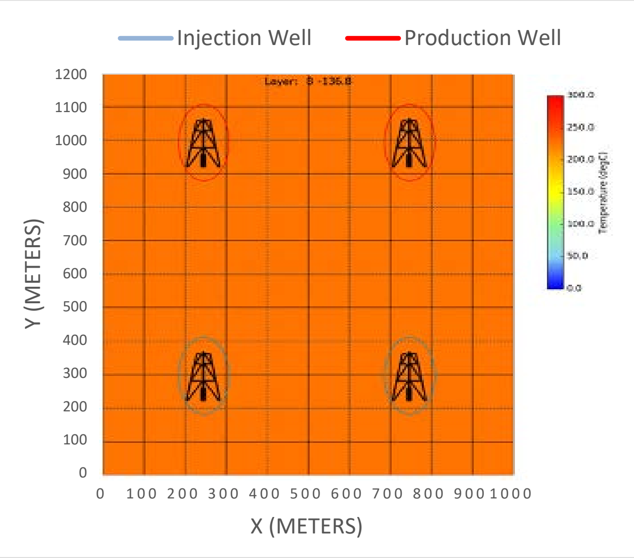

Figure 3: Reservoir model grid schematic with well locations

3.2 Process Model

The process model developed in VMGSim is based on an Organic Rankine Cycle plant (Proctor, Yu, & Young, 2017). Geothermal fluid data obtain from AUTOUGH is passed to VMGSim, where the wellbore is modeled to allow for pressure drop and phase change. Fluid from the wellhead passes through a separator where separated fluid is passed through individual heat exchangers. Pentane the working fluid selected exchanges with steam and brine in exchangers VapBrine and VapSteam. Vaporized Pentane is then passed through an expander to generate a constant power. This power is a function of both pentane flow rate and pressure. Expanded pentane is then passed through a recuperating heat exchanger (Recoup1) and is then condensed using an Air Cooler. The condensed pentane is brought up to working pressure using a pump and is then preheated with cooled brine (Preheat). Cooled brine leaving the preheater is pumped and injection wellbores are then simulated. Injection flow rate, temperature and pressure is parsed back into the reservoir simulation. Figure 2 depicts a block flow diagram showing the movement of information through the coupled process.

The process plant runs in essentially an open-loop fashion, where pentane flowrate and pressure is kept fixed resulting in fixed power generation.

Figure 4 shows the difference between injection with and without process plant coupling.

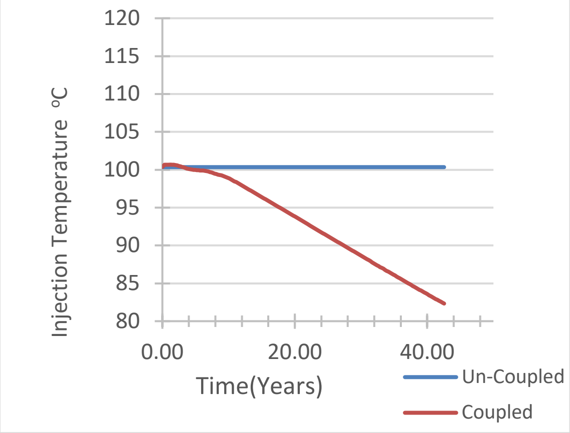

Figure 4: Brine injection temperature of coupled and un-coupled model

A comparison of production temperature in Figure 5 shows little effect in both coupled and non-coupled cases. This is due to the fact that the production is very small compared with the overall capacity of the reservoir. As a result reduced injection temperature does not significantly affect production.

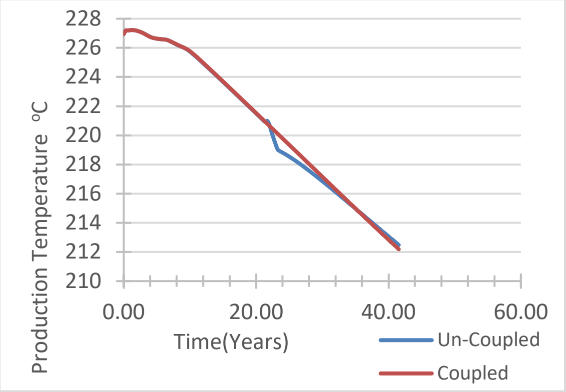

Figure 5: Production temperature of coupled and un-coupled models

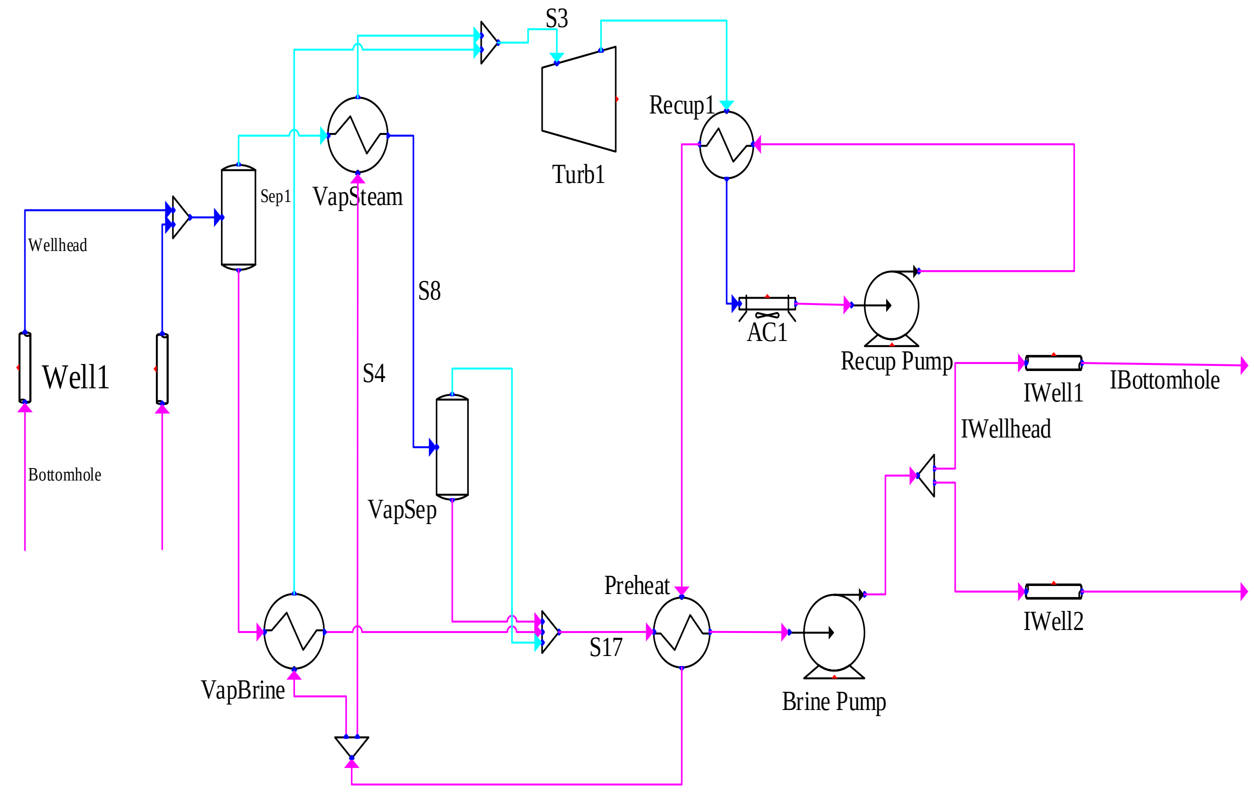

Figure 6: Process flow diagram of geothermal VMGSim simulation

Table 2: Sample stream information from process simulation

	Bottomhole	**IBottomhole**	**Wellhead**	**IWellhead**	**S4**	**S8**	**S3**	**S17**
VapFrac	0	0	0.06859	0	0	0.98643	1	0
T [C]	**227**	100.4	197.3	99.9	86	197.3	135	135.1
P [kPa]	**7900**	26341.68	1481.64	15000	1250	1481.64	1220	1451.64
Mole Flow [kmol/h]	3996.61	3996.61	3996.61	3996.61	9.43	548.24	2144.63	7993.21
Mass Flow [kg/h]	**72000**	72000	72000	72000	680.32	9876.72	154732.77	144000
Volume Flow [m3/h]	86.392	74.616	747.441	74.799	1.208	1322.286	4418.675	154.517
n-PENTANE [Fraction]	**0**	0	0	0	1	0	1	0
WATER [Fraction]	**1**	1	1	1	0	1	0	1

Figure 7 shows the temperature at the bottom of the injector, for coupled and un-coupled models. As can be seen there is no significant difference in grid block temperature between the 2 cases. This reinforces the finding that the injected flow rate did not have a significant impact on the reservoir temperature even with such large difference in injection temperatures.

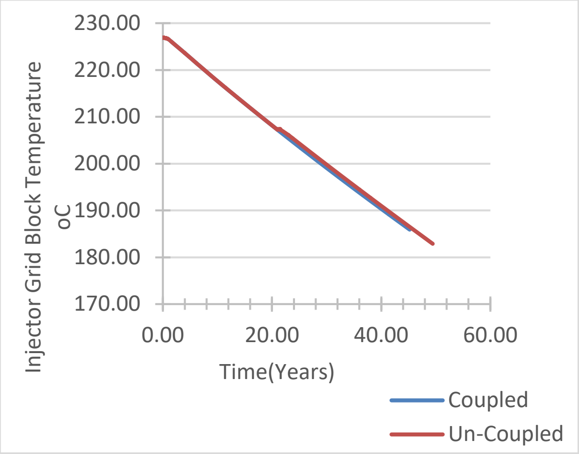

Figure 7: Injector gridblock temperature

The comparison was re-run but with reduced gridblock size. The gridblock size was reduced to 30m by 30m in the X and Y direction resulting in a 91% model size reduction. As a result of this the yearly production increased to 23.1% per year. The results shown in Figure 8, show a larger temperature difference between the original and reduced models.

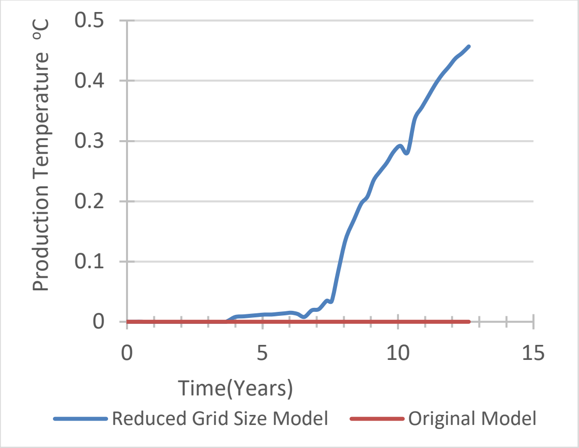

Figure 8: Production temperature difference between original and reduced model

3.3 Fouling

Fouling is a large issue in geothermal power plants, where scaling in the form of silica comes out of solution and forms scale on heat exchanger walls. The impact on heat transfer results in a reduction in power generation, as a result regular cleaning to remove scaling is required.

To create an accurate fouling model, an understanding of the chemistry of the geothermal fluid is required. (Wilson, Webster-Brown, & Brown, 2007) showed that different geothermal fluids react differently as a result of temperature decreases. Ngawha for example is temperature dependent whereas Wairakei is pH dependent when it comes to silica deposition rate. As a result deposition rate is a function of both pH and temperature. A process simulation model was developed to demonstrate the impact in power generation as a result of fouling. The pentane flow rate was allowed to change while maintaining working fluid pressure.

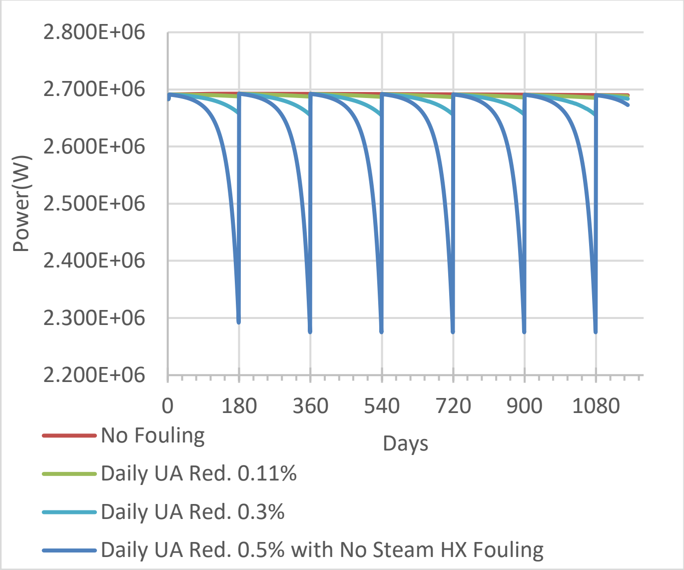

Figure 9: Fouling relationship with different UA reduction factors

To implement fouling reduction in heat transfer coefficient (UA) was induced in the process simulation. The original heat transfer coefficients where multiplied by a daily reduction factor of their original starting UA. The fact that the heat exchangers are in series resulted in an exponential power loss relationship as heat transfer reduced. Different case runs where performed as shown in Figure 9 where scaling is induced and cleaned after 6 months of operation. Increasing the UA reduction factor of 0.5% per day resulted in temperature crosses. Studies have shown that silica is rarely found in steam and thus fouling for the steam heat exchanger was not included (Mroczek, Graham, Siega, & Bacon, 2017). The worst case of fouling results in a 15% reduction of power generation. This information is useful when determining the maintenance schedule for plants to ensure the optimal time for cleaning. Figure 10 shows the effect fouling has on injection temperature.

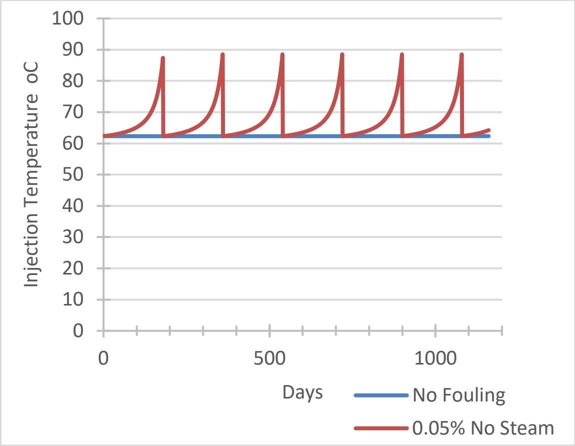

Figure 10: Fouling Effect on Brine Injection Temperature

4. CONCLUSIONS AND FURTHER WORK

Typically during forecasting or future prediction runs, injection rates and temperatu[1-11]res are kept constant as a result temperature and flow changes due to both fouling and natural decline are not accurately represented. The study conducted on both coupled and un-coupled models show that there is a difference between both methods. As reservoir model size is reduced the difference becomes more apparent with respect to keeping constant power generation. Typical reservoirs are more compartmentalized due to faults that naturally occur within the field, as a result it is expected to see that coupling will have a larger effect due to this.

Reduction in reservoir temperature allows process engineers who have used the coupled model to plan both shut downs and changes in plant operation well in advance as scaling in some reservoirs is temperature dependent. As a result cleaning of heat exchanger will become more regular and the need predictable.

Actual power loss due to fouling shows a linear trend compared the simulations run. Fouling simulation conducted shows a requirement for studying the history of fouling in a plant prior to modeling to accurately mimic real life power reduction.

For future work incorporating pressure drop and loss in well injectivity due to fouling is needed. Fouling reduces the amount of brine that is able to be injected. As a result detecting how much brine must be released elsewhere is essential for both process and ecological planning. Addition of day/night cycle would allow the ability to model plant parasitic load and adjust geothermal fluid flowrate to compensate. Ambient temperature changes affect power generation dramatically and the ability to incorporate changes due to this into the reservoir is vital in determining optimal plant operation between day and night.

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