Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

Fuzzy Control of Calcium Carbonate and Silica Scales in Geothermal Systems

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Keywords: fuzzy control, scaling, geothermal systems

ABSTRACT

Calcium carbonate and silica scaling occurrence are the main problems, which directly affect the efficiency of production during operations for a geothermal power plant or a district heating system. Although their precipitation mechanisms differ, both can be observed with different proportions in production and reinjection wells and surface equipment in geothermal systems. Thus, scale prevention and control systems are very important and controlling scaling is easier compared to removing scales from wells and equipment after precipitation in a geothermal system. There are a few methods for controlling silica and calcium carbonate precipitations in geothermal wells and surface equipment. Most production and reinjection wells require the implementation of a silica/calcium carbonate inhibition system to prevent silica/calcite precipitation inside the casing or pipes and separators in geothermal fields. Installing inhibitor systems is the best and most practical solution to prevent scaling problems and production loss if the optimum inhibitor dosages are determined and applied effectively in geothermal systems. Less than optimum ratios of inhibitors can result in product overfeed, increased costs, and in some cases, inhibitor induced fouling. This may be solved by the usage of a fuzzy controller in geothermal systems. It is difficult to obtain the mathematical model describing the relationship between geothermal fluid characteristics and inhibitor because the system is nonlinear and has a few dependent and independent variables. Fuzzy control may replaces the role of a mathematical model in conservative controllers and substitutes it with another one that is built from a smaller number of rules that, in general, only describes a small section of the whole system. In this study, two fuzzy logic controllers have been designed to control the precipitation of silica and calcium carbonate by using scale inhibitors.

1. INTRODUCTION

Geothermal energy is a renewable and sustainable energy source. Although it is called sustainable, some treatments are needed to provide continuous power generation in geothermal systems. Treatments are necessary because geothermal fluids are from deeper zones in the subsurface and these fluids are highly mineralized hot waters and these can likewise include steam and gas, such as CO_2, in the system. There are some important processes in geothermal systems and this includes having a scaling prevention system for the reinjection system and cooling water systems. Using these systems improve the sustainability of the geothermal field. One of the main scaling prevention systems is the chemical inhibitor system, which is highly critical for proper fluid production and reinjection. If this kind system is not used in a geothermal facility, the energy or heat capacity will decrease in a short time after starting geothermal production in a field. In this study, two fuzzy logic controllers are designed to control of the precipitation of silica and calcium carbonate by using scale inhibitors. The simulation results are presented and discussed in this study.

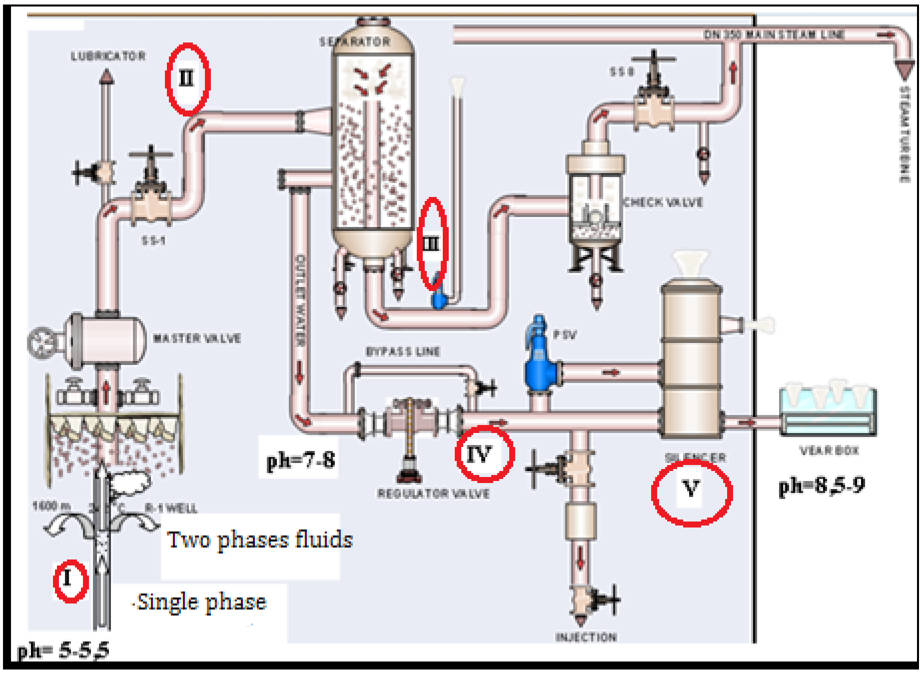
2. MAIN SCALING TYPES IN GEOTHERMAL SYSTEMS: CALCITE AND SILICA SCALING

In general, scaling is the most important problem in water-dominated geothermal systems. This is because it occurs in a borehole and it decreases the flow rate of geofluids from the borehole and reduces the net energy production (Haizlip Robinson et al, 2012). Scaling is a precipitation of some minerals in geothermal waters at different thermodynamic conditions based on the pressure and temperature. Moreover, pH values likewise affect the stability of the minerals in geothermal waters (Figure 1).

Although calcite and silica scales both occur in a geothermal system, their precipitation principles are quite different. The solubility of calcite and silica minerals depends on the pH and temperature. However, silica solubility increases with temperature while calcite solubility decreases with temperature in a geothermal system. Depending on the temperature, silica scaling is generally expected to be high in areas where the temperature of geofluids decreases. This includes reinjection lines and surface equipment such as separators. It should be noted that temperature and pH adjustments can be used to prevent silica scaling to some extent in pipes, even without the usage of scale inhibitors. On the other hand, calcite scaling starts at the flash point, where geofluids separate to two phases as water and steam and gas, because of decreasing of CO_2 in the system.

To prevent scaling in the system, scale inhibitor systems are used in geothermal fields. The chemical inhibitor system consists of the following: chemical (inhibitor) tank, inhibitor pumps, lubricator system and capillary tubing (Figure 2). The system is installed at the wellhead for production wells (Haklidir Tut et al, 2011). To prevent silica scaling in the region that is upstream of the reinjection pump, a chemical dosing system may be installed on the surface facility for the treatment of brine.

Scale inhibitors are mainly divided into two groups: phosphonate and polymer types. Polymer type inhibitors are generally preferred when the reservoir temperature is higher than 180°C (Aksoy, 2007, Haklıdır Tut, 2012). This is because the polymer type inhibitor is more stable at high temperatures. The optimum inhibitor dosages are determined by short-term tests in a well or surface equipment. The dosages may be changed between 3 to 6 ppm, depending on the geothermal field characterization results.



I- CaCO3, II- CaCO3-Sülfit, III- Silika, IV- Silika, V-CaCO3

Figure 1: Scaling points in a geothermal power generation system

Figure 2: Scale inhibitor system at production well in a geothermal field (Photo: Kizildere GPP-Turkey)

3. FUZZY CONTROL

Fuzzy control is basically a multivalued logic system that allows intermediate values to be between conventional evaluations such as “yes or no” or “true or false”. Fuzzy logic control was introduced by Lotfi A. Zadeh, a professor at the University of California, Berkeley, in 1965 (Zadeh, 1965). Fuzzy controllers were first applied in 1982 to control a cement kiln. Currently, fuzzy systems are widely used in many engineering applications (Nedungadi, 1992).

The advantages of fuzzy control are the following:

- to increase robustness in spite of sensor failures
- to provide ability to handle nonlinearities without control system degradation.
- to use a language which has natural linguistic adjectives and interrelations (much easier understanding)

Fuzzy control replaces the role of mathematical models in traditional controllers and substitutes it with another one that is built from a number of smaller rules that, in general, only describes a small section of the whole system (Nedungadi, 1992).

3.1 Fuzzy Controller Design

Fuzzification is the process of decomposing a system input and/or output into one or more fuzzy sets. The membership function is a graphical representation of the magnitude of participation of each input. Many types of curves can be used, but triangular shaped membership functions are the most common. The process of fuzzification allows the system inputs and outputs to be expressed in linguistic terms so that rules can be applied in a simple manner to express a complex system (Godey Simoes, 2007).

3.2 Inference

In the inference subprocess, the truth-value for the premise of each rule is computed and applied to the conclusion part of each rule. This results in one fuzzy subset to be assigned to each output variable for each rule (Horstkotte, 2007).

3.3 Rule Set

As mentioned in the previous section, fuzzy control incorporates a simple, rule-based "if X and Y then Z" approach to solving control problems rather than attempting to model a system mathematically. The fuzzy logic model is empirically based, relying on an operator's experience rather than their technical understanding of the system (Granino 1995).

For example, when dealing with temperature control terms like "If (process is too cold) and (process getting colder) then (add heat to the process)" and "If (process is too hot) and (process heating rapidly) then (cool process quickly)" can be used.

3.4 Defuzzification

The defuzzification subprocess is required to convert the fuzzy result into an exact output value. The output value is calculated by summing the product of the input set memberships for each input multiplied by the assigned output value in the rules set (Haklidir, 2009).

4. SIMULATION

Installing inhibitor systems is the best and practical solution to prevent scaling problems and production loss if the optimum inhibitor dosages are determined and applied effectively in geothermal systems. Less than optimum ratios of inhibitors can result in product overfeed, increased costs, and in some cases, inhibitor induced fouling. In this study, fuzzy controllers are used to solve this problem in geothermal systems.

It is difficult to obtain the mathematical model describing the relationship of geothermal fluid characteristics and inhibitors because the system is nonlinear and has a few dependent and independent variables. Fuzzy control replaces the role of the mathematical model in conservative controllers and substitutes it with another that is built from a number of smaller rules that on general only describe a small section of the whole system (Haklidir, 2009). In this study, two fuzzy logic controllers are designed to control of the precipitation of silica and calcium carbonate by using scale inhibitors.

4.1 Control of Calcium Carbonate

In this study, a fuzzy control system for controlling of calcium carbonate precipitations was created. The inputs were the hardness of calcium carbonate and flow rate and the output was the concentration of inhibitor. Figure 3 shows a diagrammatic view of the fuzzy logic controlled system.

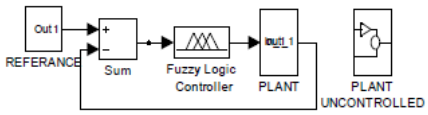


Figure 3: A diagrammatic view of calcium carbonate fuzzy controlled system

The Fuzzy Associative Memory, a set of rules to represent all combinations of inputs, is shown in Figure 4. The hardness of calcium carbonate and flow rate are characterized by the following primary fuzzy sets: Very High (VHH), High (HH), Medium (MH), Low (LH), Very Low (VLH), VLF, LF, MF, HF, VHF (Table 1a).

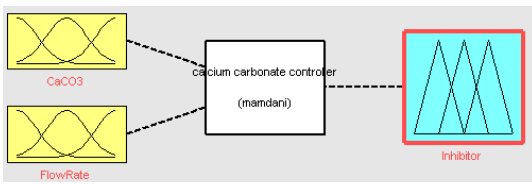


Figure 4: Inputs and output of calcium carbonate fuzzy controller

Table 1a: Primary fuzzy sets for calcium carbonate

		Flow Rate				
		VLF	**LF**	**MF**	**HF**	**VHF**
Hardness of CaCO3	**VLH**	IH2	IH2	IH1	IH1	M
	LH	IH2	IH1	IH1	M	IL1
	MH	IH1	IH1	M	IL1	IL1
	HH	IH1	M	IL1	IL1	IL2
	VHH	M	IL1	IL1	IL2	IL2

For this study, a few parameters such as calcium hardness (sampling point was the weir box), flow rate of a well and inhibitor dosages were taken from a geothermal field from Turkey. The authors assumed that the flow rates changes between 100 t/h and 200 t/h in the selected well and inhibitor dosages may be changed between 4 ppm and 8 ppm. Hardness values were then analyzed correctly for these dosage values in the field laboratory (Table 1b).

Table 1b: Simulation test results of calcium carbonate hardness and dosage

Hardness of CaCO3 (ppm)	Flow Rate (tph)	Fuzzy Inhibitor Scale (ppm)
56,00	147,00	5,60
45,00	147,00	6,50
35,60	147,00	7,00

4.2 Control of Silica

In the fuzzy control system for controlling of silica precipitations, the inputs are the concentration of silica and pH and the output is the concentration of the inhibitor. Figure 5 shows a diagrammatic view of the fuzzy logic controlled system.

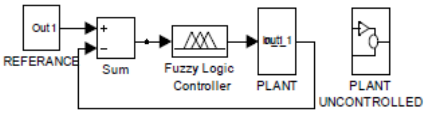


Figure 5: A diagrammatic view of silica fuzzy controlled system

In the Fuzzy Associative Memory, a set of rules to represent all combinations of inputs, as shown in Figure 6. The hardness of silica and pH are characterized by the following primary fuzzy sets: Very High (VHC), High (HC), Medium (MC), Low (LC), Very Low (VLC), VLP, LP, MP, HP, VHP (Table 2a).

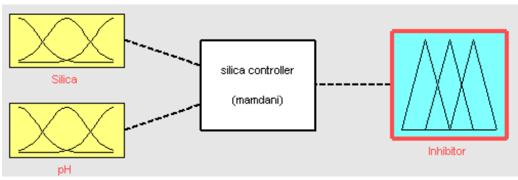


Figure 6: Inputs and output of silica fuzzy controller

For this study, a few parameters such as silica concentrations and pH values were taken from a geothermal field from Turkey. The authors assume that the pH values change between 7.5 and 9 in the selected well/line depending on sampling points. It was also assumed that the silica concentrations were analyzed correctly in the field laboratory.

Table 2a: Primary fuzzy sets for silica

		pH				
		VLF	**LF**	**MF**	**HF**	**VHF**
Concentration of Silica	**VLC**	IH2	IH2	IH1	IH1	M
	LC	IH2	IH1	IH1	M	IL1
	MC	IH1	IH1	M	IL1	IL1
	HC	IH1	M	IL1	IL1	IL2
	VHC	M	IL1	IL1	IL2	IL2

Table 2a: Simulation results for silica

Concentration of Silica (ppm)	pH	Fuzzy Inhibitor Scale (ppm)
323,00	8,00	7,00
505,00	7,20	7,00
564,00	9,40	5,00

5. CONCLUSIONS

Calcium carbonate scaling and silica scaling are very common problems for a geothermal system. These scales affect fluid production from a production well or reinjection of brine in geothermal fields. Although geothermal energy is a sustainable energy source, the precipitation of these minerals in the water phase at different temperatures, pressures and pH conditions affect the sustainability of a geothermal system. With this reason, these scaling occurrences must be prevented in geothermal fluids and this can be achieved by using scale inhibitor dosage systems in geothermal systems. The principle of the dosages system is to determine optimum inhibitor dosages using inhibitor tests for a well or a part of geothermal system. In most geothermal fields, the dosing of an inhibitor can be applied manually (by a responsible person in the field). After the application, analyses of Ca ion hardness and silica concentrations are necessary.

In this study, an attempt was made to use fuzzy control systems for controlling inhibitor systems in geothermal fields. Two fuzzy controllers were applied to the system in a simulation environment. The performance of the controllers was acceptable and they satisfied the needs from basic calculations. For future studies, the controller should be applied to the system continuously and potentially, it can be applied to the real power plant.

REFERENCES

Aksoy, N: Scaling and Scale Preventing Methods in Geothermal Fields., Tescon Proceedings, (2007) İzmir, Turkey

Godey Simoes, M : Introduction to fuzzy control. Tutorial Colorado School of Mines, (2007), Colorado, USA.

Granino, A.K. : Neural Networks and fuzzy logic control on personal computers and work stations.The MIT Press, ISBN 0262112051, (1995), London.

Haizlip Robinson, J. Güney, A., Haklıdır Tut, F.S., Garg, K. S: The impact of High Noncondensible Gas Concentrations on Well Performance Kızıldere Geothermal Reservoir, Turkey. Proceedings, Thirty-Seventh Workshop on Geothermal Reservoir Engineering Stanford University, (2012), CA, USA.

Haklidir, M., Tasdelen, İ : Modeling, Simulation and Fuzzy Control of an Anthropomorphic Robot Arm by usin Dymola. Journal of Intelligent Manuf., 2009.

Haklidir Tut, F.S., Akın, T., Parlaktuna, Ç., Turk, D., Savas., T: Scaling Types and Prevention and Control of Scaling in the Operation Stage in Geothermal Fields: Kızıldere Geothermal Field Case Study. 64th Turkey Geological Congress, (2011), Ankara-TR.

Haklidir Tut, F.S.: “Importance of Monitoring of Control Parameters in Scale Occurrence and Prevention due to Geothermal Fluids”. Geothermal Sources Exploration and Application Symposium in 08-09.12.2012, ITU, İstanbul- Turkey (Turkish).

Horstkotte, E.: Fuzzy Logic Overview, http://www.austinlinks.com/Fuzzy/overview.html, (2007)

Nedungadi, A.: A Fuzzy Robot Controller- Hardware Implementatio, IEEE International Conference on Fuzzy Systems, (1992)

Zadeh L.: "Fuzzy sets", Information and Control 8 (3): 338–353, (1965).