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Geothermal produced fluids: Characteristics, treatment technologies, and management options

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ABSTRACT

Geothermal power plants use geothermal fluids as a resource and create waste residuals as part of the power generation process. Both the geofluid resource and waste stream are considered produced fluids. The chemical and physical nature of produced fluids can have a major impact on the geothermal power industry and influence the feasibility of power development, exploration approaches, plant design, operating practices, and reuse/disposal of residuals. In general, produced fluids include anything that comes out of a geothermal field and must subsequently be managed on the surface. These fluids vary greatly, depending on the reservoir being harnessed, plant design, and life cycle stage in which the fluid exists, but generally include water and fluids used to drill wells, fluids used to stimulate wells in enhanced geothermal systems, and makeup and/or cooling water used during operation of a power plant. Additional geothermal-related produced fluids include many substances that are similar to waste streams from the oil and gas industry, such as scale, flash tank solids, precipitated solids from brine treatment, hydrogen sulfide, and cooling-tower-related waste.

This review paper aims to provide baseline knowledge on specific technologies and technology areas associated with geothermal power production. Specifically, this research focused on management techniques related to fluids produced and used during the operational stage of a power plant, the vast majority of which are employed in the generation of electricity. The general characteristics of produced fluids are discussed. Constituents of interest that tend to drive the selection of treatment technologies are described, including total dissolved solids, noncondensable gases, scale, corrosion, silicon dioxide, metal sulfides, calcium carbonate, metals, and naturally occurring radioactive material. Management options for produced fluids that require additional treatment for these constituents are also discussed, including surface disposal; reuse/recycle; agricultural, industrial, and domestic uses; mineral extraction and recovery; and solid waste handling.

Contents

Abbreviations: AGGD, Argonne Geothermal Geochemical Database; BPJ, best professional judgment; CFR, Code of Federal Regulations; CWA, Clean Water Act; DCMD, direct contact membrane distillation; EGSs, enhanced geothermal systems; ELGs, effluent limitations guidelines; EMD, electrolytic manganese dioxide; GHG, greenhouse gas; HP, high-pressure; kg, kilogram(s); L, liter(s); mg, milligram(s); MSF, multi-stage flash; MED, multiple effect distillation; MWe, megawatt electrical; NCGs, noncondensable gases; NF, nanofiltration; NH_3, ammonia; NORM, naturally occurring radioactive material; NPDES, National Pollutant Discharge Elimination System; ppm, parts per million; RO, reverse osmosis; TDS, total dissolved solids; TENORM, technically enhanced naturally occurring radioactive material

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1. Introduction

"Produced fluids," in the context of this paper, encompass the variety of fluids produced on-site during the various stages of geothermal energy exploration, field development, and power plant operations. Broadly, the term produced fluids includes any fluid that comes out of a well and subsequently must be managed on the surface. These fluids vary greatly, depending on the life cycle stage in which the fluid exists, but generally include water and fluids used to drill geothermal wells, fluids used to stimulate wells in enhanced geothermal systems (EGSs), and makeup and/or cooling water used during operation of a geothermal power plant. Additional geothermal-related produced fluids include many substances that are similar to exempt wastes (i.e., under Title 40, Part 261.4(b)(5) of the *Code of Federal Regulations* [40 CFR 261.4(b)(5)]) from the oil and gas exploration and production industry, such as scale, flash tank solids, precipitated solids from brine treatment, hydrogen sulfide, and cooling-tower-related waste. However, geothermal hazardous wastes (e.g., lubricants, hydraulic fluids, solvents, paints, and sanitary wastes) are not considered produced fluids for the purposes of this paper and are not discussed further.

The characterization of produced fluids is critical in determining appropriate management approaches, including consideration of specialized handling and potential environmental implications. This paper specifically focuses on some of the management techniques related to fluids produced and used during the operational stage of a geothermal power plant, the vast majority of which are employed in the generation of electricity.

2. General characteristics of operational produced fluids

The fluid that is extracted from the geothermal resource is commonly referred to as the geofluid. Geofluid is produced from a geothermal reservoir and directed into the power plant. Following the extraction of heat for the production of electric power, some fraction of the geofluid is then reinjected into the rock formation. At some geothermal power plants, other fluids associated with operation (e.g., condensate and cooling water blowdown) are injected along with the geofluid [1]. Any uncondensed vapor escapes from the cooling tower. In selected systems, the geofluid may also be reused as a working fluid to manage dissolved solids and minimize scaling [2].

The chemical composition of geofluids varies widely between and within geothermal fields, and in some cases, over time within the same geothermal well [2]. The exact chemical makeup of the geofluid can have significant implications for both the design and operation of a geothermal plant and its potential environmental impact. The chemical characteristics of geofluids were compiled in 2010 into the Argonne Geothermal Geochemical Database (AGGD) [2], which is available in the Geothermal Data Repository (http://gdr.openei.org) and was expanded upon in follow-up research focusing on EGSs [3]. For the composition analysis, 90 °C was considered the cutoff temperature for being identified as a geothermal source. The pH values for the AGGD data appeared to be roughly normally distributed around a median of 7.3, with the majority of values falling between 5 and 10. The full pH range was found to vary from as low as 0.9 to as high as 11.8, illustrating the broad range of characteristics common among geofluids. The most common chemical constituents reported for geothermal samples from the AGGD are presented as box-and-whisker plots in Fig. 1 [2]. The data indicate that the major constituents include sodium (Na), chloride (Cl), bicarbonate (HCO_3), sulfate (SO_4^{2-}), silica (SiO_2), calcium (Ca), and potassium (K). However, the data also illustrate that the concentration of any chemical constituent can vary by around one to nearly six orders of magnitude between the 25th and 75th percentile (represented by the boxes) and by at least two to more than nine orders of magnitude across the extremes of the distribution (represented by the extended whisker lines on either side of the boxes).

3. Treatment technologies for operational constituents of interest

Although there is wide variability in geofluid chemical constituents, several constituents of interest can potentially affect geothermal power plant operations. These include total dissolved solids (TDS), noncondensable gases (NCGs), constituents associated with scale and corrosion, heavy metals, and naturally occurring radioactive material (NORM). These constituents, along with selected treatment options for mitigation (if deemed