RESEARCH DIRECTIONS IN SOLIDS DEPOSITION IN GEOTHERMAL SYSTEMS

D.M. THOMAS and J.S. GUDMUNDSSON*

Hawaii Institute of Geophysics, 2525 Correa Road, Honolulu, Hawaii 96822, U.S.A..
* National Energy Authority, Gransásvegur 9, 108 Reykjavik, Iceland

Abstract - The closing session of the International Workshop on the Deposition of Solids in Geothermal Systems consisted of the formation of special interest working groups to discuss future research directions in the fields of carbonate deposition, silica scale, sulfide deposition, treatment methodologies, heat exchanger engineering, and water/rock reactions. Recommendations made by the working groups for future research included the following: development of more complete and accurate models of the physical and chemical mechanisms associated with the nucleation, adhesion, and growth of scale minerals onto substrate surfaces; investigation and synthesis of more efficient and cost effective chemical scale inhibitors; improvements in heat exchanger materials, design, and operational characteristics; and development of more general economic models for heat extraction facilities that will allow an evaluation of the costs and benefits of various scale-control strategies.

INTRODUCTION

The International Workshop on the Deposition of Solids in Geothermal Systems held in Reykjavik, Iceland in August 1988 included the presentation of the papers published in this special volume as well as the formation of working groups currently involved in scale-deposition research. The purpose of these groups was to review the current status of research into scale-deposition processes and to make recommendations on future research that will enable us to better understand and control scale deposition from geothermal fluids. The working group topics and their respective chairmen were: Carbonate Deposition, M. Reed; Silica Scaling, R. Itoi; Sulfide Deposition, C. Fouillac; Treatment Methodologies, A. Karabelas; Heat Exchanger Engineering, P. Fryer; and Water/Rock Reactions, A. Milodowski. A summary of the working groups' recommendations is presented below.

CARBONATE DEPOSITION WORKING GROUP

The Carbonate Deposition Working Group (CDWG) identified several areas in which our current understanding and control of carbonate scale is less than it should be. The most pressing needs for future investigations or innovations were:

(1) The kinetics and thermodynamics of scale formation: Carbonate minerals known to precipitate from laboratory or naturally occurring fluids include calcite, aragonite, vaterite, and other hydrous cation carbonates. Even though a number of studies have been performed on the thermodynamics and kinetics of formation of the individual carbonate mineral phases, relatively

little is known about how the geothermal fluid chemistry affects the mineralogy, the rate, or the morphology of the scale deposited. The CDWG recommended that future laboratory investigations of carbonate scale deposition should focus on mineral formation in chemically complex solutions that mimic natural geothermal fluids in order to define the influence of accessory dissolved-ions on the scale-formation process. It was suggested that this research will provide the insight into the kinetics and thermodynamics of carbonate scale-formation that is required to gain greater control over the deposition process.

(2) The surface chemistry of scale deposition: There is too little known about substrate effects on the rate of nucleation and deposition of carbonate from solution. Although it has been established that the rate of deposition of calcite on a clean pipe surface is different from that on a corroded or already scaled surface, the chemical or physical mechanism for the difference is not known. It was suggested that a better understanding of these effects might allow us to design a surface that would inhibit scale formation until the fluid reaches a location where it could be more easily or cheaply removed.

(3) Carbonate mitigation measures: The available methods for inhibiting carbonate deposition or for removing it need substantial improvement. The control techniques currently in use include brine pressurization, boiling-zone control, and addition of chemical inhibitors. Pressurization of brine to maintain a single-phase fluid typically requires pumping of the reservoir fluids, which can add substantially to both capital and maintenance costs of a geothermal utilization facility. Control of the downhole boiling zone in a geothermal well does not prevent scale formation, but only spreads the deposition zone over a longer interval of well casing, reducing the frequency of well clean-out procedures. Organic scale inhibitors used for scale control can be both unstable in high enthalpy systems (calcium phosphonate) and quite expensive to use on a continuing basis (polyacrylic acid) whereas acidification or CO₂ addition can affect the deposition of other minerals (eg. silica or iron carbonate), increase corrosion in the casing and surface equipment, or decrease the plant operational efficiency. Removal of carbonate scale is typically accomplished mechanically (reaming) or by acidization of the well. Reaming can be done with the well shut in, which requires two weeks or more of lost production capacity, or with the well in production with the fluids (and reaming debris) discharged at the surface. Although the latter technique requires less time than the former, the presently available rotating heads that make this method possible have a short service life and leave little margin for safety of drill rig personnel. Development of better high-temperature elastomers was identified as the most pressing requirement to help alleviate this problem. Acidization of the formation is able to remove carbonate scale but the effects of the acid treatment on the formation are poorly known and the method requires shutting in the well and loss of productivity during the cleaning period. It was therefore suggested by the CDWG that additional field studies be conducted on improved chemical scale inhibitors and removal agents and that further development of on-line reaming equipment be pursued.

In summary, the Carbonate Working Group recommended that the areas of research most likely to yield improvements in carbonate scale control technology were: further investigations of the kinetics of carbonate scale formation in a variety of chemical environments; development of a generalized model of the mechanism of scale nucleation and deposition onto solid substrates; development of additional scale inhibiting agents; and development of better chemical and mechanical methods of removing scale that has already been deposited onto a solid substrate.

SILICA SCALE WORKING GROUP

The Silica Scale Working Group (SSWG) identified several areas in which additional laboratory and field research is needed. One of the most important problems is our inability to predict the rate or characteristics of silica deposition from a geothermal field prior to exploitation. The SSWG suggested that the absence of standardized testing and reporting procedures has made it nearly impossible to apply results of previous tests on geothermal fluids of known characteristics to a new geothermal fluid having known, but different, composition and temperature. Standardization of testing methods was suggested

as
inv
How
con
sil
Dev
add
hyd
dep
phy
tur
dev
to

ana
pro
in
mag
pos
Per
tra
dep

res
sys
sys
res
to
Alt
eva
the
col
re
ex
col
col

ty
fr
fo
ph
de
re
of
st
nu
pr
Ac
of
ch
he

co
fo
de
me
de
a
e
a

as being the most feasible approach to alleviating this problem. Further investigations were also recommended into the following research areas: (1) How the fluid chemistry, and in particular the chloride and transition metal concentrations, affect silica nucleation and polymerization, the rate of silica deposition and the characteristics of the scale deposited; (2) Development of a generalized model of the silica deposition process that addresses not only the chemical controls over deposition, but also the hydrodynamic effects downhole and in surface equipment that leads to deposition of silica from the liquid phase; (3) An investigation of the physical processes associated with deposition of silica (and other salts) onto turbine inlet equipment by aerosol brine carried in the steam phase; (4) The development of an effective, economically viable inhibitor that would be able to control the location or the morphology of the silica scale formed.

Several specific experiments recommended by the SSWG included: (1) An analysis of silica scale deposition rates and morphology in the fluid production zone through the installation and recovery of a retrievable liner in a producing geothermal well; (2) Further characterization of the effect of magnetic and electric fields on silica polymer surface charges and the possible application of field effects to silica recovery or inhibition; (3) Performance of a long-term reinjection experiment to determine whether a transition metal-based reagent could be used to prevent or retard silica deposition from waste fluids until they have been returned to the reservoir.

METAL SULFIDES WORKING GROUP

The Metal Sulfides Working Group (MSWG) reported that the mechanisms responsible for the formation of metal sulfides in low enthalpy geothermal systems were fundamentally different from those occurring in high enthalpy systems and required different approaches to solve. The key process responsible for sulfide deposition from low enthalpy geothermal fluids appears to be the mobilization of iron due to corrosion of well-casing alloys. Although several different corrosion and deposition inhibitors have been evaluated for low enthalpy fluids, there appears to be little agreement about their effectiveness. The MSWG recommended that additional field studies be conducted on existing inhibitors to determine appropriate dosages and their relative effectiveness and that an effort be undertaken to develop new, less expensive inhibitors. Continued testing of corrosion resistant alloys and composite casing materials was also recommended in an effort to find the most cost-effective means of preventing corrosion-mediated scale deposition.

In high enthalpy systems, the source of scale-forming dissolved ions is typically the reservoir fluid, and the scale minerals formed are different from those found in low enthalpy systems. Similarly, the chemical mechanism for the formation of metal sulfide/oxide scale is also different; the key phenomenon appears to be the decrease in pH associated with fluid flashing and degassing of the reservoir fluid. Hence, the areas of research that were recommended included: (1) Evaluation of the technical and economic viability of producing high enthalpy fluids under single phase conditions; (2) Further study of the chemical and hydrodynamic parameters that control sulfide nucleation and substrate attachment; (3) Analysis of how well completion practices, and especially how casing diameter, affect the scaling process; (4) Additional investigation of innovative pH control methods; and (5) Development of more general models of sulfide scale-formation processes that include both chemical and hydrodynamic effects occurring during the fluid production and heat extraction process.

TREATMENT METHODOLOGIES WORKING GROUP

The results and recommendations of the Treatments Working Group (TMWG) corresponded closely with those of the scale mineral working groups but focussed particularly on three areas in which additional research and development are needed: development of additional chemical inhibitors that are more cost effective and more thermally stable than those now available; development of better physical and chemical models of nucleation, adhesion, and growth processes of all types of scale minerals; and improvements to our economic modelling capabilities that will allow better assessment of the costs and benefits of the various scale treatment options now in use. The TMWG

noted that, although there are a number of organic corrosion inhibitors, surfactants, and crystal growth inhibitors available, the cost of their application on a commercial scale is unacceptably high and they typically cannot tolerate temperatures above about 250°C. Development of additional chemical inhibitors that would be more cost effective and capable of treating high-enthalpy fluids would be a substantial advancement in scale control technology. Further field and laboratory studies of the existing chemical scale inhibitors were recommended to document the effects of geothermal fluid chemistry on the type and the dosage of inhibitor applied. It was suggested that this type of data would allow us to generalize site specific data to geothermal fluids in other locations that have similar compositions.

The TMWG found that our understanding of the scale mineral crystallization process and the mechanisms responsible for scale adhesion to a solid substrate surface is very limited. Development of more realistic and complete models for these processes would enable researchers investigating applied control methods to redirect their efforts away from "trial and error" development of scale inhibitors and more toward a process-, or mechanism-, based control of scale deposition.

The final area identified for additional effort by the TMWG was development of generalized models for economic analyses of: optimization of steam recovery versus maintenance frequency when using pressure/pH control of scale formation; balancing the cost of exotic alloys for casing or surface equipment against maintenance costs associated with corrosion or scaling; and evaluating the costs of inhibitor addition versus the cost of facility maintenance. The TMWG also suggested that more emphasis be placed on research into how power plant process design affects scale deposition rates and how to optimize, a priori, the design of a heat extraction facility to minimize scale deposition.

HEAT EXCHANGER WORKING GROUP

The Heat Exchanger Working Group (HEWG) noted that there is a vast potential for heat extraction from what is now considered waste fluids and that a great deal of research remains to be done before this heat can be economically recovered. The major problems encountered in the utilization of heat exchanger systems include: acid gas mediated corrosion and scaling in steam condensing systems; corrosion and scale deposition on heat exchanger surfaces that use geothermal fluids on the hot side and cold, oxygenated, mineral-laden, water on the cold side; and scale and corrosion from geothermal fluids used in binary-cycle electrical production. Research needed to address these problems include: innovative engineering design of heat exchanger materials and surfaces that inhibit corrosion or adhesion of scale minerals; additional investigations of the chemistry of the scale nucleation and adhesion process; and new approaches to heat exchanger operation including fluidized bed exchangers and the use of turbulence promoters. The objectives of this research would be, at the least, to minimize scale deposition on heat exchanger surfaces, and at best, to inhibit scale crystallization until the fluids can be returned to the geothermal reservoir.

WATER/ROCK REACTIONS WORKING GROUP

The Water/Rock Reactions Working Group (WRRWG) identified two major goals in their field of investigation: (1) The development of methods to predict changes in production fluid chemistry that occur as a result of fluid withdrawal and boiling in a geothermal reservoir and; (2) The capability to forecast the changes in fluid chemistry and reservoir permeability resulting from injection of fluids having known dissolved and suspended solids concentrations. To expand our capabilities in this area, a much larger database must be acquired on the equilibrium thermodynamics and the kinetics of mineral deposition and mineral transformation under reservoir conditions. Of particular interest is the acquisition of laboratory data for deposition and dissolution of naturally occurring mineral suites in contact with fluid compositions similar to those encountered in the natural environment rather than for the pure liquid or mineral phases that are more frequently studied in laboratory investigations. Laboratory testing was recommended to determine

the
rese
rein

T
recc
unde

(
phys
mech
proc
hydr
geot

and
use

metl

com
opt.

Ork
Ins
Dep
Bar
One
and
the

Not

the effects of artificially induced changes that may occur in a thermal reservoir as a result of such things as acidization of production wells or reinjection of chemical inhibitors into a geothermal reservoir.

SUMMARY AND CONCLUSIONS

There is substantial concurrence among the workshop participants on their recommendations of additional research that is required to improve our understanding, and control, of the solids deposition phenomena:

- (1) The development of more advanced models of the chemistry and the physics of the solids deposition process, emphasizing in particular: the mechanisms of nucleation, adhesion, and growth of mineral scale; how these processes are influenced by naturally occurring fluid compositions; and how hydrodynamic processes associated with production and utilization of geothermal fluids affect scale formation.
- (2) The development of more efficient and cost-effective scale inhibitors and an improvement in our understanding of how and where they can best be used.
- (3) The development of more effective heat exchanger technology and the methods to optimize their performance.
- (4) The development of more general economic models for analyzing the compromises inherent in designing a geothermal utilization scheme that will optimize heat recovery and capital and maintenance costs.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the support and assistance provided by Orkustofnun (the National Energy Authority of Iceland) and the Hawaii Institute of Geophysics in the organization of the International Workshop on Deposition of Solids in Geothermal Systems. We also would like to thank Barbara Jones for editorial assistance in the preparation of this manuscript. One of the authors (DMT) especially thanks the Hawaii Department of Business and Economic Development for providing travel support enabling him to attend the workshop.

Note: HIG Contribution No. 2066.