Assessment of Potential Economic Benefits of Silica in Geothermal Brine at Menengai, Kenya

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Keywords

Menengai, Silica extraction, Geothermal Brine, Silica, Colloidal Silica

ABSTRACT

This Paper assesses the potential economic benefits that can be derived from extraction of silica from geothermal brine at the Menengai Geothermal Field, Kenya. Geothermal development at Menengai geothermal field is at an advanced stage with commencement of construction of power plants for generation of 105 MWe planned for 2017. Menengai geothermal fluids exhibit varying chemical properties observed to be distinct from well to well. The silica content in the brine discharge in this field is significant and can be extracted for commercial use. For the wells that will be connected to the power plant, 430 kg of silica in tones per hour of brine, assuming separation at 7 bara, is estimated. Extraction of silica will help reduce the troublesome silica scaling that occurs in drilling pipes as well as allow for further applications of brine. Extraction of silica can also help make Geothermal Energy more attractive to potential investors.

1. Introduction

The Geothermal Development Company (GDC) is a fully government-owned company in Kenya's energy sector. GDC was formed in 2008 as a Special Purpose Vehicle (SPV) to accelerate the development of geothermal resources in Kenya. GDC is tasked with developing steam fields and selling geothermal steam for electricity generation to KenGen and to private investors. Menengai geothermal field is one of the new fields currently being developed in Kenya by GDC. The Geothermal field is hosted in the Menengai caldera, located in the central segment of the Kenya Rift valley (Figure 1). Drilling started in February 2011 and is currently ongoing. As of April 2017, 37 wells had been drilled to completion and over 140 MWe equivalent of steam realized from tested wells. As part of the Government of Kenya’s Public Private Partnership initiative, three independent power producers (IPPs) have been awarded contracts to each construct a 35 MWe power plant producing a combined 105 MWe. They are expected to break ground in the course of the year.

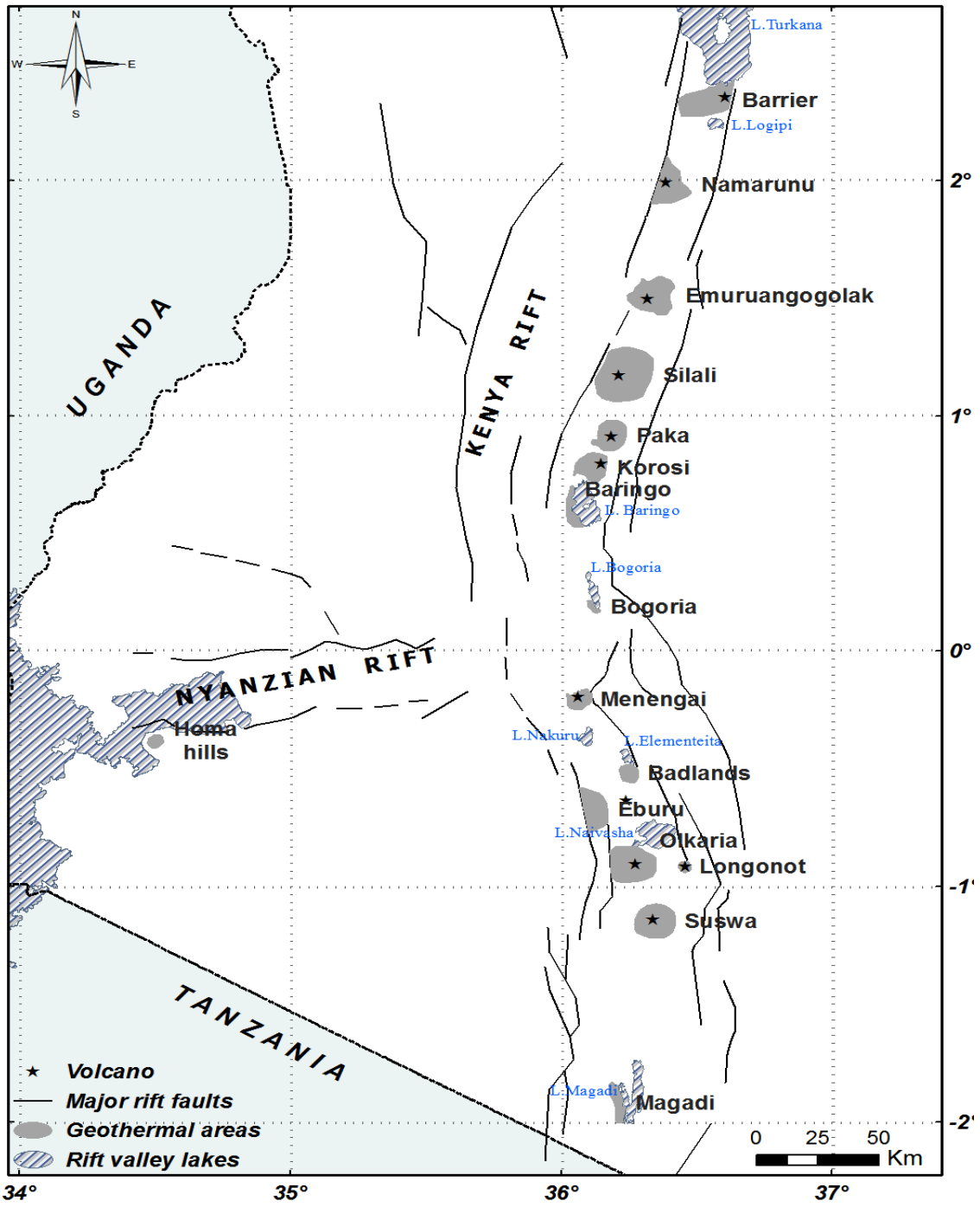


Figure 1: Location of the Menengai geothermal prospect and other prospects along the Kenya Rift Valley.

2. Overview of the Chemistry of Menengai Field

Menengai geothermal wells generally exhibit widely varying chemical properties, being quite distinct from well to well as described by Kipng'ok (2011); Sekento, (2012), Malimo (2013), Kanda (2013), Kipngok et al. (2014) and Auko (2015). Variations in both the volatiles and the non-volatiles in the fluid discharge suggest heterogeneity of the reservoirs tapped by the wells. The fluid discharge predominantly belongs to the sodium bicarbonate facies (Figure 2). Dissolved content ranges from 1,700 to 7,000 mg/kg (Figure 3) while pH values lie between 8.5 and 10 (Figure 4). Chloride concentrations vary from 370 to 1,300 mg/kg while silica contents range from 250 mg/kg to about 1500 mg/kg (Figure 4). Low calcium is observed which lies between 0.07 and 1.2 mg/kg. The reported low Calcium concentrations could be the consequence of removal of calcium from the fluid as a result of formation of calcium carbonate upon flashing of the geothermal water. Fluoride concentrations on the other hand are notably high in the well discharges (ranging from 80 to 600 mg/kg) and could be due to two possibilities; removal of calcium as calcite deposits leading to excess F or the addition of fluoride to the waters by condensation of volcanic gases (hydrogen fluoride).

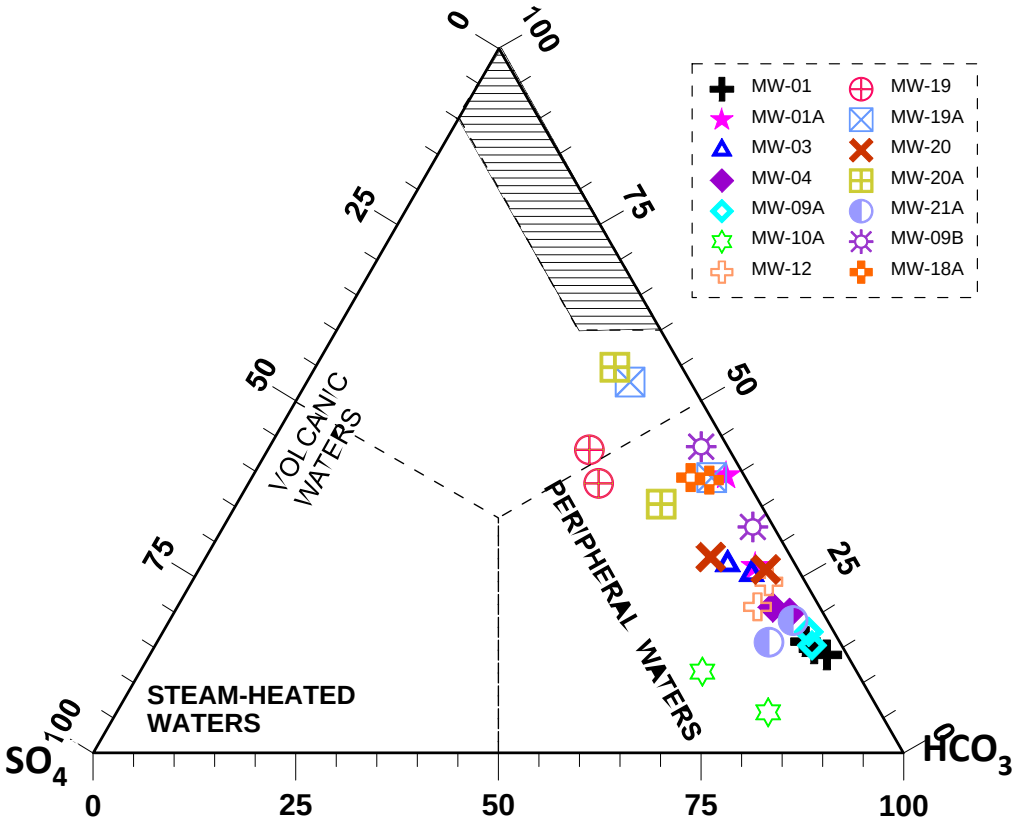


Figure 2: Cl-HCO3-SO4 ternary for Menengai well discharge fluid

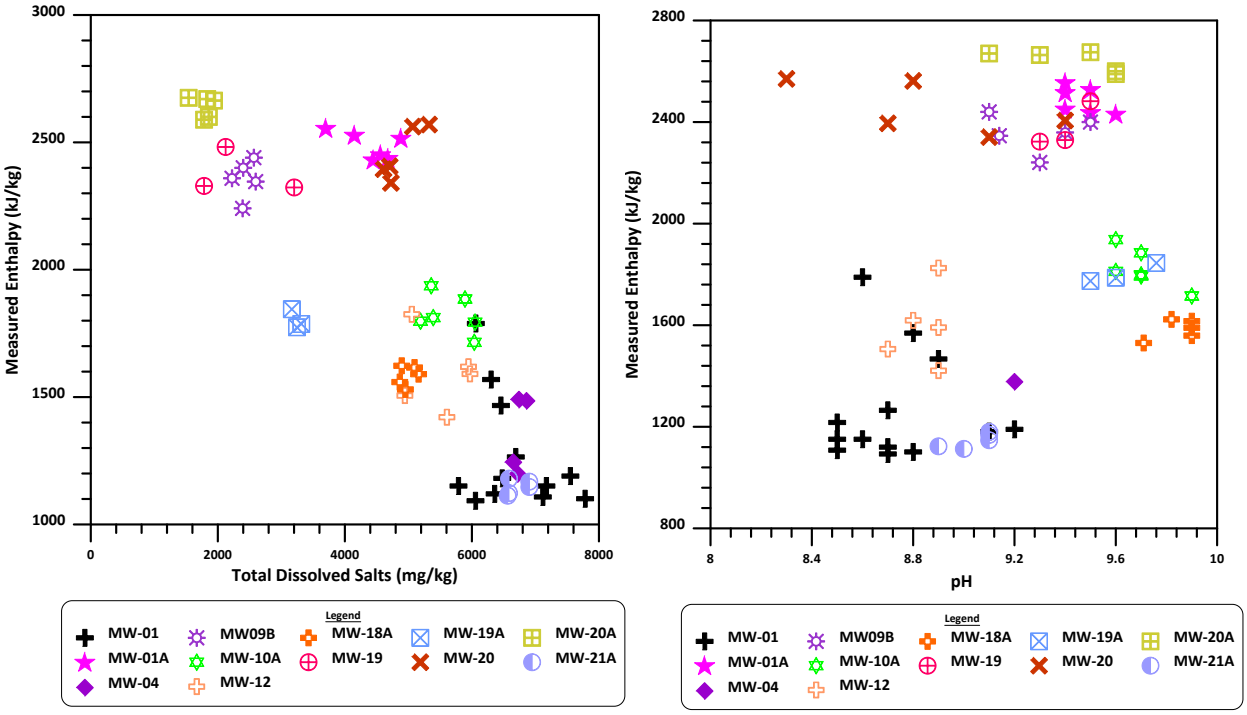


Figure 3: Correlation of TDS content (left) and pH (right) with enthalpy for Menengai discharge fluids

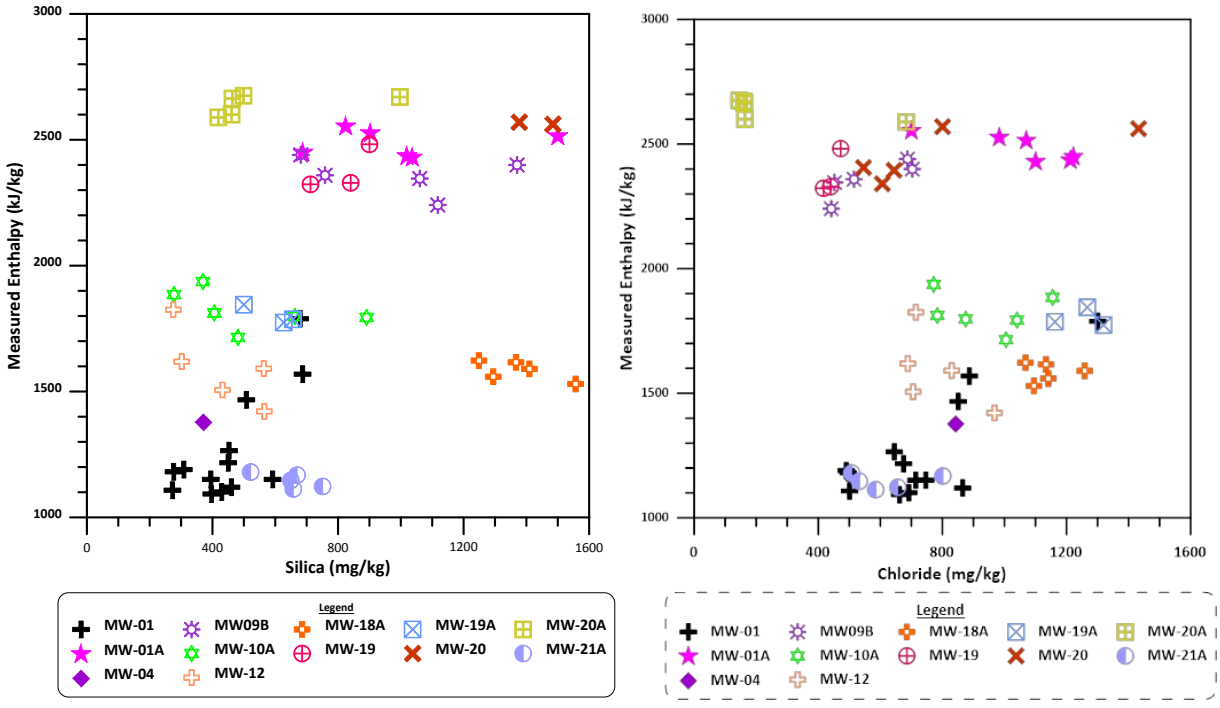


Figure 4: Correlation of silica (left) and chloride (right) with enthalpy for Menengai wells, assuming phase separation at 7 bara.

2.1 Silica Content in Menengai Separated Brine

The chemical composition of geothermal fluids is determined by their origin, magmatic, meteoric etc., the lithology of the rocks with which the fluids have interacted, the temperature at which that interaction takes place, the chemistry of the fluids (e.g. pH), and impacts of processes such as boiling and dilution (). The solubility of silica in geothermal waters is temperature dependent, increasing with increase in temperature. The silica content of Menengai wells geothermal brine separated at 7 bara vary widely, ranging from about 250 to 1500 mg/kg, most of which correlate with well discharge enthalpy as measured (Figure 4). Notably, of the wells to be connected for the planned generation of 105 MWe, a number of them discharge single phase steam. The silica content of the two-phase discharges is given in Table 1. The computed silica concentrations for the yields an estimate of about 438 kg per.

Table 1: Silica content in separated geothermal water at Menengai

Well ID	Silica (mg/kg)	Brine Flow (t/hr)	kg of Silica t/hr of brine
MW-01	580	110	64
MW-01A	990	50	50
MW-04	370	44	16
MW-09B	1000	6	6
MW-10A	515	27	14
MW-12	430	20	9
MW-13B	600	65	39
****MW-18A**	1375	50	69
MW-19	790	30	24
MW-19A	660	25	17
MW-20	1185	65	77
MW-20A	570	16	9
MW-21A	650	130	85
Total		**638**	**477**

****The well is not part of the 105 MWe due to its location on the eastern sector of the field while the rest of the wells and the power plant site are situated within the central part of the Menengai field. The well however is considered in the calculations because it is planned to be utilized for electricity generation using the wellhead technology.**

3. Manufacture and Application of Colloidal Silica/Silica Sols

Co-production of minerals has received notable interest in the recent past and has subsequently attracted increased research including work in Japan, Russia (Kashpura, et al., 2000), and the U.S (Bourcier, et al., 2005, Lin, et al., 2000). The formation of ore deposits is however constrained by the concentrations and fluxes of metals in hydrothermal solutions, yet these are poorly known

because of the great difficulty in obtaining samples of deep hot solutions for trace metal analyses (Brown, et al., 2007).

Silica deposition can cause difficult operation problems and have serious economic consequences ranging from equipment damage and failure, to power generation and thus may limit the efficient use of geothermal energy. One possible solution to the silica scaling problem is to remove the silica from the geothermal brine, which would then allow further utilization of heat not normally available (Brown and Bacon, 2000). By perfecting ways to extract valuable minerals in the geothermal process, the cost of geothermal power is brought down and geothermal development is made more attractive. Moreover, the removal of silica from the brine allows a large range of downstream processes. Other mineral extraction processes become much easier when the silica is removed and heat exchangers can also be much more easily utilized without the threat of silica deposition.

Several approaches have been used to extract silica from geothermal brine. At Mammoth Pacific LP geothermal power plant in Mammoth Lakes, California, silica extraction process involves running a geothermal fluid through a reverse-osmosis separation process to create freshwater and concentrated brine. In New Zealand a pilot plant at the Wairakei geothermal system was designed to produce colloidal silica from geothermal water (Brown and Bacon, 2000). Two step process was involved in production of silica that is; cooling geothermal waters to induce polymerization leading to colloid formation, and ultrafiltration to remove water and concentrate the silica colloids. The removal of silica from the brine allows a large range of downstream processes. Other mineral extraction processes become much easier when silica is removed and heat exchangers can also be much more readily utilized without the threat of silica deposition (Brown and Bacon, 2009).

Generally, from the approaches used in the different geothermal fields noted, colloidal silica is most often prepared in a multi-step process where an alkali-silicate solution is partially neutralized, leading to the formation of silica nuclei. The subunits of colloidal silica particles are typically in the range of 1 to 5 nm. Whether or not these subunits are joined together depends on the conditions of polymerization. Initial acidification of a water-glass (sodium silicate) solution yields $Si(OH)_4$.

If the pH is reduced to below 7 or if salt is added, then the units tend to fuse together in chains. These products are often called silica gels. If the pH is kept slightly on the alkaline side of neutral, then the subunits stay separated, and they gradually grow. These products are often called precipitated silica or silica sols. Hydrogen ions from the surface of colloidal silica tend to dissociate in aqueous solution, yielding a high negative charge. Substitution of some of the Si atoms by Al is known to increase the negative colloidal charge, especially when it is evaluated at pH below the neutral point. Because of the very small size, the surface area of colloidal silica is very high.

The colloidal suspension is stabilized by pH adjustment and then concentrated, usually by evaporation. The maximum concentration obtainable depends on the particle size. For example, 50 nm particles can be concentrated to greater than 50 wt% solids while 10 nm particles can only be concentrated to approximately 30 wt% solids before the suspension becomes too unstable.

Bourcier et al. (2009) described two ways of extracting silica. In the first method, Reverse Osmosis (RO) concentrate enriched in Silica is connected to an ultrafiltration (UF) tank and run separately and the silica colloids separated in batch mode. In the second method, the RO concentrate is equalized to the UF and then run continuously.

4. Economic Analysis

Entingh, et al., 2005 estimated the potential revenue stream that can be generated from the sale of extracted silica in geothermal brine in Salton Sea and Coso, Californier geothermal fields**.** Their calculation was based on 60% silica recovery rate and a selling price of 2,200 USD per metric ton and a plant capacity factor of 95%. Assuming no much changes have occurred in the market, the silica content in the brine for the 105 MWe wells at Menengai yields a concentration of about 2500 metric tons per year (see Table 1). Accordingly, the potential annual revenue stream from the sale of extracted silica from the waste brine during the 105 MW electricity generation at Menengai is approximately $5.5 million (about KSh. 550), keeping everything else constant.

4.1 Uses of Colloidal Silica

Colloidal silica has a range of applications, a few of which are highlighted below:

Table 2: Commercial uses of silica

Application	**Silica Use**	**Type of silica**
Concrete making	Concrete additive to a. enhance pozzolanic reaction b. increase compressive strength c. reduce permeability of hardened concrete d. reduce setting time	• Precipitated • Colloidal • Fumed
Ground consolation	a. Binder to soils in construction b. Drilling operation to improve soil structure, for water proofing, fill voids and fractures c. Underground works	• Colloidal • Fumed
Paints and coatings	a. Enhances contrast ratio, tint strength and brightness b. Anti-settling agent	• Precipitated • Fumed
Paper manufacturing	a. Efficient ink absorption b. Increased static friction on packaging paper c. Enhance paper texture (glossiness)	• Precipitated • Colloidal • Fumed
Adhesives and sealants	a. Flow control b. Enhance mechanical properties of cured adhesive: strength, elongation, etc	• Precipitated • Fumed
Food and nutrition	Additive to processed foods a. To prevent poor flow and caking in powders	• Precipitated • Colloidal

Application	Silica Use	Type of silica
	(seasonings, salt, milk powder) b. Thickener in pastes c. Carrier of flavours d. Clarify beverages & prevent foaming	• Fumed
Rubber production	a. Reinforcing filler material (tear strength, abrasion resistance, aging resistance and adhesion)	• Precipitated • Fumed
Pharmaceutical application	a. Prevent poor flow and caking of powder drugs b. Carriers of active pharmaceutical ingredients c. Thickener for gels and ointments	• Precipitated • Colloidal • Fumed
Dental applications	a. Enhance flow properties of tooth paste b. To enhance mechanical properties of dentures c. Added as filler to the dental composite material	• Precipitated • Colloidal

Figures 5 and 6 provide examples where colloidal silica is applied.



Figure 5: Image of moisture absorbent silica gel (used in bags, shoes and most leather items use desiccant silica gel as a moisture absorbent to ensure that no mold grows)



Figure 6: Image of a section of Kenya's Standard Gauge Railway (colloidal silica is used to increase friction by coating railway tracks to promote traction)

5. Market Analysis

The silica present in the Menengai Geothermal Field brine is significant, estimated at 477 kg per ton of brine produced per hour. Bourcier et al. (2009) enumerated the reasons why they targeted colloidal silica as follows:

- "Colloidal silica has relatively higher value per mass of silica than the other products.
- The geothermal fluid produces relatively pure silica that is most advantageous for colloidal silica markets. Many precipitated silicas contain several weight percent impurities.
- No post-processing is required to produce colloidal silica, whereas precipitated silicas must be dried and stored under controlled conditions.
- No chemical additives such as acids or bases to change pH, are needed, which minimizes production costs, and does not limit re-injection of the geothermal fluid.
- Colloidal silica can only be produced in low salinity fluids."

Menengai Geothermal field displays low salinity fluids and thus extraction of colloidal silica would be provide a great opportunity.

CONCLUSION

- Significant silica content is present in the Menengai geothermal field separated brine and can be extracted for commercial uses.
- Extracting silica from the waste brine has numerous potential benefits that include; lessen/remove the effects of scaling, allow further utilization of the brine, and use colloidal silica for commercial purposes.
- By perfecting ways to extract valuable minerals in the geothermal process, the cost of geothermal power is brought down and geothermal energy becomes even more attractive.

REFERENCES

Auko L Evaluation of fluid mineral interaction in the Menengai Geothermal System, Central Rift, Kenya [Report]. - [s.l.] : UNU-GTP Publications, Report 8, 2014.

Bourcier W L, Lin M and Nix G Recovery of minerals and metals from geothermal fluids [Report]. - Livermore : No. UCRL-CONF-215135. Lawrence Livermore National Laboratory (LLNL), Livermore, CA, 2005., 2005.

Bourcier William [et al.] Pilot-Scale Geothermal Silica Recovery at Mammoth Lakes [Report]. - California : California Energy Commission, 2009.

Brown Kevin L. and Bacon Lew G. Manufacture of Silica Sols from Separated Geothermal Water [Report]. - [s.l.] : Proceedings, World Geothermal Congress, 2000.

Brown Kevin L. and Bacon Lew G. Pilot plant experiments at Wairakei Power Station. [Report]. - [s.l.] : Geothermics 38, 2009.

Brown Kevin L. and Simmons Stuart F. The flux of gold and related metals through a volcanic arc, Taupo Volcanic Zone, New Zealand [Report]. - [s.l.] : The Geological Society of America, 2007.

Entingh D and Vimmerstedt L Geothermal Chemical Byproducts Recovery: Markets and Potential Revenues [Report]. - Rockville : Princeton Energy Resources International, LLC, Rockville MD, USA, 55 pp., 2005.

Geothermal Development Company GDC website [Online] // GDC website. - May 30, 2017. - www.gdc.co.ke.

Gordon Bllomquist and R Economic Benefits of Mineral Extraction from Geothermal Brine [Report]. - Washington : Washington State University Extension Energy Program, 2006.

IMA Europe [Online] // CrystallineSilica.eu. - May 30, 2017. - http://www.crystallinesilica.eu/what-are-main-uses-silica.

Kanda I.K. and J.K. Suwai Hydrogeochemistry of Shallow and Deep Water Aquifers of Menengai Geothermal Area, Kenya Rift Valley [Report]. - [s.l.] : GRC transactions, Vol 37, 2013.

Kashpura V N and Potapov V Study of the amorphous silica scales formation at the Mutnovskoe hydrothermal field (Russia) [Conference] // Proc. 25th Workshop on Geothermal Reservoir Engineering (p. 381). - 2000.

Kipng'ok J Fluid chemistry, feed zones and boiling in the first geothermal exploration well at Menengai, Kenya [Report]. - [s.l.] : UNU-GTP publications, Report 15, 2011.

Lin H P [et al.] A direct surface silyl modification of acid-synthesized mesoporous silica [Journal]. - [s.l.] : New Journal of Chemistry, , 2000. - 5 : Vol. 24.

Malimo S.J Fluid Chemistry of Menengai Geothermal Wells, Kenya [Report]. - [s.l.] : Geothermal Resources Council Transactions, Vol. 37, 2013.

Sekento L.R. Geochemical and isotopic study of the Menengai geothermal field, Kenya, [Report]. - [s.l.] : UNU-GTP Publications, Report 31, 2012.