Presented at the Workshop for Decision Makers on Direct Heating Use of Geothermal Resources in Asia,
organized by UNU-GTP, TBLRREM and TBGMED, in Tianjin, China, 11-18 May, 2008.

UNITED NATIONS UNIVERSITY
GEOTHERMAL TRAINING PROGRAMME

TBLRREM TBGMED

ADVANCES IN ISOTOPE HYDROLOGY AND GEOCHEMISTRY FOR GEOTHERMAL RESERVOIR MANAGEMENT THROUGH INTERNATIONAL COOPERATION

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ABSTRACT

Isotope hydrology and geochemistry have been widely applied in geothermal reservoir management in the past decade, which was made possible by the joint efforts of international organizations and participating institutions as well as individual scientists through effective international cooperation. Major progress has been made in understanding of the origin of acid fluids in geothermal reservoirs, in solving particular technical issues in various types of geothermal exploration programmes in different continents, in improving analytical quality of geothermal water chemistry through inter-laboratory comparison exercises and training, as well as in establishing comprehensive monitoring programmes for sustainable development of geothermal reservoirs. Regional and inter-regional cooperation projects offered good opportunities for transfer of know-how and technology through training courses and site demonstration. In view of the current situation when the world is faced by a major common task to mitigate climate change, it is more necessary than ever for countries to work together to increase the contribution of geothermal energy in national energy mix through promoting R&D and transfer of technology for a cleaner and safer world.

1. INTRODUCTION

As the world is acting to mitigate climate change, it is more urgent than ever for countries to increase the contribution of new & renewable energy sources including geothermal energy to national energy mix through promoting R&D and transfer of technology. Drawing from experience gained in application of isotope hydrology and geochemistry for geothermal reservoir management, it can be expected that through international cooperation of countries concerned, the current tasks faced by the geothermal community can be better fulfilled.

Hydrological and geochemical processes are essential information needed in geothermal reservoir management. Isotopes, including environmental and artificial ones, are very special and powerful tools in these studies. These studies integrated with chemistry and other tools have made significant contributions to geothermal energy development around the globe. Since the beginning of the new millennium, while more isotope data is gathered for new exploratory geothermal prospects, environmental isotopes have been increasingly used to monitor changes in the geothermal reservoirs of producing fields, and artificial radiotracers have been more widely applied to assist in enhancing re-injection.

Transfer of technology to developing countries in Africa, Asia and Latin America, as well as cooperation among the countries, have generated promising outcomes with the following major progress: increased availability of chemical and isotopic data for development of new geothermal prospects and management of producing geothermal fields, wider use of isotopes such as sulphur species (S-34 and O-18 in H_2S and aqueous SO_4), increased use of noble gas isotopes including those at the scale of individual fields and even for reservoir monitoring, application of Strontium and boron isotopes for improved understanding of water-rock interaction processes, recognition of drinking water quality and other environmental issues in geothermal development and potential contributions of isotope hydrology and geochemistry, improved capacity and more field applications using radiotracers (I-131, I-125 and S-35).

These major technical achievements have largely been covered by recent literature (IAEA, 2004, Guima and Pang, 2005, IAEA, 2005, Pang and Truesdell, 2005, Pang, 2006, Pang and Armannsson, 2006). This paper is intended to highlight some of them with emphasis on the role of international cooperation and to provide perspectives on future directions.

2. INVESTIGATING ACID FLUIDS IN GEOTHERMAL RESERVOIRS

Natural waters with pH values lower than 5 found in geothermal areas are called 'acidic fluids'. These fluids occur in geothermal well discharges, especially in geothermal areas associated with recent volcanism such as the geothermal areas in Central America, Japan and the Philippines. Acidic fluids cause serious damage to production wells. Their origin needs to be understood in order to design appropriate preventive or treatment measures.

Realizing the potential contribution of stable isotopes of the water molecule and those of sulphur compounds in tracing the sources of acidic fluids, especially the sulphate type of acidity in geothermal well discharges, the IAEA organized a Coordinated Research Project (CRP) with the objectives of integrating isotope techniques, the isotopes of sulphur compounds in particular, into: 1) identification of the origin of the water component in acidic fluids, 2) identification of the origin of sulphur compounds in acidic fluids and 3) study on mixing of waters from different sources to form acidic fluids.

Ten research groups from China, Indonesia, Italy, Japan, Mexico, the Philippines, the Russian Federation, Turkey and the United States of America participated in the CRP and carried out field and laboratory investigations on twenty geothermal fields. Samples of geothermal waters, gases and minerals were collected and analyzed for the following isotopes: $\delta^{18}O$, $\delta^{2}H$, $\delta^{3}H$ of water, $\delta^{34}S$ in H_2S gas, $\delta^{34}S$ in aqueous sulphate (SO_4), $\delta^{18}O$ in aqueous sulphate (SO_4), $\delta^{34}S$ in anhydrite and pyrite and $\delta^{18}O$ in anhydrite as required by the individual research projects.

Isotopic composition of oxygen-18 and deuterium in water sampled from acidic wells indicates that they are mixtures of meteoric and magmatic waters. Examples of this type of geothermal systems are Miravalles in Costa Rica, Onikobe in Japan, Los Humeros in Mexico and Several fields in the Philippines. It has further shown that acidic fluids are isotopically heavier in some systems, implying a larger fraction of magmatic inputs. This isotopic evidence confirms the hypothesis that some acidic fluids are un-neutralized magmatic water.

$\delta^{34}S$ in H_2S and in SO_4 samples from both acidic and neutral wells were obtained in the research. In neutral wells, they are identical, with $\delta^{34}S$ values in the range of ±5 ‰ deviation from 0 ‰ VCDT that was accepted for un-altered magmatic H_2S, as observed in New Zealand geothermal systems. In acidic wells, fractionation of ^{34}S between H_2S and SO_4 has been recognized. Furthermore, there is a negative correlation between pH of water and ^{34}S (H_2S) but positive correlation with that in SO_4, implying an isotope exchange between the two.

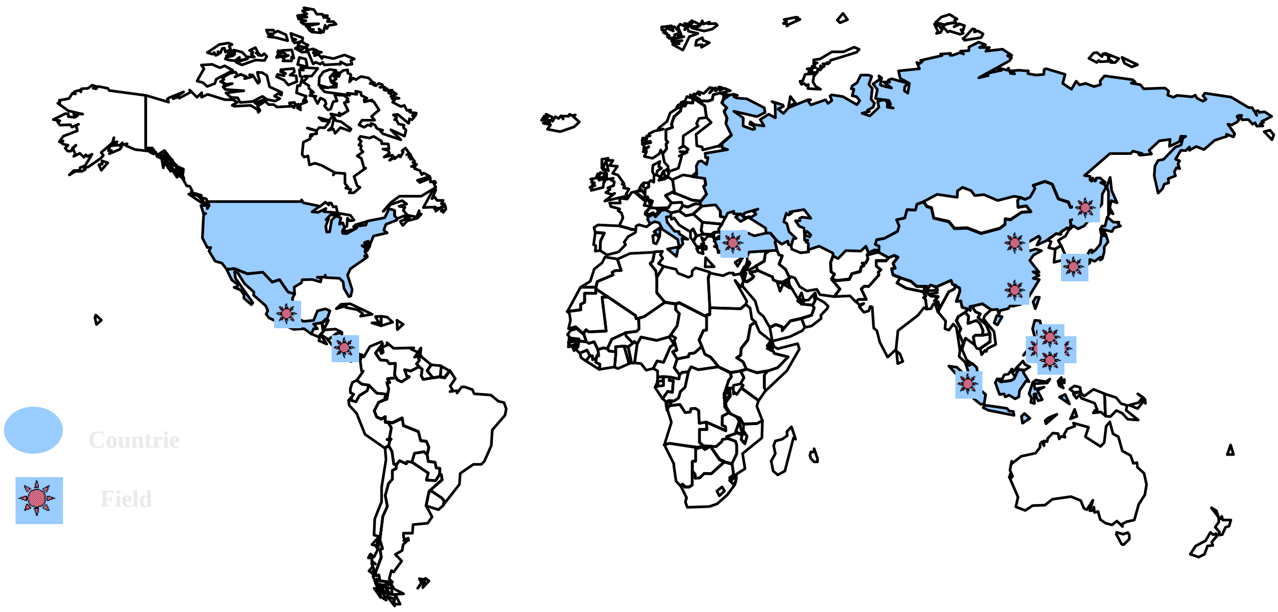

FIGURE1: Countries and corresponding geothermal fields involved in the research project on acid fluids in geothermal systems (IAEA, 2005).

3. INCORPORATING ISOTOPES INTO RESERVOIR MONITORING PROGRAMMES

Management of geothermal resources in producing fields is becoming more and more important. For example, Central American region is very rich in geothermal resources due to its tectonic setting to be a chain of volcanoes. Actual development of geothermal resources for electric energy generation started in 1980s. Now, there are 7 producing fields in 4 countries, Costa Rica, El Salvador, Guatemala and Nicaragua. The contribution of geothermal energy to the total electricity consumption is considerable, with 23% for El Salvador and 14 % for Nicaragua, 10% for Costa Rica and 10% for Guatemala in 2002. There are 7 geothermal reservoirs altogether currently producing a total capacity of 300 Mw_e in the region. In Miravalles geothermal field in Costa Rica, observations show that the steam pressure in the underground geothermal reservoir has dropped about 2.0 bars per year in the last 7years of production. This behaviour of the field has posed a major challenge for the sustainability of the production. Injection of wastewater from the power plant has been considered a solution to this kind of problems in many geothermal fields. However, this may be ineffective if handled inappropriately, or it may cause the reservoir cooling too quickly.

Based on experience form other regions and especially that of developed countries, like Iceland, New Zealand and the Philippines, environmental isotopes such as $\delta^{18}O$ and $\delta^{2}H$ of water, are useful tools in providing information on geothermal reservoir processes. The IAEA has therefore established projects to transfer technology on geothermal reservoir monitoring using chemical and isotopic techniques to Africa, Asia and Latin America. However, management of reservoirs is not always an easy job.

In year 2001, isotopic analysis was added to the monitoring programs of geothermal producing fields in four countries in Central America: El Salvador, Costa Rica, Guatemala and Nicaragua. Isotopic monitoring, like chemical motoring, of geothermal reservoirs require establishment of baseline as the starting point of a monitoring program. Subsequent regular sampling of well discharges will show changes with production if any. Generally speaking, the frequency of sampling is higher during the early stages of discharge. Occasionally, samples should be taken for analysis of all major components in both water and gas samples but otherwise partial analysis is considered sufficient (Arnorsson, 2000). The number and frequency of samples can be optimized by following the history of chemical evolution of the reservoir.

4. INTER-LABORATORY COMPARISON FOR IMPROVED ANALYTICAL CAPACITY

Geothermal systems are characterized by fluid chemistry. Considerable amount of information is derived from its chemical composition such as origin, deep temperature by geothermometry and monitoring changes in the reservoir due to production. Accurate chemical analysis is essential in order to predict reservoir changes correctly and manage geothermal reservoirs successfully. Geothermal waters are highly saline with high concentrations of Na, Ca, K, SiO_2, and SO_4 and weak acids. These components are known to interfere in most analyses and require specific procedures designed to minimize these interferences.

Under the auspice of the International Atomic Energy Agency, many inter-laboratory comparison exercises of geothermal water chemistry have been conducted in 1985, 1997, 1999, 2000, 2001 and 2003. Number of participant laboratories reached 40 and they are from all continents. A recent assessment using statistical method shows that the analytical capacity of participating labs, especially those from developing countries have considerably improved their quality of results.

Based on inter-laboratory comparison exercises in 1999, 2000, 2001 and 2003, 66.7 % of the laboratories that regularly participated in this activity have either maintained their good performance or improved their performance over the years. An increase in the number of laboratories that obtained statistically accepted results above 80% also indicates that there are improvements in the analytical performance of these laboratories. Chemical parameters with high statistical outliers are Cl in low levels and HCO_3 and SiO_2 in highly saline water. Ca consistently has high statistical outliers in all inter-laboratory comparison exercises for all types of water. Na results are considered highly reproducible. By calculating the z-scores of each parameter analyzed, a long-term evaluation may be carried out by the laboratory to assess their individual performance and determine ways to improve their analytical measurements (Pang & Dargie, 2004, Guima & Pang, 2005).

5. RADIOTRACERS FOR BETTER RE-INJECTION DESIGNS

During a workshop in Kenya in 2002, a survey was conducted among the participants to collect information on the application of radiotracers in geothermal reservoir management. The participating countries were China, Costa Rica, El Salvador, Guatemala, Indonesia, Kenya, Mexico, Nicaragua and the Philippines. The results showed an urgent need to transfer technology on this subject, including data interpretation tools. IAEA has provided support to Guatemala and Nicaragua to become new users of radiotracers for inter-well tracer tests.

More tracer tests have been implemented in other fields, especially in inter-well connection studies. They have proven to be very useful in the management of the geothermal reservoirs involved. In Tianjin geothermal field of China, where there are 200 wells supplying hot water for space heat during winter time, injection has been a major challenge because it is a sandstone aquifer (Pang, 2000, Minisale, et al. 2008, in press). In downtown Tianjin, the geothermal water is mainly used for space heating, bathing and recreation. Only <20% of the geothermal water is injected into the reservoir. To evaluate the flow path of injected brine in the reservoir, three injection projects have been implemented since 1996. Initially KI and KBr were used as tracers. But the tests resulted in non-detectable level of tracer return in the observation wells. Recently radiotracer I-125 was introduced in

the tests and tracer return curve was successfully established that provided essential information on the inter-well connections in the geothermal reservoirs (Zhao, 2002).
Hydrological studies using isotope techniques in geothermal reservoir management, including the use of environmental isotopes as well as radiotracers artificially introduced have seen considerable progress in the last several years. Through effective technology transfer, developing countries, such as those in the Central America region, have acquired and are applying the advanced technology.

6. OUTLOOK ON FUTURE COOPERATION AMONG ASIAN COUNTRIES

Areas of priorities for international cooperation among the Asian countries related to direct heating use of geothermal energy have been tentatively identified, as follows:

1) Compilation of a technical kit for ground source heat pump applications including means for assessment of their environmental impacts
2) Transfer of know-how and technology for conventional hydrothermal resources exploration and management
3) Joint research on re-injection into geothermal reservoirs with low permeability
4) A joint programme on re-assessment of geothermal energy potential in view of the advances in new technology for the region

7. CONCLUSIONS

Applications of isotope techniques as powerful tools for geothermal reservoir management have gained much progress in the past decade through international cooperation in research and technology transfer. Further development and wider use are considered beneficial to many countries with producing geothermal fields.

It has been shown that international cooperation has promoted the application of novel technology. Strengthening such cooperation will help to speed up geothermal energy programme expansion in the future, in the areas identified, and those that are to emerge in Asia.

ACKNOWLEDGEMENTS

This review is a reflection of scientific perspective and personal view of the author, which does not necessarily represent that of the International Atomic Energy Agency (IAEA) in Vienna. The author would like to thank colleagues at the isotope hydrology section for their support in various aspects. Thanks are also due to scientists and institutions in the countries who worked as implementing partners for their cooperation and dedication to the projects mentioned and not mentioned in the paper. I would like to thank Dr. Ingvar Fridleifsson, director of the UNU geothermal training programme, for his invitation for the author to make this contribution.

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