ANNEX I

Project Plan

Properties of two phase flow of water and steam in geothermal reservoirs

Project ID: 09-01-011

Coordinator: Guðrún Sævarsdóttir, Reykjavík University

Start date: 01.08.2010

Duration: 36 months

Partners: University of Iceland, Keilir, ISOR

1 Project description

General description of the project, clarify what the intended work involves and specify the need or importance for this work in connection with geothermal energy.

Understanding two phase flow of steam and water in geothermal reservoirs is of great importance since it dictates how well high temperature geothermal areas can be utilized for heat and power production. This phenomenon involves complex interaction between the two phases when they are present in a porous rock and consequently, state of the art flow relations must be modified, partly empirically, to account for this. In two phase porous flow several important parameters must be aggregated to account for the two different phases, such as density, enthalpy, viscosity, porosity and permeability. Some of these aggregated parameters are easy to calculate, but others require more elaborate treatment, which is especially true for the permeability, referred to as relative permeability in two phase flow.

The goal of this project is to study two phase flow in geothermal reservoirs, both theoretically using mathematical models and by conducting experiments on such flow situations. The theoretical part involves development of new and improved relations that account for the complex interaction between phases in porous flow. Traditional relation for such flow is the Darcy equation, which relates superficial flow velocity to pressure gradient, through fluid permeability and viscosity. However, phase interaction must be taken into account in the two phase case where effects such as weight difference, friction and surface tension must be included in the known relation. Relations regarding convective and diffusive energy transport will also be coupled to the flow model to include effects of phase changes, especially when the fluid flows in a vertical direction in gravity. The results will be an improved set of relations that describe energy transport in geothermal reservoirs. The equations will be implemented in a simulation tool in order to be able to perform investigations on case studies and comparisons with measurements.

The experimental part of the project is essential in order to verify new relations and model results that will be developed or improved, as described above. This requires a setup that represents conditions in geothermal reservoirs in a sufficiently accurate manner, but can be built and operated in a lab where all relevant parameters can be controlled and variables measured. The experimental setup will be built at Keilir at Ásbrú, Reykjanesbæ, where housing and necessary auxiliary components will be provided.

The testing apparatus consists of a vertical steel pipe, up to 12 m high, with diameter approximately 15 cm. This pipe will be filled with gravel of different porosity and a mixture of steam and water will be pumped into the bottom of the pipe. The mixture will typically flow upwards, changing phase in the process, and reach the top in a different state than in the beginning. Measurements of temperature and pressure will be performed along the pipe to gather information about the steam/water ratio and the vertical pressure gradient. The apparatus will be designed to withstand a pressure up to 120 bar and temperature up to 320°C. The pipe will be insulated to approach adiabadic conditions and can therefore be used to mimic ground conditions at various depth and temperature.

This project is planned as a three year Ph.D. project where the main task of the student is to study theoretical models of two phase flow in porous media. The task of the student also involves designing and operating the experimental apparatus, which will be used to verify model hypothesis and to gather data on which to build new empirical relations that can be used to developed new models for this specific two phase case.

The project plan also assumes that master's students will participate in the project. The first planned M.Sc. project, for which funding is sought here, will focus on the vibration of the tube and the Acoustic Emission/Microseismic (AE/MS) activity emitted from within the tube. Vibration and AE/MS measurements will be made at regularly spaced points along the tube, i.e. where the temperature and pressure measurements will also be made. The task of the student will be the design of measurement technique, implementation of data acquisition and the preliminary interpretation of the experimental data.

The applicants believe that the described interaction between the two phases has not been studied sufficiently to conclude which effect it has on the overall flow. It is therefore necessary to get a conclusion on how important these effects are, to be able to make new empirical formulas that are not included in the simulation tools available today. Research of these effects should lead to better understanding of behavior of geothermal fluid in reservoirs and consequently better tools to forecast the response of utilized geothermal reservoirs.

Scientific merit

Numerous studies have been undertaken to simulate the flow of water and steam through porous media in geothermal reservoirs. Current formulas that are used for these simulations do not take into account the influence that the two phases have on each other where shear forces between the up flowing steam and water will affect the flow.

Experimental measurements of flow in porous media have been conducted before, as recited in Jonas et al. [1,2], but were not thorough enough to provide information sufficient to improve reservoir flow models. However they showed without doubt that the assumptions made in the current reservoir models lack proper involvement of the effects of phase interaction. It is important to clarify this matter and investigate the effect of this discrepancy in the current models.

A device for repeating and improving the former experiment is currently not available in Iceland so it will benefit researches greatly to design and build such a device that could be used to verify the mentioned models, but also for other experiments where groundwater flows in high pressure and temperature situations is under consideration.

Several investigations have revealed that a low frequency seismic noise (1–10 Hz) originates from geothermal [3] as shown by Guðmundsson&Brandssdóttir, 2008, as well as oil and gas reservoirs as shown by Landrö et al. [4]. In fact the techniquie described there, Spectraseis AG won the World Oil Award for Best Exploration Technology in Oct. 2007 for a low frequency signal processing technology to identify and delineate hydrocarbon reservoirs from the surface without drilling. However, as the authors point out the empirical evidence supports the technique but the underlying physical mechanism has not been fully identified. Guðmundsson&Brandsdóttir suggest that seismic noise could possibly be used to locate geothermal reservoirs but, that more data and research is required. The experimental setup offers an unique opportunity to study the vibration and Acoustic Emission/Microseismic (AE/MS) activity from two phase flow in porous media in a controlled laboratory environment where ground conditions at various depth and temperature can be closely imitated. Analysis of the acquired data will help understand the processes occurring in the porous media which in turn will advance vibrational–based techniques for identifying and locating geothermal reservoirs.

The improved models and simulation tool developed will be of great importance for research involving reservoir behavior and predicting production capacity of such systems. This will furthermore be strengthened by experimental validation of the model results in the proposed lab setup.

[1] Elíasson, J., Kjaran, S. and Gunnarsson, G.; „Two Phase Flow in a Porous Medium and the Concept of Relative Permeabilities“; Sixth Workshop on Geothermal Reservoir Engineering Dec. 16 - 18, Stanford University, Stanford, California; 1980

[2] Eliasson J. „Relative permeabilities in geothermal two-phase flow. A note on the state of the art.

[3] Ólafur Guðmundsson og Bryndís Brandsdóttir, "Jarðhitasuð við Ölkelduháls", unpublished research report, 2008

[4] Landrö, Martin and Amundsen, Lasse, "Low-frequency Seismic Noise: The Musicof oil?", GEO ExPro, February 2008

1.1 Objectives and GEORG WP relevance

Specify the main objectives of the project and explain the relevance it has to GEORG WP. Please also explain how the project will help GEORG achieving its main objectives

The goal of the project is to obtain an improved empirical description of the behavior of to phase flow in porous media, for better understanding of the geothermal resource (WP4). Empirical relations obtain can be utilized in existing or new software for reservoir modeling, which is a tool for improved utilization of geothermal resources (WP5).

The project involves the work of a PhD student as well as a master's student, which supports WP2.

WP Number:	Project relevance %
WP 2	20% (task 2.2)
WP 3	
WP 4	50% (task 4.1, 4.2, 4.5)
WP 5	30% (task 5.3)
WP 6	
WP 7	
WP 8	

2 Work plan and time schedule:

Provide a short work plan broken down into subtasks which should follow the logical phases of the implementation of the project. A timeline should be presented as well as list of deliverables and milestones. Please keep in mind the submission of progress- and annual reports to GEORG, while planning the deliverables and milestones.

Subtask	Start	Finish	Deliverable/Milestone
1. Literature research	1.7.2009	1.5.2010	Paper
2. Design/construction of apparatus	1.7.2009	1.5.2010	Measurements of pressure and mass flow
3. Measurements	1.5.2010	1.2.2012	Papers
4. M.Sc. project	1.5.2010	1.5.2011	Measurements of vibrations, MSc thesis
5. Simulation tool	1.1.2011	1.7.2012	Simulation tool, paper
6. Thesis	1.7.2011	1.7.2012	Ph.D.thesis

This project is planned as a 3 year Ph.D. project with following subtasks:

1. **Literature research**
   Thorough research of available literature and studies that have been made regarding two phase flow in geothermal reservoirs.

2. **Design/construction of measurement apparatus**
   The design of the measurement apparatus will be finalized, the apparatus constructed, installed and tested within the facility arranged for this project. At the end of this phase, measurements of pressure drops and mass flow rates for vapor and condensed phases should be obtainable.

3. **Measurements**

Measurements will be made with the measurement apparatus and documented for further analysis. Temperature and pressure will be measured for a given flow of water through the apparatus, which has been filled with appropriate material. Effect of changing mass flow rates and vapor/liquid fractions on the pressure drop, and the effect of different filling material on the same will be measured. Paper with the results will be published.

4. **M.Sc. Project.**
   As a part of this project, vibration measurements on the testing apparatus will be performed, this subtask is defined as a MSc project.

5. **Simulation tool**
   New empirical formulas will be derived based on the results from the measurements. A model using these formulae will be developed accordingly. Results will be published as research papers.

6. **Thesis**
   Results of the subtasks above collected in a Ph.D. thesis.

3 Project Management

Make a short description of the applicants involved in the project, inform about the resources that will be assigned to the project. Also specify in clear and simple manner who is resposible for what and how that will be managed.

The research team consists of following team members:

Guðrún Sævarsdóttir, project coordinator. Assistant professor at the Department of Mechanical and Electrical engineering , Reykjavík University. Research field is thermal fluid science with, in particular computation fluid mechanics, thermodynamics and heat transfer. Contribution to the project is project management and coordination, involvement in experimental strategy and design. Also, involvement in modeling work.

Halldór Pálsson, associate professor at the Department of industrial engineering, mechanical engineering and computer science, University of Iceland. Field of interest is thermo-fluid science with emphasis on computational fluid mechanics and thermodynamics. Research support in the project will be on the design of the experimental setup as well as solution strategies for the resulting partial differential equations resulting from the modeling.

Guðni Axelsson, Ph.D, Head of Physics Department, Iceland GeoSurvey,Also chief reservoir physicist. Involved in a variety of geothermal projects in Iceland and abroad. Adjunct professor, School of Engineering and Natural Sciences, University of Iceland. Specializes in geothermal reservoir physics, in particular testing of geothermal wells, monitoring of geothermal fields, analysis of production response data from geothermal systems, modelling of geothermal reservoirs, reinjection and tracer–tests. Also planning and management of geothermal research– and drilling projects, geothermal resource management, general ground–water hydrology and applied mathematics. Contribution to project will be expertise in geothermal reservoir modeling.

Jónas Elíasson, Ph.D, Professor emeritus, Department of Civil Engineering, University of Iceland. In the field of fluid mechanics, environmental engineering, Hydrology, Coastal Engineering and Water Power. Contribution to the project is reservoir expertise and experimental design.

Rúnar Unnþórsson, Ph.D – Director of Keilir's School of Energy and Technology. Field of interest is non-destructive evaluation/monitoring techniques and machine design. Research support in the project will be on monitoring techniques, data acquisition, signal processing and on the design of the experimental apparatus. Furthermore Rúnar will be on-site at Keilir for general support.

María S. Guðjónsdóttir, Ph.D. student will carry through the project. Experience from the geothermal field through work for consulting engineering firm in Iceland.

The research team has various experiences in the field of researches and utilization of geothermal areas. The research apparatus will be located at Keilir where a new innovation center is emerging, with an emphasis on energy related research and development. Keilir will contribute facilities for the experimental setup, and Keilirs energy lab will contribute a part of the measuring devices needed to perform the experiments.

This project will be of great importance in combining the experience and knowledge of geothermal areas together with new researches and inventions in that field. Not only by using the know-how in the Icelandic geothermal branch but also by using the research facilities being developed for this purpose.

4 Budget overview

Insert the "Costs" spreadsheet from the application documents. Explain the basic cost structure of the project. If it's assumed informative an additional budget summary can be included here, that, however, should not exclude the standard forms. Please justify, in simple terms, how the criterias of chapter 6, Section I in the „Proposal & Award Policies & Procedures Guide" are fulfilled.

	Cost item	Requested funding		Other financing		Total
2009/2010	Salaries					7.140
	Operational expenses					7.420
	Travel expenses					0
	Total 2009/2010:	1.000	7%	13.560	93%	14.560
2010/2011	Salaries					8.610
	Operational expenses					6.660
	Travel expenses					300
	Total 2010/2011:	2.300	15%	13.270	85%	15.570
2011/2012	Salaries					7.620
	Operational expenses					6.660
	Travel expenses					300
	Total 2011/2012:	1.300	9%	13.280	91%	14.580
Grand Total		4.600	10%	40.110	90%	44.710

The project is planned as a PhD study, it already has partial financing from Orkurannsóknasjóður Landsvirkjunar, 3000 kIskr pr. Year, however the total cost of salaries for a PhD. Student with related costs is 3.960 kIskr pr. year. The financing sought from GEORG is the remaining funding required for the PhD students salary, additional 1000 kIskr stipend for a MSc student and some travel costs.