ANNEX I
Project Plan

Mathematical modelling of energy flow in a geothermal reservoir

Project ID: 09-01-029

Coordinator: Halldór Pálsson, University of Iceland

Start date: January 2010

Duration: 9 months

Partners: Iceland GeoSurvey

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.

The understanding of the behavior of geothermal systems plays a major part in planning and operation of geothermal energy resources. A basis for this understanding is the gathering of knowledge about natural flow of energy through the Earth's crust, as well as the ability to predict variations in individual systems. This information is frequently acquired in the form of direct measurements on the Earth's surface or measurements in conjunction with test wells. Although this vital information can be used to develop conceptual models of geothermal systems, more thorough and complex modeling has proven useful for predicting correct behavior of such systems.

Complex geothermal reservoir models involve a mathematical model based on a system of partial differential equations. The natural phenomena such as fluid flow and energy transport are described by various conservation equations in the system. The equations are typically of the advection-diffusion type, describing e.g. conservation of mass, conservation of momentum and conservation of thermal energy. These equations are furthermore coupled with each other and are frequently non-linear, which adds greatly to the complexity of their solutions. Not only do such models strengthen the understanding of geothermal phenomena but they also present interesting challenges to mathematicians.

The Darcy-Lapwood mathematical problem can be used to describe natural flow of energy from the Earth's crust to the surface in a porous aquifer. Thus, it is of great importance regarding geothermal utilization to understand this process in depth and to be able to perform calculations on specific cases.

The project will be undertaken by a masters student, either in applied mathematics or engineering, and the student will work on both sub-projects described above. The student will take courses in applied mathematics and engineering through a new joint computational science program at the University of Iceland. The applicants will take a large role in the framework design of the proposed Icelandic reservoir modeling software together with the student. The Darcy-Lapwood case study and further analysis of it will however be mainly in the hands of the student.

Scientific merit

Numerous software packages exist that can be used for modeling and simulating fluid flow and energy transport in porous media. Some are based on commercial software packages, which are specialized codes for computational fluid dynamics. Others are more specific, and the state of the art package in this class is the Tough2, developed at Berkley Laboratories in the United States. Although Tough2 is a proven program that has been used for many years, its initial design would be considered somewhat out of date now. This reason, as well as the importance of further strengthening local expertise on reservoir modeling in Iceland, motivates the applicants to begin development of software which will be owned and operated by Icelandic universities and institutions involved in geothermal energy.

The problem described by the Darcy-Lapwood system, for buoyancy driven convection in porous media, is still unsolved for large Rayleigh numbers. The problem has been investigated in laboratory experiments but results from numerical experiments have not shown a good fit to the data acquired from the laboratory. The problem is non-linear and becomes chaotic for these large Rayleigh numbers. It is therefore of great scientific value to analyze the stability of the problem and try to determine the existence of solutions for a wide range of Rayleigh numbers.

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 purpose of this project is twofold. The first objective is to define a framework for models and software that can be used for solving partial differential equations that are associated with flow in geothermal reservoirs. The framework is the first step of developing an Icelandic reservoir modeling software package that can be used for educational and research purposes. The intention is that this software will be three dimensional and based on the finite volume method or the finite element method. Furthermore it will be designed to simulate decomposed problems on computer clusters if the modeling problems are very big and computations time consuming. A crucial part of software development such as this is the initial design phase before any programming takes place. This project will address that issue.

The second purpose is to build a relatively simple two dimensional mathematical model of a geothermal system, involving basic Rayleigh-Bernard convection. In this particular case the flow is assumed to follow a pressure gradient in the domain under consideration through the Darcy equation which is dictated by permeability, fluid viscosity and density, as well as gravity. In this model the Darcy equation is accompanied by an equation describing the conservation of energy. The energy equation incorporates three phenomena: flow of energy through convection, flow through diffusion (heat conduction) and changes in energy content over time. In its simplest form the system involves only one parameter which is the dimensionless porous Rayleigh number.

The relevance to the work packages is as follows:

WP Number:	**Project relevance %**
WP 2	40%
WP 3	
WP 4	60%
WP 5	
WP 6	
WP 7	

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
Literature review	01.01.2010	01.02.2010	Background chapter in thesis
Design of program framework	01.02.2010	01.05.2010	Short report with framework description
System modeling	16.02.2010	01.07.2010	Functional program
Case study: Darcy-Lapwood	01.06.2010	01.10.2010	Results for high Rayleigh-number
Writing of thesis	01.09.2010	01.11.2010	Submission M.Sc thesis

The project is planned as a nine month M.Sc. project with the follwing subtasks:

1. Literature review.
   In this part of the project, papers and reports relevant to geothermal reservoir modeling will be gathered and studied. A special focus will be on papers regarding the case study of a Darcy-Lapwood system.

2. Design of program framework
   The long term intention of the group is to develop numerical models for geothermal reservoirs, and in this project and initial design will be performed for such models. The milestone for this part will be a thorough description of the software structure and data formats, which can then used in the future as a reference for further software development.

3. System modeling
   Two relatively simple models will be developed. The first one will be a steady-state solver for the Poisson equation, describing e.g. potential flow in porous media. The second one will be a solver for a transport equation with both advective and diffusive terms, which describes e.g. energy flow in fluids. The models will be as general as possible and will be programmed with computer cluster applications in mind.

4. Case study: Darcy-Lapwood system
   The special case of the Darcy-Lapwood coupling between fluid flow and temperature fields will be solved by using the developed models. Furthermore , systematic mathematical analysis will be performed on the problem and its solutions, with respect to stability, uniqueness and existence.

5. Writing of thesis

The M.Sc. student will write a thesis, gathering all the information obtained in the research. It is also planned that the group will publish a paper with the most important findings in the project.

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 main work in the project will be performed by a masters student who has a good background in mathematical methods for solving partial differential equations. The work will be supervised by the applicants, and here follows a short description of them and how they can contribute to the project

Halldór Pálsson is an associate professor at the Department of industrial engineering, mechanical engineering and computer science, University of Iceland. Mechanical engineer specialized in thermo-fluid sciences, with emphasis on computational fluid dynamics. Halldór will contribute to software framework design and numerical methods for the Darcy-Lapwood system. Halldór will also co-ordinate the project work and progress.

Guðni Axelsson is the head of the physics department of ÍSOR, the Iceland GeoSurvey, and adjunct professor at UoI. He has specialized in studying the physics of geothermal systems during production, including geothermal reservoir modeling, during the last 25 years, both in Iceland and abroad. ÍSOR is the main geothermal research institute in Iceland with about 90 staff members. The institute and its predecessors have been involved in geothermal research for more than half a century. Guðni will contribute to the project by advising on the geothermal aspects of the work, in terms of general knowledge, information and data.

Ragnar Sigurðsson is a professor in mathematics at the Department of Mathematics University of Iceland. His specialization is in mathematical analysis, in particular complex analysis, Fourier analysis and partial differential equations. Ragnar will contribute to the software framework design, the numerical analysis and the mathematical analysis of the Darcy-Lapwood system.

Elínborg I. Ólafsdóttir is an associate professor in Applied mathematics at the Department of Mathematics at the University of Iceland. Her speciality is in asymptotic approximations of solutions of differential equations and in geophysical fluid dynamics. She has taken part in building a software model for analysing an oceanographical phenomenon. Elínborg will contribute to the software framework design, the numerical analysis and the mathematical analysis of the Darcy-Lapwood system.

Stefán Ingi Valdimarsson is a specialist at the Mathematics Division of the Science Institute of the University of Iceland. Stefán has specialized in Harmonic analysis. His specific research projects have included the study of Optimal transportation which has applications in geophysical fluid dynamics. He is interested in the application of mathematical research to practical real-world problems. Stefán will contribute to the software framework design and the mathematical analysis of the Darcy-Lapwood system.

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					3.570
	Operational expenses					0
	Travel expenses					0
	Total 2009/2010:	1.350	38%	2.220	62%	3.570
2010/2011	Salaries					0
	Operational expenses					0
	Travel expenses					0
	Total 2010/2011:	0	N/A	0	N/A	0
2011/2012	Salaries					0
	Operational expenses					0
	Travel expenses					0
	Total 2011/2012:	0	N/A	0	N/A	0

Grand Total	**1.350**	**38%**	**2.220**	**62%**	**3.570**

The grant from GEORG will be used exclusively to pay salaries of a masters student of the School engineering and natural sciences at University of Iceland. The magnitude of the master's project is 60 ECTS credits.