ANNEX I
Project Plan

EIGMIA

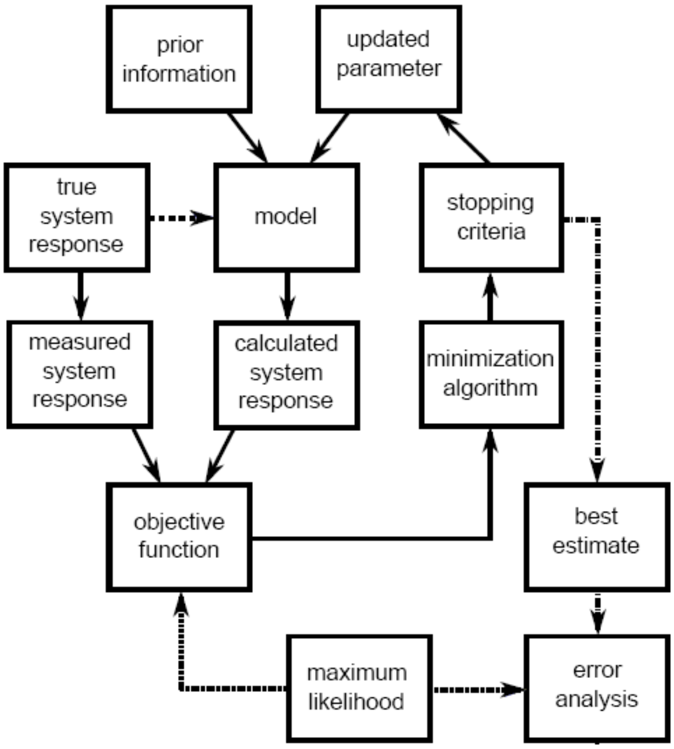
Evaluation and Improvements of Geothermal Models

using Inverse Analysis

Project ID:	09-01-028
Coordinator:	Magnus Thor Jonsson, University of Iceland
Start date:	01/2010
Duration:	3 years
Partners:	Stefan Finsterle, Staff Scientist, Lawrence Berkeley National Laboratory, Earth Sciences Division (LBNL)

1 Project description

In the project, a method will be developed to evaluate geothermal systems and to analyze and design geothermal power plants. Emphasis will be placed on bringing in an inverse modeling methodology and using it on three different aspects of geothermal power development, i.e., for (1) analyzing geothermal systems' workloads, (2) examining steam and boiling in wells and pipelines, and (3) examining the functionality of separator stations. In the project, experiments will be performed on pressure drops, temperature changes and quality factors. Data from these experiments will be used in inverse analyses to adjust models that have been developed for analyzing those factors. The figure on the next page shows how a connection forms between model development, experiments and inverse analysis.



Flow chart of the major steps of inverse analysis of geothermal systems [1].

[1] S. Finsterle, iTOUGH2 Users Guide, Berkeley: University of California, 2000

Scientific merit

Models that are mostly used to analyze geothermal reservoir systems in Iceland have been developed at Berkeley Lab (iTOUGH2). In the project, an emphasis will be placed on utilizing that knowledge to develop even further a tool for the designing of work processes for geothermal power plants. Emphasis will be placed on analyzing flow in wells and pipelines along with examining the functionality and the quality of separators. With this collaboration, a base of a solid analyzing system will be formed for steam processes—a much needed management and decision support system that does not exist today.

Education/Infrastructure quality

In the project, an important base of the collaboration between the University of Iceland and Berkeley Lab (LBNL) will be formed, where PhD students will perform research in collaboration with professors and scientists. It is additionally assumed in the project that Stefan Finsterle, Staff Scientist from LBNL, will come to Iceland and participate in the development of this technology.

Technical / Entrepreneurial / Social quality

Although geothermal energy is a renewable energy source, it can be utilized in a sustainable or excessive manner depending on the rate of exploitation. Production capacity of geothermal reservoirs can be estimated using various methods but if a sustainable use is to be achieved a comprehensive management strategy is essential. In order to assess the reservoir, extensive studies of the physical characteristics are necessary. These studies require a conceptual model that captures the salient features of the reservoir. The conceptual model is then idealized by explicit assumptions to create predictive models of various complexities.

Two main approaches have been applied in Iceland, a simple volumetric approach and an extensive well-by-well numerical model approach. The intrinsic weakness of the volumetric approach lies in the assumption of a fixed recovery factor, while energy recovery strongly depends on the hydraulic and thermodynamic characteristics of the reservoir. Numerical models take into account these physical aspects, which can be constrained with production histories

However, the underlying weakness of the extensive well-by-well approach is its complexity. If individual wells are to be modeled using complicated production histories then the heterogeneous geometrical structure has to be modeled as well; the details of the geometrical structure and related hydrothermal properties are often unknown and need to be indirectly inferred from data. The resulting inverse problem is often highly over-parameterized, leading to uncertain estimates and predictions due to strong parameter correlations. We propose to investigate approaches that combine exploration and available production data to reduce estimation uncertainty, and to include the remaining uncertainties in a comprehensive simulation-optimization framework for sustainable reservoir management.

1.1 Objectives and GEORG WP relevance

The main objective of the project is to develop improved models by using inverse analysis as a basis for providing tools for designers and decision makers in the fields of optimal geothermal exploration and power production. Another important objective is to promote possible energy viewed from a sustainable level. The project contributes to GEORG main objectives by improving the feasibility of sustainable energy production from geothermal sources and to establish creative environment through national and international operations.

Project objectives:

Develop a technology to improve usage of geothermal reservoirs and to optimize the design and placement of wells, steam gathering system and separators. In accordance with objectives in WP4: 1, 2 and in WP5: 1, 3, 5, 8.

Enlarge know-how in this important field of geothermal exploration in Iceland. In accordance with objectives in WP4: 1WP2: 1, 2 and 3.

Encourage cooperation with a research group in this field at the Berkeley Lab. In accordance with WP8.

Develop knowledge and a technology that will benefit development of geothermal power production in Iceland. In accordance with WP5.

2 Work plan and time schedule

Participants will carry out the project in the framework of the following five subtasks:

1. Introduction								
Duration	01.01.10-01.10.10	9						
Institution	UIERI	LBNL	UIERI	UIERI	UIERI	UIERI	UIERI	Total
Initials	MÞJ	SF	HH	GS	LM	DJD	ÁÓ	
Man months	0,5	0,0	4,0	2,0	0,0	1,0	1,0	8,5
Saleries	358	0	1024	512	0	210	210	2314
Travel	200	0	0	0	0	0	0	200
Facilities	142	0	568	284	0	102	102	1198
Total cost	700	0	1592	796	0	312	312	3712
GEORG funding	0	0	256	256	0	210	210	932
Other financing	700	0	1336	540	0	102	102	2780

Gathering information on modeling methods and measurement systems for analyzing and predicting the behavior of reservoirs, wells, pipelines and steam separators in geothermal systems. A comparison will be made between methods and models that have been developed and are used today.

2. Modeling								
Duration	01.01.10-31.12.11	24						
Institution	UIERI	LBNL	UIERI	UIERI	UIERI	UIERI	UIERI	Total
Initials	MÞJ	SF	HH	GS	LM	DJD	ÁÓ	
Man months	2,5	0,5	18,0	21,0	3,0	3,0	4,0	52,0
Saleries	1790	500	4608	5376	768	630	840	14512
Travel	0	520	250	250	230	0	0	1250
Facilities	710	500	2556	2982	426	306	408	7888
Total cost	2500	1520	7414	8608	1424	936	1248	23650
GEORG funding	0	1020	1024	1024	998	630	840	5536
Other financing	2500	500	6390	7584	426	306	408	18114

Applicants have been using and developing models to analyze geothermal energy systems and processing units of geothermal power plants. The objective of this subtask is to adjust and improve the models along with connecting them together where the parameters are dependent. The models that will be used are reservoir models, wellbore models, steam gathering systems and separator models.

3. Inverse Analysis

Duration	01.09.10-01.09.12	24						
Institution	UIERI	LBNL	UIERI	UIERI	UIERI	UIERI	UIERI	Total
Initials	MÞJ	SF	HH	GS	LM	DJD	ÁÓ	
Man months	1,5	2,0	8,0	7,0	6,0	4,0	2,0	30,5
Saleries	1074	2000	2048	1792	1536	840	420	9710
Travel	200	520	250	250	230	0	0	1450
Facilities	426	2000	1136	994	852	408	204	6020
Total cost	1700	4520	3434	3036	2618	1248	624	17180
GEORG funding	0	2520	768	768	1766	840	420	7082
Other financing	1700	2000	2666	2268	852	408	204	10098

Develop a methodology by using inverse analysis to improve both the topology design of geothermal models and parameter estimation. The key parameters, decision variables, and observable variables are:

- Reservoir permeability.
- Pressure in the reservoir, under static and flowing conditions.
- Pressure and temperature in the well as a function of depth, including at feed zones.
- Mass flow rates of both liquid and steam phases.
- Well design and route selection.
- Pipe dimensions, supports and anchors.
- Pressure and temperature drop in the steam gathering systems.
- Separators, the quality or dryness factor.

4. Case Study Reykjanes Power Plant

Duration	01.06.11-01.06.12	12						
Institution	UIERI	LBNL	UIERI	UIERI	UIERI	UIERI	UIERI	Total
Initials	MÞJ	SF	HH	GS	LM	DJD	ÁÓ	
Man months	1,0	0,0	2,0	2,0	0,0	0,0	1,0	6,0
Saleries	716	0	512	512	0	0	210	1950
Travel	0	0	0	0	0	0	0	0
Facilities	284	0	284	284	0	0	102	954
Total cost	1000	0	796	796	0	0	312	2904
GEORG funding	0	0	256	256	0	0	210	722
Other financing	1000	0	540	540	0	0	102	2182

The methodology will be used to analyze the Reykjanes power plant.

5. Results									
Duration	01.01.12-31.12.12	12							
Institution		UIERI	LBNL	UIERI	UIERI	UIERI	UIERI	UIERI	Total
Initials		MÞJ	SF	HH	GS	LM	DJD	ÁÓ	
Man months		0,5	0,5	4,0	4,0	1,0	1,0	1,0	12,0
Saleries		358	500	1024	1024	256	210	210	3582
Travel		200	520	250	250	230	0	0	1450
Facilities		142	500	568	568	142	102	102	2124
Total cost		700	1520	1842	1842	628	312	312	7156
GEORG funding		0	1052	256	256	486	210	210	2470
Other financing		700	468	1586	1586	142	102	102	4686

Results will be presented in MS - and PhD thesis. Also will results be presented in reviewed papers.

Summary:

Subtask	Start	Finish	Deliverable/Milestone
1. Introduction	01.01.10	01.10.10	Report
2. Modeling	01.01.10	31.12.11	Reports, Papers
3. Inverse analysis	01.09.10	01.09.12	Papers
4. Case study	01.06.11	01.06.12	Papers
5. Results	01.01.12	31.12.12	PhD thesis and papers

Deliverables and Milestones, as planned in 2010:

15.05.10 Progress Report
01.12.10 Annual Report
01.10.10 Conference paper (Stanford Geothermal Workshop Feb. 2011)
31.12.10 Paper (SHP – Two phase flow)

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 steering group of the project will be composed of Professor Magnús Þór Jónsson at the Department of Mechanical Engineering at the University of Iceland and Stefan Finsterle, Staff Scientist at the Lawrence Berkeley National Laboratory (LBNL).

Magnús Þór Jónsson will bear the main responsibility of the part of the work carried out in Iceland, while Stefan Finsterle will be the coordinator of the research in Berkeley. PhD and MSc. students will work both at the Berkeley Lab and at the University of Iceland.

EIGMIA group:

Professor Magnus Thor Jonsson
Staff Scientist Stefan Finsterle
PhD student at UI, Heimir Hjartarson
PhD student at UI, Gunnar Skúlason
PhD student at Stanford (internship), Lilja Magnúsdóttir
MSc student at UI, Daniel John Drader
MSc student at UI, Árni Ólafsson

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.

Explanation of cost

The cost items and financing contribution are basic salaries, overhead cost, fieldwork and traveling expenses.

Salaries including overhead

Participants		Basic Salaries	Salary exp.	Work facilites	Total
Magnús Þór Jónsson	MÞJ	716	144	140	1000
Stefan Finsterle	SF	1000	200	800	2000
Heimir Hjartarson	HH	256	52	90	398
Gunnar skúlason	GS	256	52	90	398
Lilja Magnúsdóttir	LM	256	52	90	398
Daniel John Drader	DJD	210	42	60	312
Árni Ólafsson	ÁÓ	210	42	60	312

Year #1									
Duration	01.01.10-31.12.10	12							
Institution	UIERI	LBNL	UIERI	UIERI	UIERI	UIERI	UIERI	Total	
Initials	MÞJ	SF	HH	GS	LM	DJD	ÁÓ		
Man months	2,0	1,0	12,0	12,0	3,0	6,0	6,0	42,0	
Saleries	1432	1000	3072	3072	768	1260	1260	11864	
Travel	200	520	250	250	230	0	0	1450	
Facilities	568	1000	1704	1704	426	612	612	6626	
Total cost	2200	2520	5026	5026	1424	1872	1872	19940	
GEORG funding	0	1020	720	720	940	1260	1260	5920	
Other financing	2200	1500	4306	4306	484	612	612	14020	

Contribution:

Manpower Cost:

MTJ : 1000 K-IKR /month, 100% UI contribution
SF : 2000 K-IKR/month , 50% Own contribution, 50% GEORG
HH : 398 K-IKR /month, 80% UI, Research fond, 20% GEORG
GS : 398 K-IKR /month, 80% UI, Research fond, 20% GEORG
LM : 398 K-IKR /month, 40% UI, Research fond, 60% GEORG
DJD : 312 K-IKR /month, 40% UI, Research fond, 60% GEORG
ÁÓ : 312 K-IKR /month, 40% UI, Research fond, 60% GEORG

Traveling expenses:

SF : 520 K-IKR 100% GEORG
MTJ : 200 K-IKR 100% Sáttmálasjóður
HH, GS: 530 K-IKR 100% GEORG

Consortium: UIERI and LBNL

Name of Project: Evaluation and Improvements of Geothermal Models using Inverse Analysis

ISK '000	Year		Year 1 2009/2010		Year 2 2010/2011		Year 3 2011/2012		
Salaries including overhead		**Unit cost**	Man-months	Total	Man-months	Total	Man-months	Total	
Research coordinator	MTJ	1.000	2	2.000	2	2.000	2	2.000	
Research coordinator	SF	2.000	1	2.000	1	2.000	1	2.000	
PhD student	HH	398	12	4.776	12	4.776	12	4.776	
PhD student	GS	398	12	4.776	12	4.776	12	4.776	
PhD student	LM	398	3	1.194	4	1.592	3	1.194	
MS student	DJD	312	6	1.872	3	936	0	0	
MS student	ÁÓ	312	6	1.872	3	936	0	0	
Total			42	18.490	37	17.016	30	14.746	
Operational exp.									
Fieldwork and data collection				0		0		0	
Total				0		0		0	
Travel expenses									
Visit SF to Iceland (2 weeks per year)				520		520		520	
Visit to Berkeley (6 weeks per year)				930		930		700	
Total				1.450		1.450		1.220	
Total cost				19.940		18.466		15.966	
Financing									
Contribution UI Saleries /Travel		MTJ, HH, GS		12.520		10.396		10.546	
Own contribution Saleries		SF		1.500		1.000		1.500	
Total other financing				14.020	70%	11.396	62%	12.046	75%
Requested funding from GEORG				5.920	30%	7.070	38%	3.920	25%
Total financing				19.940		18.466		15.966	

Year	Cost item	Requested funding		Other financing		Total
2009/2010	Salaries					18.490
	Operational expenses					0
	Travel expenses					1.450
	Total 2009/2010:	5.920	30%	14.020	70%	19.940
2010/2011	Salaries					17.016
	Operational expenses					0
	Travel expenses					1.450
	Total 2010/2011:	7.070	38%	11.396	62%	18.466
2011/2012	Salaries					14.746
	Operational expenses					0
	Travel expenses					1.220
	Total 2011/2012:	3.920	25%	12.046	75%	15.966

Grand Total	**16.910**	**31%**	**37.462**	**69%**	**54.372**

Total

Duration	01.10.10-31.12.12	36						
Institution	UIERI	LBNL	UIERI	UIERI	UIERI	UIERI	UIERI	Total
Initials	MÞJ	SF	HH	GS	LM	DJD	ÁÓ	
Man months	6,0	3,0	36,0	36,0	10,0	9,0	9,0	109,0
Saleries	4296	3000	9216	9216	2560	1890	1890	32068
Travel	600	1560	750	750	690	0	0	4350
Facilities	1704	3000	5112	5112	1420	918	918	18184
Total cost	6600	7560	15078	15078	4670	2808	2808	54602
GEORG funding	0	4592	2560	2560	3250	1890	1890	16742
Other financing	6600	2968	12518	12518	1420	918	918	37860