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Switzerland's Energy Strategy 2050 requires energy efficiency to be substantially improved, the proportion of fossil fuels in the energy supply to be considerably reduced, and nuclear power to be phased out, while meeting highly ambitious climate protection targets. One of the core implications is the need for a massive increase of the use of renewable sources for electricity generation. In this context, the Swiss Federal Office of Energy (SFOE) estimates that by 2050 deep geothermal energy could contribute 4–5 TWh per year to electricity generation in Switzerland, which would be a substantial contribution to a projected annual power need of 60 TWh. Geothermal energy is attractive because of the very large scale of the resource, its expected relatively low CO2 emissions, and its reliable, all-day domestic availability. However, the future contribution of deep geothermal energy is subject to major uncertainties: How much of this resource can be exploited and at what economic cost? What are the environmental and risk-related externalities that the public must be willing to bear? How does its overall performance compare to competing energy resources? And will the regulatory framework and public acceptance be sufficient to allow geothermal energy to provide a significant contribution? By way of this major interdisciplinary study, already considered a work of reference, TA-SWISS provides answers to these questions in a comprehensive and balanced way, thereby supplying a sound basis for stakeholder decision-making. Analyses of the fraction of geothermal wells that are dry (dry-hole fraction) indicate that geothermal reservoirs can be fitted into four basic categories: (i) Quaternary to late Tertiary sediments (almost no dry holes); (ii) Quaternary to late Tertiary extrusives (approximately 20 percent dry holes); (iii) Mesozoic or older metamorphic rocks (approximately 25-30 percent dry holes); and (iv) Precambrian or younger rocks (data limited to Roosevelt Springs where 33 percent of the wells were dry). Failure of geothermal wells to flow economically is due mainly to low-permeability formations in unfractured regions. Generally the permeability correlates inversely with the temperature-age product and directly with the original rock porosity and pore size. However, this correlation fails whenever high-stress fields provide vertical fracturing or faulting, and it is the high-stress/low-permeability category that is most amenable to artificial stimulation by hydraulic fracturing, propellant fracturing, or chemical explosive fracturing. Category (i) geothermal fields (e.g., Cerro Prieto, Mexico; Niland, CA; East Mesa, CA) are not recommended for artificial stimulation because these younger sediments almost always produce warm or hot water. Most geothermal fields fit into category (ii) (e.g., Wairakei, New Zealand; Matsukawa, Japan; Ahuachapan, El Salvador) and in the case of Mt. Home, ID, and Chandler, AZ, possess some potential for stimulation. The Geysers is a category (iii) field, and its highly stressed brittle rocks should make this site amenable to stimulation by explosive fracturing techniques. Roosevelt Springs, UT, well 9-1 is in category (iv) and is a flow failure. It represents a prime candidate for stimulation by hydraulic fracturing because it has a measured temperature of 227°C, is cased and available for experimentation, and is within 900 m of an excellent geothermal producing well. Several reservoir model improvements incorporated into the UTA model are described. The most significant modification to the model was the inclusion of semiimplicit treatment of transmissibilities so as to better handle two-phase flow problems associated with flow near the wellbore. A description of the reservoir mechanics presumed operative in geopressured-geothermal reservoirs is included. A mathematical model describing two-dimensional flow in compacting porous media is developed from the Lagrangian point of view. A description of the way the differential equations are approximated by finite differences and subsequently solved by means of numerical procedures is presented. Various sensitivity studies made with the reservoir model are described. Particular emphasis was given to the study of potential shale dewatering effects on reservoir depletion and the effects of compaction on fluid recovery. To study shale dewatering, the shale thickness and the shale vertical permeability were treated as variables in several simulation experiments. The effects of compaction were modeled with optimistic and pessimistic values for the uniaxial compaction coefficient in an attempt to define a region of expected reservoir performance. Laboratory analysis of core samples obtained from the geopressured-geothermal test well was completed by the end of year 3. These data indicate that the uniaxial compaction coefficient is of the same order of magnitude as the pessimistic value used on the sensitivity studies. Because of this the expected fluid recovery from geopressured reservoirs has been reduced to a nominal 5% of the in-place volumes rather than the previously reported 10%. Preface The Twelfth Workshop on Geothermal Reservoir Engineering was held at Stanford University on January 20-22, 1987. The year ending December 1986 was very difficult for the domestic geothermal industry. Low oil prices caused a sharp drop in geothermal steam prices. We expected to see some effect upon attendance at the Twelfth Workshop. To our surprise, the attendance was up by thirteen from previous years, with one hundred and fifty-seven registered participants. Eight foreign countries were represented: England, France, Iceland, Italy, Japan, Mexico, New Zealand, and Turkey. Despite a worldwide surplus of oil, international geothermal interest and development is growing at a remarkable pace. There were forty-one technical presentations at the Workshop. All of these are published as papers in this Proceedings volume. Seven technical papers not presented at the Workshop are also published; they concern geothermal developments and research in Iceland, Italy, and New Zealand. In addition to these forty-eight technical presentations or papers, the introductory address was given by Henry J. Ramey, Jr. from the Stanford Geothermal Program. The Workshop Banquet speaker was John R. Berg from the Department of Energy. We thank him for sharing with the Workshop participants his thoughts on the expectations of this agency in the role of alternative energy resources, specifically geothermal, within the country???s energy framework. His talk is represented as a paper in the back of this volume. The chairmen of the technical sessions made an important contribution to the workshop. Other than Stanford faculty members they included: M. Gulati, K. Goyal, G.S.

Bodvarsson, A.S. Batchelor, H. Dykstra, M.J. Reed, A. Truesdell, J.S. Gudmundsson, and J.R. Counsil. The Workshop was organized by the Stanford Geothermal Program faculty, staff, and students. We would like to thank Jean Cook, Marilyn King, Amy Osugi, Terri Ramey, and Rosalee Benelli for their valued help with the meeting arrangements and preparing the Proceedings. We also owe great thanks to our students who arranged and operated the audio-visual equipment, specially Jim Lovekin. The Twelfth Workshop was supported by the Geothermal Technology Division of the U.S. Department of Energy through Contract Nos. DE-AS03-80SF11459 and DE-AS07- 84ID12529. We deeply appreciate this continued support. January 1987 Henry J. Ramey, Jr. Paul Kruger Roland N. Horne William E. Brigham Frank G. Miller Jesus Rivera. As nations alike struggle to diversify and secure their power portfolios, geothermal energy, the essentially limitless heat emanating from the earth itself, is being harnessed at an unprecedented rate. For the last 25 years, engineers around the world tasked with taming this raw power have used "Geothermal" "Reservoir Engineering" as both a training manual and a professional reference. This long-awaited second edition of "Geothermal Reservoir Engineering" is a practical guide to the issues and tasks geothermal engineers encounter in the course of their daily jobs. The book focuses particularly on the evaluation of potential sites and provides detailed guidance on the field management of the power plants built on them. With over 100 pages of new material informed by the breakthroughs of the last 25 years, "Geothermal Reservoir Engineering" remains the only training tool and professional reference dedicated to advising both new and experienced geothermal reservoir engineers. The only resource available to help geothermal professionals make smart choices in field site selection and reservoir managementPractical focus eschews theory and basics-getting right to the heart of the important issues encountered in the fieldUpdates include coverage of advances in EGS (enhanced geothermal systems), well stimulation, well modeling, extensive field histories and preparing data for reservoir simulationCase studies provide cautionary tales and best practices that can only be imparted by a seasoned expert" A number of technical difficulties are encountered in producing geothermal energy from reservoirs containing brines with high concentrations of dissolved solids. The reduction in temperature and pressure associated with brine production results in the precipitation of solids which can form heavy scale in producing and injection wells and in surface equipment. Evidently under many conditions precipitates form in the reservoir surrounding producing wells, thereby reducing their productivity. In some cases the precipitation of solids is so severe that it can prevent economic production. This paper presents results of an investigation of the possibility of injecting a different water in a geothermal reservoir as a means of reducing problems caused by solids precipitation and scale formation. Corrosion problems may also be reduced depending upon the water-rock-metal behavior. The results are confined chiefly to reservoir mechanics, a logical first step in evaluating the process for a given reservoir. Water-rock chemistry, water treating, water supply, brine disposal and overall economics are discussed only briefly or are beyond the scope of this paper. In general the composition of water injected into geothermal reservoirs does not remain the same. In addition to mixing with the original water the injected water tends to equilibrate with the reservoir rock. if fresh water is injected it may pick up such minerals as silica, carbonate, iron, sulfur, etc. These minerals may precipitate and cause problems in producing the reservoir. Nevertheless, under suitable conditions, a change in the reservoir water may be an attractive alternative to cycling the original reservoir brine. This monograph focuses on the numerical methods needed in the context of developing a reliable simulation tool to promote the use of renewable energy. One very promising source of energy is the heat stored in the Earth's crust, which is harnessed by so-called geothermal facilities. Scientists from fields like geology, geo-engineering, geophysics and especially geomathematics are called upon to help make geothermics a reliable and safe energy production method. One of the challenges they face involves modeling the mechanical stresses at work in a reservoir. The aim of this thesis is to develop a numerical solution scheme by means of which the fluid pressure and rock stresses in a geothermal reservoir can be determined prior to well drilling and during production. For this purpose, the method should (i) include poroelastic effects, (ii) provide a means of including thermoelastic effects, (iii) be inexpensive in terms of memory and computational power, and (iv) be flexible with regard to the locations of data points. After introducing the basic equations and their relations to more familiar ones (the heat equation, Stokes equations, Cauchy-Navier equation), the "method of fundamental solutions" and its potential value concerning our task are discussed. Based on the properties of the fundamental solutions, theoretical results are established and numerical examples of stress field simulations are presented to assess the method's performance. The first-ever 3D graphics calculated for these topics, which neither requiring meshing of the domain nor involving a time-stepping scheme, make this a pioneering volume. The work on energy extraction experiments concerns the efficiency with which the in-place heat and fluids can be produced. The work on noncondensable gas reservoir engineering covers both the completed and continuing work in these two interrelated research areas: radon emanation from the rock matrix of geothermal reservoirs, and radon and ammonia variations with time and space over geothermal reservoirs. Cooperative research programs with Italy and Mexico are described. The bench-scale experiments and well test analysis section covers both experimental and theoretical studies. The small core model continues to be used for the study of temperature effects on absolute permeability. The unconsolidated sand study was completed at the beginning of this contract period. The Appendices describe some of the Stanford Geothermal program activities that results in interactions with the geothermal community. These occur in the form of SGP Technical Reports, presentations at technical meetings and publications in the open literature. Proceedings of the NATO Advanced Study Institute on Geothermal Reservoir Engineering, Antalya, Turkey, July 1-10, 1987 Geothermal Well Test Analysis: Fundamentals, Applications and Advanced Techniques provides a comprehensive review of the geothermal pressure transient analysis methodology and its similarities and differences with petroleum and groundwater well test analysis. Also discussed are the different tests undertaken in geothermal wells during completion testing, output/production testing, and the interpretation of data. In addition, the book focuses on pressure transient analysis by numerical simulation and inverse methods, also covering the familiar pressure derivative plot. Finally, non-standard geothermal pressure transient behaviors are analyzed and interpreted by numerical techniques for cases beyond the limit of existing analytical techniques. Provides a guide on the analysis of well test data in geothermal wells, including pressure transient analysis, completion testing and output testing Presents practical information on how to avoid common issues with data collection in geothermal wells Uses SI units, converting existing equations and models found in literature to this unit system instead of oilfield units The Third Workshop on Geothermal Reservoir Engineering convened at Stanford University on December 14, 1977, with 104 attendees from six nations. In keeping with the recommendations expressed by the participants at the Second Workshop, the format of the Workshop was retained, with three days of technical sessions devoted to reservoir physics, well and reservoir testing, field development, and mathematical modeling of geothermal reservoirs. The program presented 33 technical papers, summaries of which are included in these Proceedings. Although the format of the Workshop has remained constant, it is clear from a perusal of the Table of Contents that considerable advances have occurred in all phases of geothermal reservoir engineering over the past three years. Greater understanding of reservoir physics and mathematical representations of vapor-dominated and liquid-dominated reservoirs are evident; new techniques for their analysis are being developed, and significant field data from a number of newer reservoirs are analyzed. The objectives of these workshops have been to bring together researchers active in the various physical and mathematical disciplines comprising the field of geothermal reservoir engineering, to give the participants a forum for review of progress and exchange of new ideas in this rapidly developing field, and to summarize the effective state of the art of geothermal reservoir engineering in a form readily useful to the many government and private agencies involved in the development of geothermal energy. To these objectives, the Third Workshop and these Proceedings have been successfully directed. Several important events in this field have occurred since the Second Workshop in December 1976. The first among these was the incorporation of the Energy Research and Development Administration (ERDA) into the newly formed Department of Energy (DOE) which continues as the leading Federal agency in geothermal reservoir engineering research. The Third Workshop under the Stanford Geothermal Program was supported by a grant from DOE through a subcontract with the Lawrence Berkeley Laboratory of the University of California. A second significant event was the first conference under the ERDA (DOE)-ENEL cooperative program where many of the results of well testing in both nations were discussed. The Proceedings of that conference should be an important contribution to the literature. These Proceedings of the Third Workshop should also make an important contribution to the literature on geothermal reservoir engineering. Much of the data presented at the Workshop were given for the first time, and full technical papers on these subjects will appear in the professional journals. The results of these studies will assist markedly in developing the research programs to be supported by the Federal agencies, and in reducing the costs of research for individual developers and utilities. It is expected that future workshops of the Stanford Geothermal Program will be as successful as this third one. Planning and execution of the Workshop ... [see file; ljd, 10/3/2005] The

Program Committee recommended two novel sessions for the Third Workshop, both of which were included in the program. The first was the three overviews given at the Workshop by George Pinder (Princeton) on the Academic aspect, James Bresee (DOE-DGE) on the Government aspect, and Charles Morris (Phillips Petroleum) on the Industry aspect. These constituted the invited slate of presentations from the several sectors of the geothermal community. The Program Committee acknowledges their contributions with gratitude. Recognition of the importance of reservoir assurance in opting for geothermal resources as an alternate energy source for electric energy generation resulted in a Panel Session on Various Definitions of Geothermal Reservoirs. Special acknowledgments are offered to Jack Howard and Werner Schwarz (LBL) and to Jack Howard as moderator; to the panelists: James Leigh (Lloyd's Bank of California), Stephen Lipman (Union Oil), Mark Mathisen (PG & E), Patrick Muffler (USGS-MP), and Mark Silverman (DOE-SAN); and to the rapporteurs: George Frye (Aminoil), Vasel Roberts (Electrical Power Research Institute), and Alexander Graf (LBL), whose Valuable summaries are included in the Proceedings. Special thanks are also due Roland Horne, Visiting Professor from New Zealand and Program Manager of the Stanford Geothermal Program, for his efforts with the Program graduate students in conducting the Workshop. Further thanks go to Marion Wachtel, who in spite of tremendous personal hardship, administered the Workshop and prepared the Proceedings in a timely and professional manner. Professor Ramey and I also express our appreciation to the Department of Energy, whose financial support of the Workshop made possible the program and these Proceedings. Paul Kruger Stanford University December

31, 1977. Geothermal Energy Systems The book encounters basic knowledge about geothermal technology for the utilization of geothermal resources. The book helps to understand the basic geology needed for the utilization of geothermal energy, shows up the practice to make access to geothermal reservoirs by drilling and the engineering of the reservoir by enhancing methods. The book describes the technology to make use of the Earth?s heat for direct use, power, and/or chill and gives boundary conditions for its economic and environmental utilization. A special focus is made on enhanced or engineered geothermal systems (EGS) which are based on concepts which bring a priori less productive reservoirs to an economic use. From the contents: Reservoir Definition Exploration Methods Drilling into Geothermal Reservoirs Enhancing Geothermal Reservoirs Geothermal Reservoir Simulation Energetic Use of EGS Reservoirs Economic Performance and Environmental Assessment Deployment of Enhanced Geothermal Systems plants and CO2-mitigation Geothermal district space heating has been practiced in Boise over the last 85 years. The system has used to wells drilled approximately 50 ft (15 m) apart in the early 1890s. the wells have a combined maximum reported production rate of 1800 gpm (114 l/sec) at 170°F (77°C) discharge at the wellhead. The system has served as many as 400 homes and Natatorium; presently it serves approximately 200 homes and a large state laboratory and office building. The heating district remained at the present capacity (two wells) for 85 years primarily because of the unknown nature of the reservoir and availability of other energy sources. Not until 1974 was the question of further development given serious consideration. Rising energy costs due to expanding energy demands and higher costs for foreign oil brought about a reevaluation of the resource. The INEL, Boise State University, and the Idaho Bureau of Mines and Geology began an investigation into the nature of the resource and the economics of space heating several large buildings and homes. Two deep, approximately 1250 ft (381 m), exploratory wells were drilled and tested by the INEL to determine the nature and size of the reservoir. Drilling and reservoir engineering test results have confirmed the presence of a large reservoir that can be developed further without adversely effecting the two production wells and heating system now in operation. 4 figs., 1 tab.

Southeastern Idaho exhibits numerous warm springs, warm water from shallow wells, and hot water within oil and gas test wells that indicate a potential for geothermal development in the area. Although the area exhibits several thermal expressions, the measured geothermal gradients vary substantially (19 - 61 oC/km) within this area, potentially suggesting a redistribution of heat in the overlying ground water from deeper geothermal reservoirs. We have estimated reservoir temperatures from measured water compositions using an inverse modeling technique (Reservoir Temperature Estimator, RTEst) that calculates the temperature at which multiple minerals are simultaneously at equilibrium while explicitly accounting for the possible loss of volatile constituents (e.g., CO_2), boiling and/or water mixing. Compositions of a selected group of thermal waters representing southeastern Idaho hot/warm springs and wells were used for the development of temperature estimates. The temperature estimates in the the region varied from moderately warm (59 oC) to over 175 oC. Specifically, hot springs near Preston, Idaho resulted in the highest temperature estimates in the region. In this dissertation, two specific numerical models have been developed to address the issues associated with utilization of supercritical CO2, like fracture creation, proppant placement and fracture closure in unconventional gas reservoirs, reservoir stimulation, heat production and CO2 sequestration in deep geothermal reservoirs, respectively. In unconventional gas reservoir, the model consisting of classic fracture model, proppant transport model as well as temperature-sensitive fracturing fluids (CO2, thickened CO2 and guar gum) has been integrated into the popular THM coupled framework (TOUGH2MP-FLAC3D), which has the ability to simulate single fracture propagation driven by different fracturing fluids in non-isothermal condition. To characterize the fracture network propagation and internal multi fluids behavior in deep geothermal reservoirs, an anisotropic permeability model on the foundation of the continuum anisotropic damage model has been developed and integrated into the popular THM coupled framework (TOUGH2MP-FLAC3D) as well. This model has the potential to simulate the reservoir stimulation and heat extraction based on a CO2-EGS concept. Geothermal Reservoir Engineering offers a comprehensive account of geothermal reservoir engineering and a guide to the state-of-the-art technology, with emphasis on practicality. Topics covered include well completion and warm-up, flow testing, and field monitoring and management. A case study of a geothermal well in New Zealand is also presented. Comprised of 10 chapters, this book opens with an overview of geothermal reservoirs and the development of geothermal reservoir engineering as a discipline. The following chapters focus on conceptual models of geothermal fields; simple models that illustrate some of the processes taking place in geothermal reservoirs under exploitation;

measurements in a well from spudding-in up to first discharge; and flow measurement. The next chapter provides a case history of one well in the Broadlands Geothermal Field in New Zealand, with particular reference to its drilling, measurement, discharge, and data analysis/interpretation. The changes that have occurred in exploited geothermal fields are also reviewed. The final chapter considers three major problems of geothermal reservoir engineering: rapid entry of external cooler water, or return of reinjected water, in fractured reservoirs; the effects of exploitation on natural discharges; and subsidence. This monograph serves as both a text for students and a manual for working professionals in the field of geothermal reservoir engineering. It will also be of interest to engineers and scientists of other disciplines.