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REPORT ON THE EXTENSION OF UNU FELLOWSHIP FOR STUDIES IN RESERVOIR ENGINEERING

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UNU Geothermal Training Programme, Iceland
Report 1980-10

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by

Zosimo F. Sarmiento[+]

1. PURPOSE

The author of this report was given the opportunity to take an additional course in Reservoir Engineering lasting seven weeks after completing the six months course in Borehole Geophysics. This was to further enhance his training in geothermal energy. It was the wish of the Fellow and his superiors as well as the UNU that the Fellow should take an extension course because of his involvement in well testing and reservoir engineering activities back in his home country. He has some practical background in the execution of well testing programs, but requires more familarization with the principles and interpretation of transient well testing.

2. INTRODUCTION OF TRAINING

The course started about one week after the Fellow arrived from one week's excursion to Italian geothermal fields. Initially some matters pertaining to a project in borehole geophysics were attended to such as finalizing the draft of a manuscript. On Oct. 28 the course officially started by doing an independent reading of "Groundwater

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Hydrology and Hydraulics" by Mc Whorter and Sunada (1977) which discusses the main background and principles applied in hydrology. Afterwards approximately 20 problems or exercises given at the end of each chapter were solved and submitted for correction and discussion to the supervisors.

3. SCOPE AND TOPICS COVERED

3.1 Hydrology

A review of the reservoir properties such as rock properties (i.e. porosity, permeability), fluid properties (i.e. density, viscosity) aquifer properties (i.e. storage coefficient, barometric pressure effects, tidal effects) and reservoir characteristics was undertaken before going on with the independent reading. These subjects can be found and are discussed in the lecture notes by Jonas Eliasson, intended for the introductory course at UNU Geothermal Training Programme.

The reading and solving of problems on Groundwater Hydrology and Hydraulics by McWhorter and Sunada (1977) took about 2 weeks from October 28 to Nov. 12. The following problems and topics were dealt with:

Chapter II - Ground water storage and supply

a) porosity

b) storage coefficient definition

c) pore volume compressibility and water compressibility

d) barometric efficiency and tidal effects and its relation to water level fluctuations

Chapter III - Darcy's law and Basic Differential Equation. In this chapter, Darcy's law states that the flowrate Q is proportional to energy loss and inversely proportional to the length of the flowpath. In its simplest form it is expressed as

$$Q = KA\frac{dh}{dz}$$

where Q = flowrate (m^3/s)

K = hydraulic conductivity (m/s)

$\frac{dh}{dz}$ = hydraulic gradient

Aside from the above, included in this chapter are:

(a) the difference between the hydraulic conductivity K and the intrinsic permeability k. The former is a hydrogeologic parameter with a dimension L/T and the latter is a geologic parameter with a dimension L^2. Significance of their use is also emphasized, i.e. using the intrinsic permeability k for two phase flow and non-isothermal flow.

(b) Darcy velocity which is expressed as

$$q = \frac{Q}{A}$$

and seepage velocity V which is expressed as

$$V = \frac{Q}{\phi A}$$

where

Q = flowrate (m^3/s)

A = area

ϕ = porosity

(c) Derivation of the differential equation involving the radial flow of fluid with circular geometry as solved in the exercise (problem 29, p. 108) is one of those topics pertinent to the application of differential equations.

Chapter IV - Steady groundwater hydraulics. Most of the problems solved in this chapter deal with the drawdown in a well at a distance from a producing well discharging at a constant rate. This chapter describes the most important application of transient well testing as the reader is given the techniques and solutions on how to collect and interpret data in a producing field . Long term monitoring of the field and the performance of the well may predict future reservoir performance. Knowledge of the reservoir performance is important for the engineer to be able to control production in a given area.

Special problems encountered with fresh and seawater interference were also solved (exercise no. 36 p. 175). This is a very good example of complex reservoirs. Though the problem is not as elaborate, it exemplifies almost identical conditions to those encountered in Svartsengi regarding a fresh water aquifer.

Chapter V - Unsteady groundwater hydraulics. In this chapter the characteristics of unsteady groundwater flow where the pizometric head changes with time due to pumping are presented.

Theis solution or the line source solution is presented together with methods for estimating the reservoir parameters, transmissivity and storage coefficient. These mehods are also discussed in the lecture notes prepared by Snorri Páll Kjaran on Reservoir Engineering. Jacob´s solution for leaky aquifers provides tools for determining the reservoir parameters in leaky aquifers.

The remaining topic in the book involves the simulation of aquifers using the finite difference technique. Due to limited time this was skipped and instead the actual study on geothermal well testing and reservoir engineering commenced.

4. RESERVOIR ENGINEERING LECTURE NOTES BY SNORRI PÁLL KJARAN

From November 12 to December 3 1980 most of the time was devoted to reading the lecture notes intended for the UNU Geothermal Training Programme. Although they are not fully completed yet, the subjects covered by the author of this report is believed to be very relevant for the study of geothermal reservoir engineering.

The following subjects were dealt with in the text:

4.1 Differential equation for isothermal horizontal flow

Since the principles for the flow of fluids in porous media are based on groundwater hydrology similar conditions are applied in the description of well testing and fluid flows in geothermal reservoirs except when dealing with non-isothermal flows.

In this chapter the boundary and initial conditions required to solve the differential equations by analytical methods are presented.

The basic differential equation or the diffusivity equation expressed as

$$\frac{1}{r} \frac{\partial}{\partial r}\left(r\frac{\partial p}{\partial r}\right) = \frac{\phi \mu C}{K} \frac{\partial p}{\partial t}$$

is discussed in detail.

As mentioned before, solution to this equation is only possible if the boundary and the initial conditions are known. It is thus emphasized here that all equations applied in transient analysis are derived from the above equation.

4.2 Flow behaviour of a producing well

In the course of the study the most relevant topic studied is the pressure behaviour in a producing reservoir. What is meant by this is the characteristics of the pressure profiles within the vicinity of a producing or observation well as well as in other parts of the system when the resource is being depleted. By analysing the pressure decline the resevoir characteristics can be determined.

The response of the reservoir to production can be characterized by the following flow regimes:

A. Infinite reservoir case - In this type the pressure decline around a producing well is not affected by the boundary condition and the reservoir is acting as it were of infinite areal extent. The solution to the equation in this case is called the Theis solution or the exponential integral solution.

B. Transition - It is the behaviour of the reservoir when it can no longer be looked upon as infinite. In the case that the pressure decline has struck impermeable boundaries at some distance from the well, but is still spreading to other sides, the pressure decline would be a straight line with steeper slope than in case A.

C. The pseudo-steady state - This flow regime characterizes the proportionality of pressure decline to time. This is so because at this state, the drawdown has reacted impermeable boundaries all around the producing well and the reservoir is being emptied at a constant rate.

D. The steady state - This is the condition describing a flow regime when the pressure does not drop any more and remains constant with time. Actually the pressure decline has produced a new inflow which is equal to the mass outflow and thus producing steady state conditions.

The above subjects form basis of the study which was conducted through independent reading. Each solution to the basic equation is discussed thoroughly in the lecture notes and will not be repeated here. However, what was done by the author of this report was to read the subjects in the text and later deliver a lecture on the subject. Corrections and further suggestions to the author's understanding were thus brought out in the course of the lecture. This proceeded for about two weeks, Nov. 12 to Nov. 23. Due to limited time it was not continued but the above four topics were completed. Instead, exercises on data collected from actual geothermal fields in Iceland were done.

5. EXERCISE I. SVARTSENGI GEOTHERMAL FIELD

The exercise included the determination of the reservoir parameter like the transmissivity and storage coefficient based on a drawdown measurement in an observation well within the field. The data used was published in Kjaran et al. (1979), Reservoir engineering aspects of Svartsengi. Values for T obtained is .018 m^2/s and .012 for the storage coefficient.

After several years of production, it is found that a semi-steady state condition is obtained. From the semi-steady state part of the drawdown curve the area of the reservoir as well as the geometrical shape was determined. The resulting area of the reservoir corresponds to approximately 15 km^2 with a shape of a very long rectangular trench. In this rectangular trench model the production well is interpreted to be located very near the end of the trench. The result of this analysis coincides with the one presented by Kjaran et al. (1979).

This kind of exercise is important as it demonstrates how the modelling of a geothermal system is done.

6. EXERCISE II. SELFOSS GEOTHERMAL FIELD

The Selfoss geothermal field in Southern Iceland is a low temperature field consisting of a leaky aquifer. The leakage is vertically downwards through a semipermeable layer into the main aquifer as a result of the pressure drawdown during pumping in the main aquifer.

The reservoir parameters T and S are determined using the early transient data taken from well no. 7 while well no. 10 is flowing at 40 l/s. Plot of the drawdown vs log time shows that the curve deviates from the theoretical infinite case curve following as the drawdown becomes steady. Comparison of T and S obtained using the experimental integral solution (using the initial transient data) shows similar values to the values obtained applying the match point method using type curves for non-steady state leaky aquifer.

The transmissivity is found to be $1.88x10^{-4}\overset{2}{m}{}^{2}/s$ and the storage coefficient 2.18×0^{-4}. Then the steady state drawdown in three observation wells in the field were used to determine independent value for the transmissivity But since the three observation wells were approximately at the same distance from the producing wells the analysis was not successful. Instead, the drawdown in the three wells was determined using the above values for S and T.

Now the following problems were solved:
1) Estimating the permeability of the semipermeable layer and the thickness of the main aquifer. 2) The drawdown as a function of time due to multiple flow rates are also solved as well as the drawdown as a function of radius after thirty years of production. 3) The minimum spacing of wells given the depth of the pumps in the well is determined. Assuming the maximum depth of pumps to be 50 meters below the water table, the minimum spacing of wells should be about 95 meters.

Many actual examples of transient pressure and well testing analysis in different geothermal fields are given in the lecture notes.

After these exercises were submitted this progress report was prepared. The nature of this report then is different from the preceding report because no specific project was worked out by the undersigned. And as seen from the exercises the subjects are too broad to discuss in detail.

7. FINAL REMARKS

The outcome of the study is felt to be a rewarding one, as the author was oriented and introduced to the main principles of well testing, in particular to the derivation of the different equations traditionally used in reservoir engineering. This has been of great importance to the author because these subjects are rarely discussed in detail in the existing geothermal literature. In particular to this, the training manual in reservoir engineering prepared by Snorri Páll Kjaran has been very helpful because it provides the necessary imformation required to understand thoroughly the interpretation and analysis of well testing methods in geothermal energy. Without this manuscript, the author could only resort to reading the books or articles used in basic groundwater hydrology and in the petroleum industry, where the matters are treated quite differently.

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ACKNOWLEDGEMENTS

Grateful acknowledgement is due to Professor Jonas Elíasson and Snorri Páll Kjaran, who shared their time, effort and knowledge in making the extension course possible. Their lecture notes and experience formed the core of the study. Further acknowledgement is due to Dr. Ingvar B. Fridleifsson, UNU and PNOC management for their consideration in the writer's extended training.