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Dynamic Modeling of Darajat Field Using Numerical Simulation

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ABSTRACT

A preliminary comparison study of simple vapor dominated reservoir models using TOUGH2 and CHEARS® (ChevronTexaco Extended Application Reservoir Simulator) reservoir simulators was conducted. The purpose of the study was to verify the ability of CHEARS® to simulate a vapor dominated reservoir. CHEARS® was designed to simulate the recovery processes for oil and gas reservoirs. The result showed that both simulators generate similar and consistent responses. Based on this preliminary comparative study, a full field model of the Darajat vapor dominated field in Indonesia has been built.

The numerical model of the Darajat field was constructed based on the detailed reservoir characterization work using earth modeling gOcad® software. A CHEARS® reservoir model was used to simulate the natural state and 10 years of production history from the field. The good agreement between the CHEARS® simulated results and the field data obtained prior to and during the field production, demonstrates the simulator's ability to simulate a vapor dominated geothermal reservoir. The model was used to forecast the field's potential responses based on different field development scenarios.

1. INTRODUCTION

The Darajat Geothermal Field is located in the West Java province of Indonesia, about 150 km south of the Jakarta, capital of Indonesia and 35 km southeast of Bandung, capital city of West Java. Geothermal investigations at Darajat began in the early 1970's, when surface scientific reconnaissance indicated the existence of a vapor dominated reservoir in a similar hydrological setting to the nearby Kamojang Field.

Figure 1: Darajat geothermal field site location

Darajat Unit I with a generating capacity of 55 MW was commissioned for commercial operation in October 1994. Following the successful operation of Unit I, a second unit with a nameplate capacity of 81.3 MW was put on production in June 2000.

A series of numerical simulations have been carried out by GENZL since 1990 by using MULKOM and TOUGH2 simulators, which have been widely used to simulate geothermal reservoirs. The initial model has been modified by taking into account the results of the more recently drill wells. The new wells drilled as a result of 1996-98 drilling campaign have extended considerably the knowledge of the reservoir. In 2002 an improved Darajat numerical simulation study was carried out internally by Amoseas using AUTOUGH2 (The University of Auckland version of TOUGH2) and is based on new a geological model with 18 layers and about 8,000 grid cells. Later in 2003, a detailed reservoir characterization study performed by Amoseas Indonesia and ChevronTexaco Energy Technology Company resulted in a new geologic model which represented the complex geology of the Darajat field. The static model was built using gOcad® software, consisting of more than 9 million cells and run using CHEARS® simulator.

2. GENERIC CONCEPTUAL MODEL OF VAPOR DOMINATED RESERVOIR

Before starting to construct the Darajat dynamic model using CHEARS® a preliminary study, a simple generic model representing a vapor dominated reservoir system was developed, using AUTOUGH2 and CHEARS®. The intension of the study was to investigate the ability of CHEARS® to generate a vapor dominated reservoir, by comparing the natural state responses from both simulators.

Vapor dominated systems are conceptually constructed by a vapor dominated reservoir overlain by a generally low permeability rock, in which heat transfer takes place mainly by conduction. In the main vapor dominated zone, vertical gradients of pressure and temperature are small so that the conductive heat flow is relatively small. Heat transfer in these zones occurs by means of a vapor-liquid counter flow processes, known as a heat pipe. Vapor originates at depth from boiling of liquid and it rises to shallower horizons where it condenses and deposits its large latent heat through vaporization. The condensate then returns to depth driven by gravitational forces (Pruess, et.al,1985).

For this study, a single porosity model with a total vertical depth of 2,700 m and an area of 2 X 3.5 km^2 was assembled representing the reservoir. The model is discrete into 13 layers, with thicknesses varying from 250 m at the top to 200 m at the bottom boundaries. The vertical layers of the model are assumed to be 500 m high, with an area of 500 X 400 m square (Figure 2). A spring serves as a natural discharge at a constant rate of +/- 30 kg/s was created at the top of the reservoir. The rate is consistent compared to estimated natural discharge at vapor dominated geothermal fields.

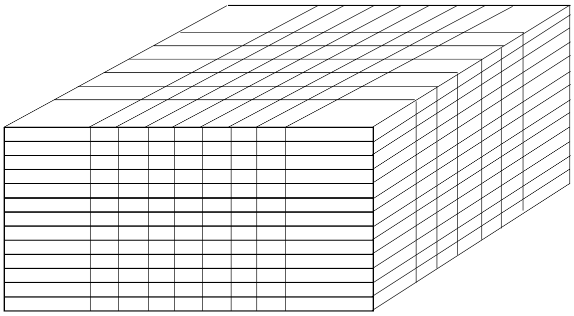

Figure 2: A simple model of vapor dominated reservoir

2.1. AUTOUGH2 dynamic model

The AUTOUGH2 dynamic model was initially developed as a single liquid system in gravitational equilibrium with all boundaries impermeable to fluid flow. A uniform heat flux was imposed at the second bottom layer, while heat loss is allowed through the upper boundary, a cap-rock, via conduction. For relative permeabilities, Corey's curve (1954) was chosen, whereas linear capillary functions were employed in the analysis. The following parameters were held constant in all simulations performed: porosity of 10%, rock density of 2,500 kg/m3, rock grain specific heat of 1,000 J/kg ^{O}C, formation heat conductivity of 2.5 W/m ^{O}C, and initial liquid saturation of 44%.

To evolve a vapor dominated system, constant pressure and saturation boundaries were imposed at the bottom boundary of the model. The constant pressure and saturation boundaries were represented by the large cells volumes imposed at the bottom boundary. A steady state was approached within a few thousand years, in which pressure, temperature, and saturation profiles revealed no changes and developed a steam reservoir. To achieve a "best fit", the model was tuned by varying the permeabilities and deliverability parameters.

2.2. CHEARS® dynamic model

A dynamic model with similar geometry construction to the AUTOUGH2 model was built on the CHEARS® simulator. Since CHEARS® is designed to simulate the recovery processes of a hydrocarbon reservoir (oil and gas) under primary and enhanced recovery process, a special data input manipulation was made in order to satisfy CHEARS® requirements, Thus, the vapor dominated model built on the CHEARS® platform could be run.

A thermal compositional CHEARS® module was chosen to construct a vapor dominated dynamic model. Three phase relative permeability curves were used by setting a very low value for residual oil saturation to keep oil immobile. All rock properties are similar to the AUTOUGH2 model. To replace mass production by surface manifestation during pre-exploitation time, a mass and heat injector well was put at the base of the model, in addition to the constant pressure and saturation boundaries imposed at the bottom of the model. The model was initially saturated with a liquid phase and run up to a few thousand years before reaching a nearly steady state fluid and heat equilibrium in which pressure and temperature gradients inside the reservoir exhibited a vapor dominated profile.

Figure 3 shows the pressure, temperature and liquid saturation profiles of both AUTOUGH2 and CHEARS® models respectively. In general, the similar model response between AUTOUGH2 and CHEARS® demonstrated the ability of CHEARS® to simulate the natural state of a vapor dominated reservoir.

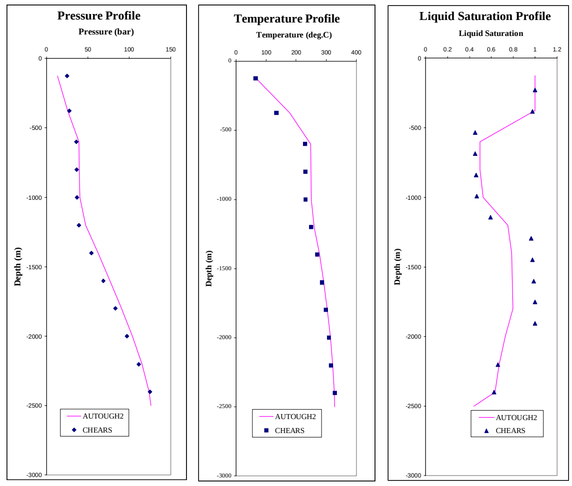

Figure 3: Pressure temperature and saturation profiles.

3. DARAJAT DYNAMIC MODEL

3.1 Static model description

The static model, the result of detailed reservoir characterization work, represented the complex geology of the Darajat field. The model consists of 9,363,456 cells (144 X 127 X 512). The number of cells residing inside the reservoir boundaries varies from 1,233,560 to 1,847,544 dependent upon the location of the reservoir top. The top of the model is at 1,279 masl. Drilling data to date has yet to delineate the reservoir bottom and the deepest well encountered productive zones at its TD at around -1,000 masl. Recent micro-earthquake (MEQ) data collected at Darajat showed seismic events occurring deeper than -4,000 masl. In the absence of any definitive information on the reservoir bottom, the reservoir bottom was placed at -3,000. The core derived porosity, the facies distribution, and the petrophysical characteristics served as the basis for the porosity distribution in the static models. The model's fracture density distributions and observed fracture versus elevation trends were derived from the individual wells' Schlumberger Formation Micro Scanner (FMS) logs. However, the correlation length was very limited,, due to the broad well spacing within the reservoir. Therefore, the static models employed a geostatistical distribution technique, (e.g., Gaussian, stochastic simulations, and kriging) to populate the fracture density and other reservoir data in the reservoir regions between and at depths greater than the wells', total depths.

Well test and production log (PLT) data offered other valuable sources of information for the model building. Results of the field interference testing showed a strong level of connectivity between many wells and were very useful in guiding the assigned level of connectivity of different regions in the model. The well test data, PLT, and two permeability-fracture density transforms gave a fracture permeability distribution for the model. This initial permeability distribution provided a starting point for the model construction and would be used later as a history matching parameter in the dynamic model calibration

3.2 Model scale up

In order to construct the dynamic models for the Darajat field, a ChevronTexaco flux-based scale-up process (Durlofsky, et al, 1996) was used to reduce the size of the static model to a more manageable level. The main purposes of the scale-up were to:

1. Preserve the important characteristics of the geologic models.

2. Mimic the flow performance of the original fine grid.

3. Enable the model to run efficiently in a multi-phase flow simulation.

The number of active cells of the scaled up model was kept below 100,000 considering the potentially long turn over time for thermal models and natural state simulation times. To facilitate the scale up process, the gOcad® geostatistics software package was used.

The original x and y direction has been scaled up from 144 X 127 to 62 X 53 grids respectively. Each grid block of the fine model has the areal dimensions of 50 m x 50 m. In vertical direction the layer thickness of the original models varies from 2 m in the upper part of the model to up to 1000 m for the bottom layer, with a total number of 512 layers. These 512 layers are scaled up and reduced to 58 layers. The final dynamic model has a dimension of 60 X 53 X 58 grids with 184,440 cells, a 50 times reduction from the 9.36 million cells of the fine grid model.

3.3 Model construction

The Darajat reservoir simulation model was constructed as a single porosity model and used a range of pseudo relative permeability to mimic the vapor and liquid water flows in the fracture networks. The lateral boundaries of the reservoir are impermeable to fluid flow. The model upper boundary represents a tight cap rock with a constant temperature. A constant pressure and constant saturation boundary were imposed at the bottom layer of the model. In addition, a limited fluid recharge in the layer above the model bottom layer, away from the current production interval, was applied to make up for some of the surface discharge.

The model was initialized with two phase fluid, water and vapor, at the temperature of + 245° C to speed up the natural state equilibrium. The initial liquid saturation (swi) was near irreducible levels (swir) and varied from 30% to 90% in various models for uncertainty analysis.

3.4 Model calibration

The first step in the Darajat dynamic model calibration process was to simulate the natural state and refine the model to match the model output with the measured pressure and temperature gradients. The model was run up to a few thousand years or until the pressure, temperature, and saturation profiles reached a pseudo steady state (dynamic equilibrium). The result of the dynamic equilibrium was then used as an initial condition for production history matching. During history matching, some local adjustments to the permeability and porosity were required to calibrate the model with production history.

3.4.1 Natural state simulation

Figure 4 shows a vertical pressure gradient plot comparing the natural state simulated pressures with the measured pressures for nine wells. These measured pressures were the shut-in pressures taken at individual wells' main feed zone at various locations in the field. Since the production of Unit I had no or very little effects on the pressures at DRJ-14, DRJ-19, DRJ-20, and DRJ-21, the pressure of these wells were projected back to the pre-exploitation period (prior to October 1994) and included in the plot. The inclusion of the information at these four wells provided a better calibration of the natural state model in the north and southwest corners of the field, as well as at greater depths.

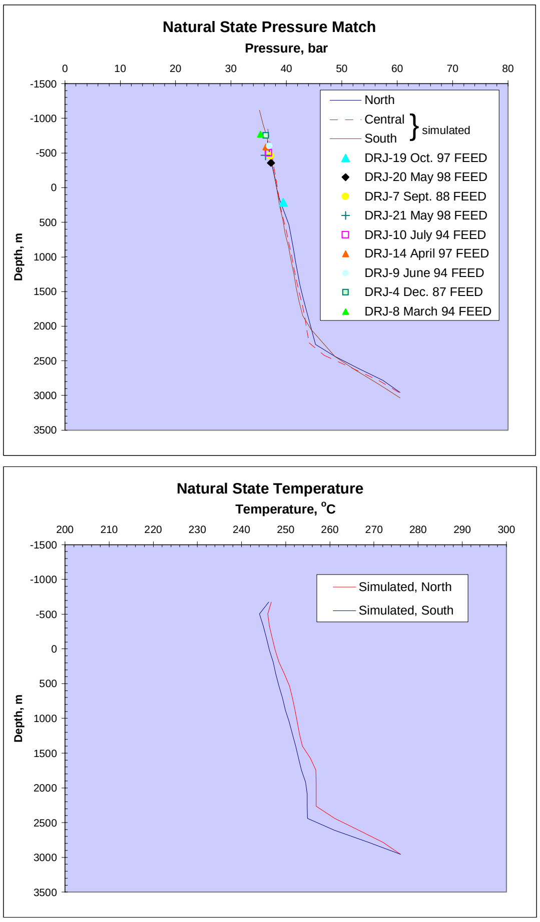

Figure 4: Natural state pressure temperature match

3.4.2 Production history matching

Darajat Unit I, with a capacity of 55 MWe, marked the field's first commercial operation in October 1994. The unit requires an average production rate of 100 kg/s water vapor. A second unit of about 90 MWe put on line in June 2000, raising the total field production rate to 252 kg/s of steam. As of December 2003, the field has produced 46,529,444 tons of steam and produced 6,458.289 GWhrs of electricity, which represents about 4% of mass in place. Condensed steam and surface water re-injection stands at 12,699,567 tons. The nine plus years of production history was used to calibrate the model.

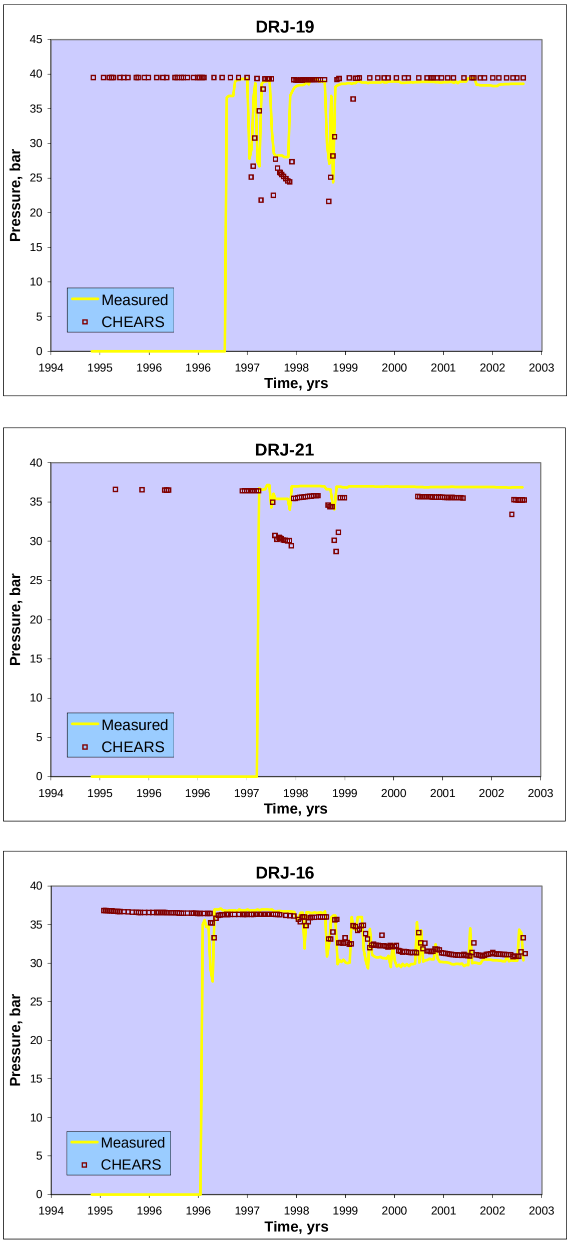

Figure 5: North wells pressure match

The matched natural state model's saturation, pressure, and temperature distributions served as the initial conditions for the field's production history matching. The model refinement and calibration required some adjustments to the local permeability structure and porosity distribution. A good match for most of the wells' pressure drawdown and decline trends responding to the production were obtained. Currently, there are 16 active and four standby wells with pressure data available for the history matching.

Figure 5 and 6 shows some typical comparisons between the simulated and measured pressures. The overall good agreement between the simulated and measured data at individual wells and the field wide levels validate these dynamic models and provide confidence for the performance projections.

It was necessary to re-checked for model consistency, by making sure that after all the modifications the history-matched model could still reproduce the calibrated natural state conditions.

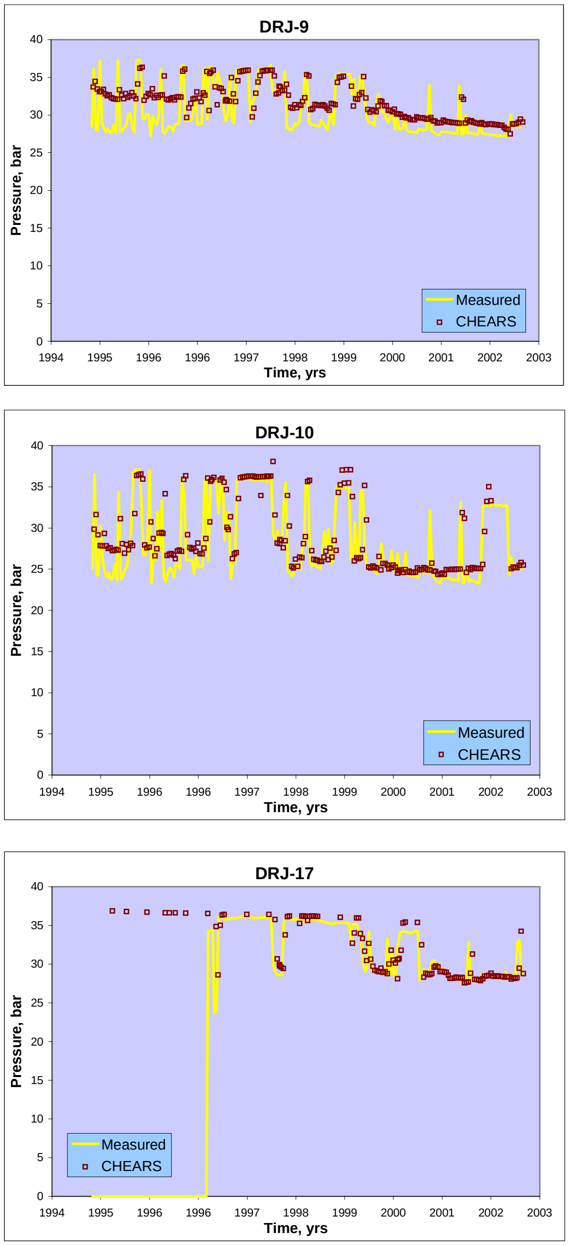

Figure 6: Central wells pressure match

4. CONCLUSION

CHEARS® simulator is able to simulate a recovery process of vapor dominated geothermal reservoir. A dynamic model of Darajat geothermal reservoir based on detailed reservoir characterization work was successfully built, calibrated and validated using CHEARS® simulator. This model was then used to estimate the generating capacity for different field development scenario.

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REFERENCES

Durlofsky, L.J., Jones, R.C., Behrens, R.A., and Milliken, W.J.: Scale Up of Heterogeneous Three Dimensional Reservoir Descriptions, SPE Journal, Vol.1, (1996).

Grant, M. A., Donaldson, I.G., and Bixley, P.F. Geothermal Reservoir Engineering, Academic Press, 1982.

Grant, M. A.: Water content of the Kawah Kamojang geothermal reservoir, Geothermic, Vol. 8, (1979).

Hoang, Viet, and Alamsyah, Ontowiryo,: Darajat Geothermal Reservoir Simulation Study (Internal report, Amoseas Indonesia Inc.), (2004).

McGuinness, M.J., Blakeley, M., Pruess, K., and O'Sullivan, M.J.: Geothermal heat pipe stability: solution selection by upstreaming and boundary conditions, Transport in Porous Media 11, (1993).

Mueller, S. Melnik, O., Spieler, O., Scheu, B., and Dingwell, D.B.: Permeability of Volcanic Rocks-Experimental Data and Modeling, Geophsical Research Abstracts, Vol. 5, 06326, (2003).

Oki D. S., Gingerich S. B, and Whitehead R.L: Hawaii Volcanic-rock aquifers, USGS Ground Water Atlas of the U.S., Alaska, Hawaii, Puerto Rico and the U.S. Virgin Islands, (1999).

O'Sullivan, M.J., Barnett, B.G., and Razali, M.Y.: Numerical Simulation of the Kamojang Geothermal Field, Indonesia, Geothermal Resources Council Transactions, Vol. 14, Part II, (1990).

O'Sullivan, M.J., Pruess, K., and Lippmann, M.J.: State of the art of geothermal reservoir simulation, Geothermics 30, (2001).

Pruess, K., and Narasimhan, T.N.: On Fluid Reserves and the Production of Superheated Steam from Fractured, Vapor-Dominated Geothermal Reservoirs, Journal of Geophysical Research, Vol. 87, (1982).

Pruess, K.: A quantitative Model of Vapor Dominated Geothermal Reservoirs as Heat Pipes in Fractured Porous Rock, Geothermal Resources Council Transactions, Vol. 9, (1985).

Pruess, K., Celati, R., Calore, C., and Cappetti, G.: On Fluid and Heat Transfer in Deep Zones of vapor Dominated Geothermal Reservoirs, Proceedings, Twelfth Workshop on Geothermal Reservoir Engineering, Stanford University, (1987), 89-96.

Pestov, I.: Modelling Studies of The Evolution of Vapor Dominated Geothermal Systems, Proceeding seventeenth N.Z.Geothermal Worshop, Auckland, (1995), 199-204.