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Utilization of Reservoir Proxy Model for Development Strategy Optimization of Combined Steam Flooding & Cyclic Steam Stimulation for Enhanced Heavy Oil Recovery

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Abstract

Steam flooding (SF) and Cyclic Steam Stimulation (CSS) are thermal recovery methods that had been proven to improve oil recovery from heavy oil reservoir. Our previous work shows that the combination of CSS and SF give the better result than solely CSS or SF. However, the optimum operating parameter of this combination is yet to be determined. Our current work aims to determine the optimum development scenario of a combined CSS-SF applied to X-Field, a heavy oil field located in Sumatera, Indonesia. A polynomial proxy model is developed to evaluate the objective function, by running several simulations for the field subsurface model using CMG-STARS simulator and CMOS to assist multiple simulations. Optimum development scenario is obtained through maximization of objective function. This work shows that the combination of proxy model development and optimization results in best scenario of combined CSS-SF for heavy oil recovery in X-Field.

Keywords: combined cyclic steam stimulation-steam flooding, proxy model, heavy oil reservoir

I. INTRODUCTION

The production of heavy oil reservoir came with several problems, such as low production rate and recovery due to high viscosity fluid. To produce high viscosity oil, a thermal recovery method is used. The steam flooding is a thermal recovery method that is applied by injecting the hot steam into reservoir through an injection well. The success of a steam flooding project is largerly determined by the steam distribution in the reservoir. Especially, in the area adjacent to a production well, where the steam temperature has already low or it has condensed. Therefore, it will generate a still-viscous-oil zone around the production well and tend to lower the production. Cyclic steam stimulation, another thermal method, is used to overcome the problem. The periodic injection of steam in the production well will assist the oil production and therefore increase the overall recovery of a steam flooding project.

The accomplishment of a thermal recovery project is determined by the development scenario, thermal property of reservoir, residual oil saturation, reservoir heterogeneity, oil viscosity, and well spacing. A thermal recovery method is a high investment project. However, it has proven to

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increase the recovery of heavy oil reservoir. Consequently, a robust yet fast prediction tools is required to optimize its overall performance.

This work put emphasize at the optimization of combined steam flooding and cyclic steam stimulation to increase the recovery of heavy oil field. To achieve this objective, a proxy model of a five-spot pattern steam injection is built based on a sensitivity analysis toward some of main parameters that affect the performance of combined steam flood-cyclic steam process. Afterwards, the model is utilized to design the development strategy to obtain the maximum performance in term of recovery factor or project NPV. Previous work by applying this workflow had been conducted for a hypothetical reservoir model with a homogeneous properties (Swadesi *et al.*, 2020). In this work, a model that is built and evaluated is based on an actual field data of an X-field, a Sumateran heavy oil field, by considering its property distribution and heterogeneity. Therefore, this work would give a more accurate insight toward the implementation of development strategy optimization in an actual heavy oil field project.

II. LITERATURE REVIEW

Steam Stimulation and Steam Flooding

Steam injection is an EOR (enhanced oil recovery) method that is conducted by injecting a portion of steam into the reservoir. It is mainly used for heavy oil reservoir with its objective to lower the oil viscosity and thus make it easier to flow into the wellbore. Steam injection can be conducted by two methods, cyclic steam stimulation (CSS) and steam flooding (Temizel *et al.*, 2016). The introduction of hot steam will contribute to several processes such as viscosity reduction, wettability change, gas expansion, etc. (Alvarez and Han, 2013). Several parameters that must be considered during the application steam injection are: oil gravity, oil viscosity, remaining oil saturation, formation thickness, average permeability, and reservoir depth.

Early development of steam flooding was performed by Shell by doing steam drive pilot project in several fields in Netherland and Venezuela during 1960's. On the other hand, the CSS process was invented by accident, also by Shell during steam drive pilot project ini Mene Grande field (Venezuela). When there was a steam breakthrough to the surface, the injection well was shut in. After the injection well was put online, there was a significant amount of oil flow to surface (Matthews, 1986). After that, most of early steam injection project was done by cyclic method, due to lower steam consumption compared to continuous steam injection.

The steam flooding process has lower thermal efficiency due to most of the heat will get lost into adjacent formation in the reservoir. It also needs larger volume of steam. However, it will give higher recovery factor approaching 50% or more. Meanwhile, the CSS required lower steam consumption and higher thermal efficiency, but it will have lower recovery factor (about 15%) due to rapid production decline after well put on production (Butler, 1991).

In the steam flooding process, steam is injected from the injection well to heat and push the oil into the production well around it. The formation will be heated to steam saturation temperature. The temperature distribution inside the formation is affected by the heat transfer coefficient of rock and fluid in the reservoir and adjacent rock layer. Several phases exist in the reservoir during steam flooding, that is closely related to the temperature distribution. In the adjacent of injection well, temperature is higher and steam quality is still high. At the distance further from injection well, when steam get saturated, some of steam will condensed and the hot water phase appear. The heat that transferred to the oil vaporizes some of its light hydrocarbon component. The oil exposed to high temperature will have lower viscosity and thus easier to flow and form an oil bank in the injection form. Several operating factors affecting the recovery factor of steam flooding project are: well spacing, steam-oil ratio, injection rate, and perforation strategy (Srochviksit and Maneeintr, 2016).

The CSS process is run by several stages, steam injection, soaking, and production process. During the steam injection and soaking, heat from steam is transferred to the fluid and rock in the formation. After several days or week, the oil viscosity and mobility will get improved, and the oil production will increase. After the production decline, the process is started all over again in a cyclic manner. The production and recovery from CSS is affected by shut in-production period, steam quality, and injection volume.

The simplified diagram to explain both mechanisms is shown in **Figure 1**.

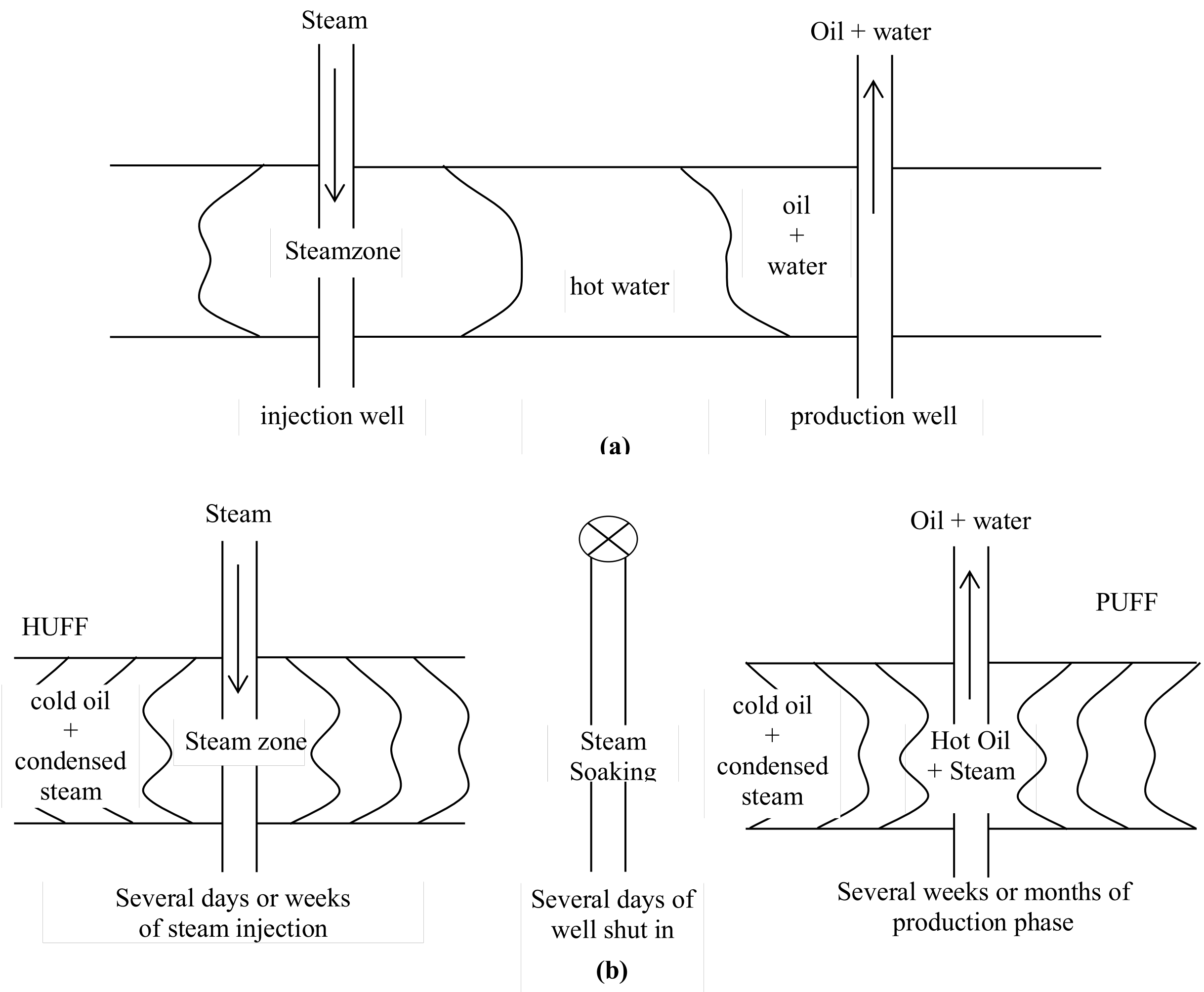

Figure 1 (a) Steam flooding (b) Cyclic Steam Stimulation mechanism

Proxy Model

Due to high cost of steam generation, the economic parameter should be considered during the optimization of steam injection development scenario. To evaluate the overall economic feasibility of the project, a modeling approach that capable of quantify all the affecting parameter of the process is required. This modeling also must consider the uncertainty and risk, related with the reservoir properties.

An optimization algorithm that based on genetic algorithm is very robust, however it take a lot of time and computational resources to do. A proxy model had been used to replace this optimization algorithm by sampling sufficient amount of that cover the range of possible parameter.

Proxy model in the reservoir engineering field can be defined as a function that is generated based on mathematical or statistical analysis of the data that can replicate the input-output relationship produced by reservoir simulation. There are several method to generate a proxy model, such as polynomial, artificial neural network, multivariate kriging, etc (Panjalizadeh, Alizadeh and Mashhadi, 2014). Proposed approach for proxy model application in development optimization are as follows:

1. Objective function and parameter definition;
2. Sensitivity analysis;
3. Sampling and Proxy Model construction;
4. Optimization algorithm.

In this work, polynomial regression will be used as proxy model. This method has several advantages such as: more simple, flexible, and computational efficient. However, this method gives a poor performance for highly nonlinear multidimensional spaces. The general quadratic polynomial regression model can be in the form of the following equations (Zubarev, 2009):

$$y(x) = \beta_0 + \sum_{i=1}^{nd} \beta_i x_i + \sum_{i=1}^{nd} \sum_{\substack{j=1 \\ j>i}}^{nd} \beta_{ij} x_i x_j + \sum_{i=1}^{nd} \beta_{ii} x_i^2$$

For higher order polynomial, the equation used for proxy model development can be derived from following form:

$$y(x) = (\alpha + \sum_{i} \beta_i x_i)^n$$

where α and β as a constant that after derivation become the regression parameter.

Proxy model is constructed by performing regression, i.e. selecting the regression parameter that minimize the error between the objective function obtained from experiment (in this work by running a simulation) and objective function calculated using above polynomial equation (in above equation is $y(x)$)

III. RESEARCH METHODOLOGY

Methods

This research is first started by collecting field data and then a reservoir simulation model is constructed. The simulation of this model becomes the sampling tools in the development of proxy models. The proxy model development scenario is performed by refer to the work by (Zubarev, 2009) in the following diagram

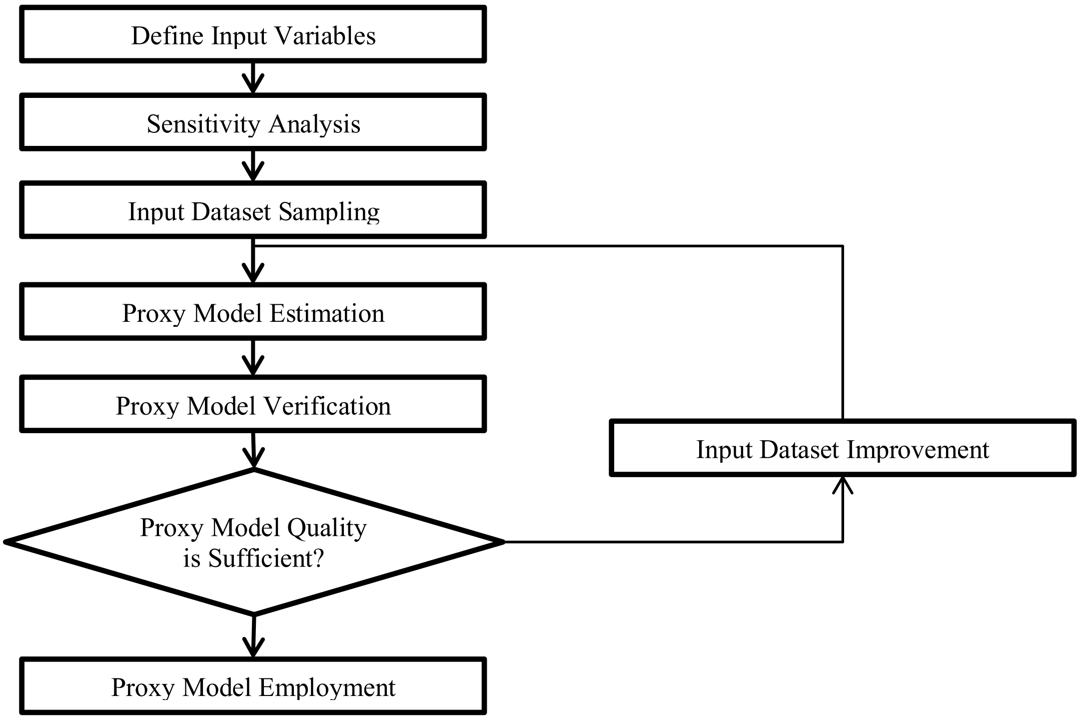

Figure 2 Proxy Model Development Workflow

The parameter to be investigated in this study is categorized as follow:

1) Given parameters: Reservoir & fluid property (*k*, μ_o, *PV*, S_o, *T*, rock & fluid heat capacity)
2) Controlled parameters: Injection strategy (Qinj, steam quality,well schedule & spacing)
3) Economic parameters: Oil price, steam generation cost, well cost.

Several proposed parameters then selected by running sensitivity study so that the proxy model dimension is simpler, and therefore avoid an exhaustive simulation running.

The parameter sampling is designed to cover the parameter range required for proxy model construction. Based on this parameter combination, a simulation is run to obtain the value of objective function. Then a polynomial regression is done to get the polynomial coefficient for proxy model.

The proxy model quality assessment is done by a technique called blind testing. A simulation is run for the parameter outside the previous sampling. Then the objective function resulted from simulation is compared to the objective function calculated by current proxy model. If the error is still significant, then the simulation result used for the blind testing is included for improvement of the proxy model.

After the proxy model quality is sufficient, an optimization method is used to obtain the optimum development scenario. A multivariateoptimization method can be used, such as steepest ascent, conjugate gradient, and Newton method (Chapra and Canale, 2015).

IV. FINDING AND DISCUSSION

Reservoir Modeling

The X-field that become the object for this study is a heavy oil field located in Sumatera. Reservoir depth is about 120 – 600 ft. The contour map of the reservoir is shown in Figure 3.

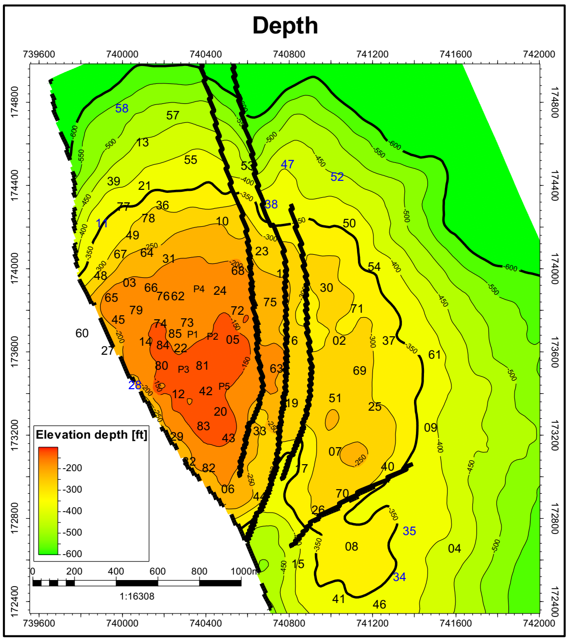

Figure 3 Depth Structure Map of Studied Reservoir

For current study, a 5-spot pattern is selected based on well location in the crestal area of the structure. The reservoir model is displayed in **Figure 4**.

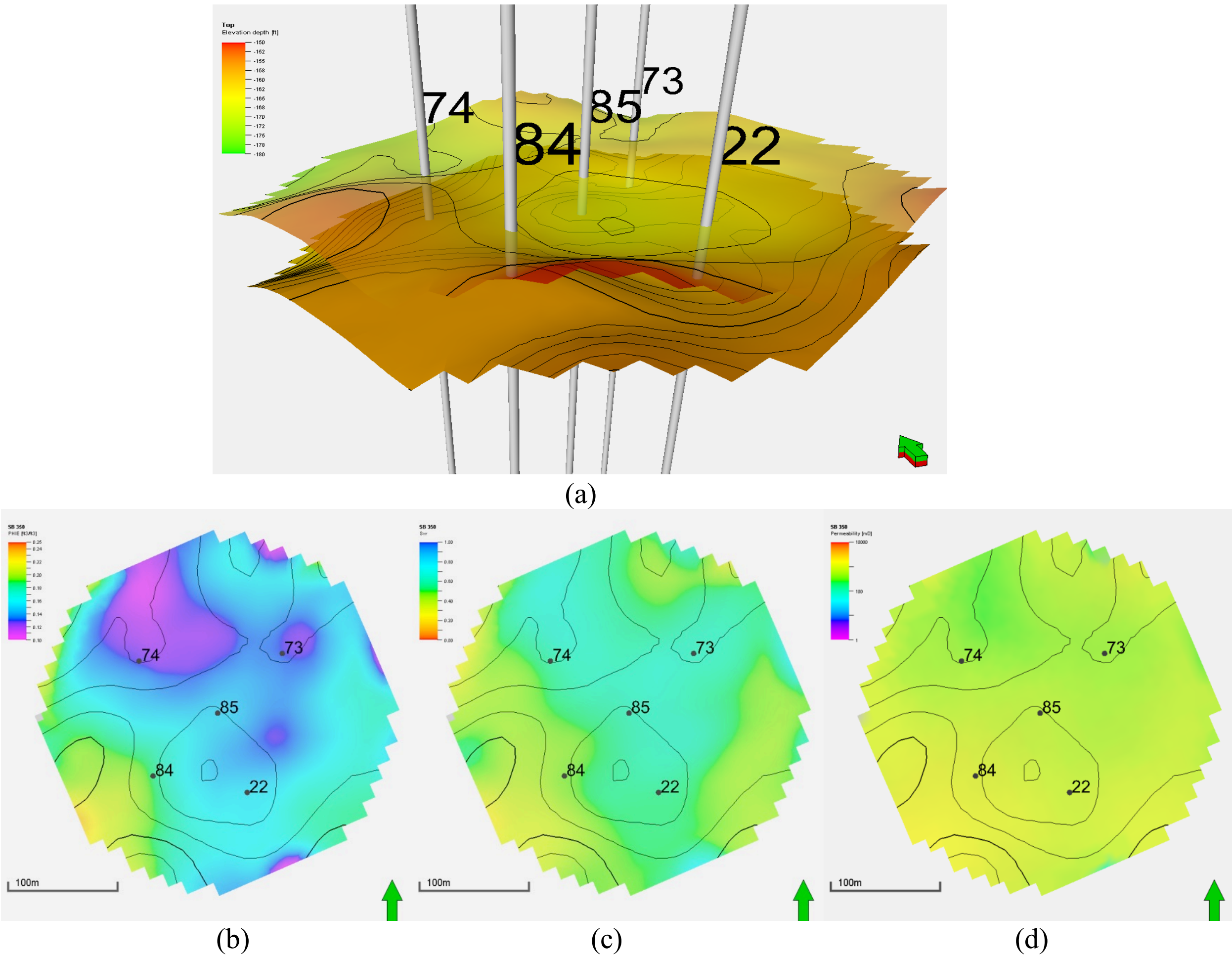

Figure 4 Reservoir Model of Zone D-350 (a) Depth structure (b) Porosity Map (c) Sw map (d) Permeability Map

The oil produced from the X-field is characterized as heavy oil with 20 °API gravity with more than 500 cp in viscosity. Initial reservoir pressure is about 58-79 psi, and ther initial reservoir temperature about 135 °F. The field had been producing since 1970's with cumulative production of 21 MMSTB.

a. Sensitivity Analysis
b. Proxy Model Construction
c. Optimization

V.CONCLUSION AND FURTHER RESEARCH

The main conclusions of the study may be presented in a short Conclusions section, which may stand alone or form a subsection of a Discussion or Results and Discussion section. The conclusion section should lead the reader to important matter of the paper. It also can be followed by suggestion or recommendation related to further research. Limitation and contribution of research should be addressed in this section.

REFERENCES

Alvarez, J. and Han, S. (2013) 'Current Overview of Cyclic Steam Injection Process', *Journal of Petroleum Science Research*. doi: 10.1190/1.1444903.

Butler, R. M. (1991) *Thermal Recovery of Oil and Bitumen*. Prentice Hall.

Chapra, S. C. and Canale, R. P. (2015) *Numerical Methods for Engineers 7th edition*, *Numerical Methods for Engineers, Second Edition*. McGraw-Hill. doi: 10.1201/9781420010244.

Matthews, C. S. (1986) 'STEAMFLOODING.', in *Society of Petroleum Engineers of AIME, (Paper) SPE*.

Panjalizadeh, H., Alizadeh, N. and Mashhadi, H. (2014) 'A workflow for risk analysis and optimization of steam flooding scenario using static and dynamic proxy models', *Journal of Petroleum Science and Engineering*. doi: 10.1016/j.petrol.2014.06.010.

Srochviksit, S. and Maneeintr, K. (2016) 'Simulation on Heavy Oil Production from Steam-Flooding', in *MATEC Web of Conferences*. doi: 10.1051/matecconf/20166807002.

Swadesi, B. *et al.* (2020) 'Simulasi Reservoir Heavy Oil dengan Multistaging Development Modifikasi Inverted 5-Spot Kombinasi Cyclic Steam Stimulation (CSS) dan Steamflooding', in *Prosiding Seminar Nasional Teknik Kimia "Kejuangan" 2020*. Jurusan Teknik Kimia UPN 'Veteran' Yogyakarta. Available at: http://jurnal.upnyk.ac.id/index.php/kejuangan/article/view/3598.

Temizel, C. *et al.* (2016) 'Optimization of Steamflooding heavy oil reservoirs under uncertainty', in *Society of Petroleum Engineers - SPE Asia Pacific Oil and Gas Conference and Exhibition 2016*. doi: 10.2118/182190-ms.

Zubarev, D. I. (2009) 'Pros and cons of applying proxy-models as a substitute for full reservoir simulations', in *Proceedings - SPE Annual Technical Conference and Exhibition*. doi: 10.2118/124815-ms.