

STUDY ON INCREASING PRODUCTION AND POTENTIAL OF KHORAT SAND GAS USING FRACTURING AND COMPUTER SIMULATION

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Abstract

The objectives of this research are to 1) evaluate the potential and risks in the petroleum reserve of a gas field using SPE/AAPG/WPG basis and Monte Carlo Method, 2) study of hydraulic fracturing (HF) and simulation model using computer program, evaluate production efficiency 3) study the development of gas reservoir in tight sand and compare the gas flow rate before and after hydraulic fracturing by using PKN model, and 4) evaluate risks in investment for hydraulic fracturing method and petroleum production using a computer program. The study is based on 6 US\$/MMBTU of natural gas prices. The assessment indicated the most likely probability to find the small gas field with the reserve of 150 Bcf (billion cu.ft.). The Khorat sand gas fields, will need to be fracked with HF when the IRR is less than 10%. In the NE Thailand and Thai III, before HF the Khorat sand gas field starts production of 11 MMSCF/day and lasts for the first year then declines to end at 5.2 MMSCF/day in the 20th year with the total production of 55.82 MMMSCF, IRR of 4.11%. After 1500 barrels of fluid HF, the gas field starts production of 25 MMSCF/day and lasts to 1 year then declines to end at 5.5 MMSCF/day with the recovery of 93.14 MMMSCF, IRR of 24.23%.

Keywords: Gas fields reserve, hydraulic fracture, production efficiency, reservoir simulation, petroleum economics

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Introduction

At present, the demand for petroleum in Thailand is increasing to 1,800,000 barrels of oil equivalent per day of which the indigenous petroleum production accounts for about 50%. Petroleum exploration and development in Thailand must be activated in order to increase the indigenous petroleum supply and lower petroleum imports. Therefore, the Thai government should encourage oil companies to explore for new petroleum fields and increase recovery from the existing petroleum fields, especially in the northeast (NE). A petroleum potential assessment in the area should be done to

promote the activities. The evaluation of undiscovered and discovered resources with a risk assessment will be necessary. The most likely future discoveries in the Khorat sand gas fields should be evaluated with value added to make them capable of economic development. The utilization of natural gas for power generation in the NE of Thailand is not the most advantageous since the country can import much cheaper electricity from Laos. The most value added indigenous natural gas should replace the expensive, imported liquefied natural gas for natural gas vehicles

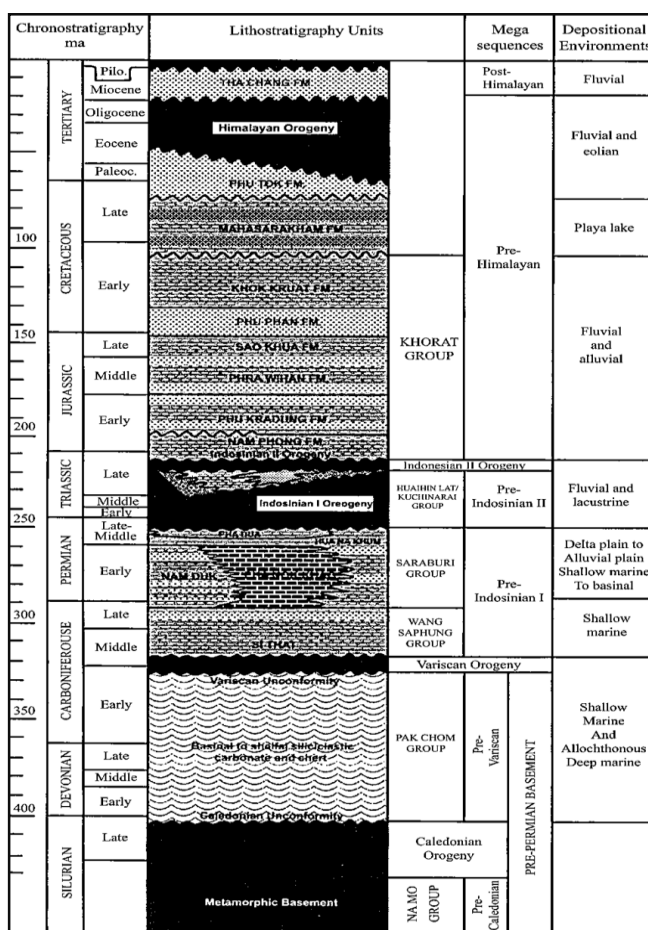


Figure 1. Stratigraphy of Khorat Plateau (Sattayarak, 2005)

(NGV) (Kriangkrai and Akkhapun, 2015). This research includes (1) compiling petroleum exploration and production information in the NE; (2) developing software for potential petroleum assessment using the Monte Carlo simulation for maximum success probability (MSP); the petroleum economic software is developed to consider the expected monetary value P50, rate of return, present profit to investment ratio, and sensitivity analysis; (3) calculating and comparing gas in place using the FASPU and MSP programs; (4) determine the reserve, hydraulic fracturing, and production of the Khorat sand gas fields using reservoir simulation; and (5) developing the petroleum economic software to evaluate the expected monetary value P50, rate of return, present profit to investment ratio, and sensitivity analysis.

Methodology

Compiling Petroleum Exploration and Development in NE Thailand

Petroleum exploration in the Khorat Plateau began in 1962, when Union Oil Company of California, the first international oil company in Thailand was awarded a permit to explore for petroleum in NE Thailand under the country's mining laws. The first exploration well in the Khorat Plateau, Kuchinarai-1, was drilled by Union Oil Company in 1971 and resulted in a dry well. The second phase of exploration started in 1979, and Esso Khorat Inc. drilled the first well Namphong-1 in 1981, and 28 million cubic feet of dry gas per day was encountered from fractured Permian carbonate; the Nam Phong gas field is still in production. From 1982-1990, 12 more wells were drilled by Esso, of which the Phu Horm gas field was under appraisal by Amerada Hess. Significant gas flow from Dong Mun-1 was recognized, but no significant discovery was recognized at the others and all were mostly dry (Kriangkrai, 1995, 2005).

The third, fourth, and fifth phases of exploration began in 1991 due to discovery of the Triassic lacustrine sequence between the Permian and the Khorat strata. Many exploratory

wells were drilled but no significant reserves were discovered (Kriangkrai, 1995, 2005). Amerada Hess has resumed production at Sinphuhorm gas field since 2002; the company drilled PH3, PH4, PH5, PH6, PH7, and PH10, but only 4 wells are productive. Apico (Khorat) drilled DM3 and SPH1 in 2008, and ST3 in 2009, and now owns the production area in this field and entered into production in 2012 (Kriangkrai, 2011).

The last round of petroleum exploration drilling and development began in 2007 when many concession blocks were awarded in the NE. After the 19th and 20th concession bidding rounds, a few oil companies, such as Apico (Khorat), PTTEP International, Salamander Energy, TPI Polene Power, and Shaanxi Yanchang Petroleum, are exploring for petroleum in the NE area. Up to now, there are about 57 exploratory wells that have been drilled in the NE. The Korat plateau stratigraphic sequence is recognized as in Figure 1 (Kriangkrai and Akkhapun, 2011, 2015).

Guidelines for Risk Assessment of Petroleum Prospect

The Coordinating Committee for Coastal and Offshore Geoscience Programmes in East and Southeast Asia's (CCOP) Guidelines for Risk Assessment of Petroleum Prospects was applied to evaluate the probability occurrences of geological features. Geochronological risk assessment is achieved by evaluating the relevant geological processes and events in a logical time sequence. The geological process starts with the deposition of the reservoir rock, and continues with the formation of a sealed trap. We must consider the source rock's maturation, the migration of hydrocarbons from the mature source rock into the trap, the accumulation of hydrocarbons in the trap, and finally the post-accumulation history of the trap and its hydrocarbons. In prospect evaluation, a prospect is identified and mapped on the basis of geophysical and geological data. The prospect's resource potential in a successful case is calculated using suitable software employing the Monte-Carlo simulation, stochastic methods, or some other form of calculation. Quantitative data for the prospect is derived

from the most likely geological model and is given with a range of uncertainty (Figure 2). Risk is assigned to the probability of discovery of a minimum volume derived from the volumetric estimate, and is evaluated with respect to the geological risk. The reliability of the prospect definition will depend on the adequacy of the database and on the choice of reliable models for the relevant geological factors. Risk assessment is therefore an analysis of the reliability of the database and of the probability of occurrence of the geological models relevant to the prospect under evaluation. For each prospect a value of probability of discovery is estimated (CCOP, 2000).

Khorat Sand Gas Field Model Simulations

The Khorat sand gas field represents the largest gas reservoirs in NE Thailand with gas in place of 150 MMMSCF. Each reservoir has been modeled both monocline (Figure 3) and anticline. The model consists of 50×50 grid

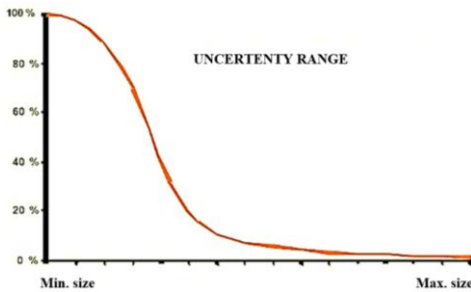


Figure 2. Cumulative frequency diagram showing range of uncertainty. (CCOP, 2000)

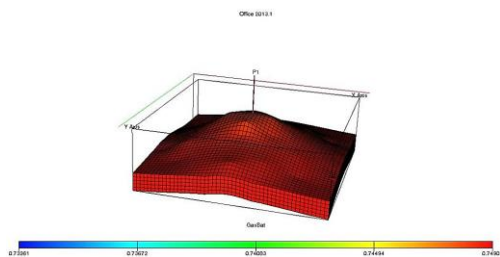


Figure 3. Gas saturation in Khorat sand gas field Model

blocks in the area view and with 5 layers totalling 12500 blocks, as shown in Figure 5.

Hydraulic Fracturing (HF), the PKN Model, and Hydraulic Fracturing Pattern

Hydraulic Fracturing (HF) and the PKN Model

Two-dimensional models are closed-form analytical approximations assuming a constant and known fracture height. For a fracture length much larger than the fracture height ($x_f \gg h_f$), the Perkins and Kern and Nordgren or PKN model is an appropriate approximation (Perkins and Kern, 1961; Nordgren, 1972).

The PKN model is depicted in Figure 4 and has an elliptical shape at the wellbore. The maximum width is at the centerline of this ellipse, with 0 width at the top and bottom. For a Newtonian fluid, the width, when the fracture half-length is equal to x_f , is given (in coherent units) by

$$w(0, t) = C_2 \left[\frac{(1-\nu)q_i^2 \mu}{G h_f} \right]^{\frac{1}{5}} \times t^{\frac{1}{5}} \quad (1)$$

$$x_f = C_1 \left[\frac{G q_i^3}{(1-\nu)\mu h_f^2} \right]^{\frac{1}{5}} \times t^{\frac{4}{5}} \quad (2)$$

$$G = \frac{E}{2(1+\nu)} \quad (3)$$

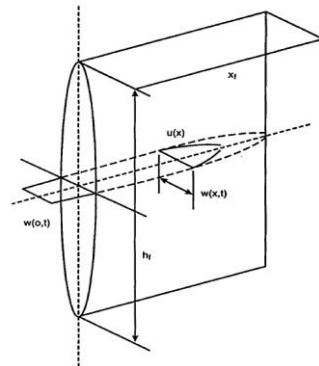


Figure 4. The PKN geometry (Perkins and Kern, 1961; Nordgren, 1972)

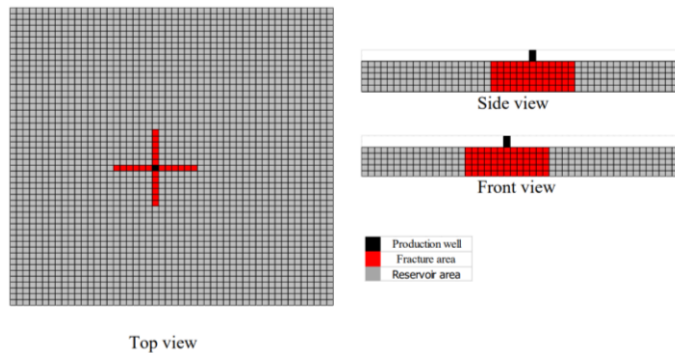


Figure 5. The vertical hydraulic fracture pattern with the model 50x50x5 cell

In Equations (1), (2), and (3), q_i is the injection rate, μ is the apparent viscosity, ν is the Poisson ratio, and G is the elastic shear modulus and is related to Young's modulus, E .

The permeability of the fracture is given as:

$$k_f = 7.7(10^{12})w_f^2 \quad (4)$$

Hydraulic Fracturing Pattern

The model using vertical hydraulic fracturing in the reservoir area is 53,820,000 ft², the fracture length at the time of injection (L_f) is 1796 ft, the fracture width at the time of injection (w_f) is 0.038 ft, permeability in the reservoir before HF is 0.09- 7 md, and permeability of the fracture is 11.287×10^9 md.

Khorat Sand Gas Field Assessment

The result of the study on the petroleum system of the NE region can be summarized as follows:

Source Rocks

The geochemical data from the Late Triassic Huai Hin Lat Group, the Permian Hua Na Kham and Pha Nok Khao Formations, and the Late Carboniferous Wang Saphung Group suggest that they contain good to fair source richness.

Reservoir Rocks

The most significant reservoir rocks in the NE region are the Khorat Group sequence including sandstone.

Seal Rocks

A thick sequence of fine and dense rocks on top of saturated hydrocarbon beds in the NE is common; for example, the lower part of the Khorat Group contains a thick and monotonous layer of claystone with argillaceous cement and, thus, permeabilities are expected to be very poor.

Traps

The geologic structures and stratigraphic petroleum traps in the NE region were successfully tested.

The geologic model used in the assessment of the Khorat Plateau shows that oil and gas generated from source rocks in the Paleocene Epoch, following the Cretaceous Period burial, migrated upward along faults into the Permian carbonate reservoirs and possibly into the Triassic synrift clastic reservoirs within the structural traps. The probability of these geological variances are tabulated in Tables 1 and 2.

The petroleum volumetric reserve calculation is assessed with the Monte Carlo simulation by numerical methods using random numbers and a function of the engineering (area of closure (A), thickness (h), porosity (Φ), gas saturation (S_g), gas recovery factor (RF), and gas formation volume factor (B_g)).

$$Reserve = \frac{43,560Ah\Phi S_g}{B_g} \times RF \quad (5)$$

Table 1. Probability of petroleum geological variances with play level (attributes)

Play attributes	Probability	Descriptions
Hydrocarbon source	0.70	Pha Nok Khao Formation has high potential to be a good source rock.
Timing	1.00	Petroleum originated from source rock (Permian carbonate) and migrated to reservoir (Huai Hin Lat Formation) at suitable timing (Late Triassic).
Migration	1.00	Migration of petroleum from source rock to reservoir is suitable in both petroleum quantity and migration path.
Potential Reservoir Facie	0.70	Reservoir has some suitable and enough quantity of porosity and permeability.
Marginal Play Probabilities	$0.70 \times 1.00 \times 1.00 \times 0.7 = 0.49$	

Table 2. Probability of petroleum geological variances within prospect attributes

Prospect attributes	Probability	Descriptions
Trapping Mechanism	0.80	Shale interbedded sandstone of Khorat Group can be a good seal for hydrocarbon accumulated in the rock older than the Khorat Group rocks.
Effective Porosity	0.90	Reservoir has good average porosity (>3%).
Hydrocarbon accumulation	0.80	There are enough suitable traps for hydrocarbon accumulation (>17%).
Conditional Deposit Probabilities		$= 0.80 \times 0.90 \times 0.80 = 0.576$

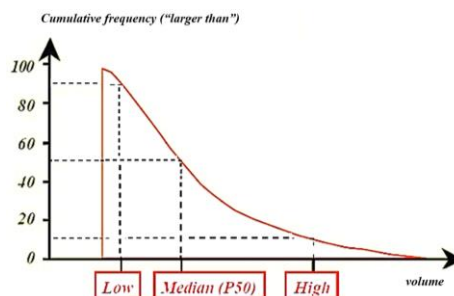
From several hundred to several thousand trials are generally used to obtain suitable results, which makes the technique less suitable for hand calculations than for the electronic computer. Many thousands of reserves were combined as a cumulative probability (frequency) distribution to give the resources at P95 (Proved), P50 (Proved + Probable), and P10 (Proved + Probable + Possible) reserves, as shown in Figure 4.

Assessment and Simulation Results

Petroleum Potential Assessment

The petroleum resources potential in prospect

The gas fields were evaluated with the FASPU and MSP programs, as shown in Table 3. In 1 prospect, the probability of finding gas in place is 65-103, 149-156, and 213-339 MMMSCF (billion SCF) at high (90-95%), medium (50%), and low (5-10%) confidence, respectively.

**Figure 6. Cumulative frequency of volume distribution output (6) (CCOP, 2000)**

Reservoir Simulation Results

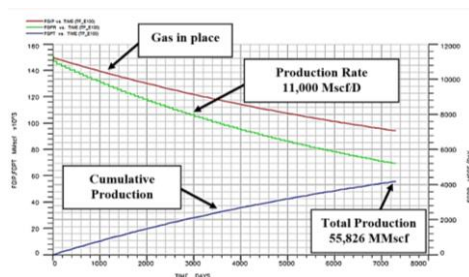
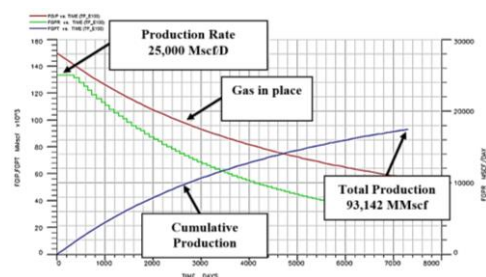
The gas in place of 150 MMMSCF was simulated. Before HF, the Khorat sand gas field starts production of 10 MMSCF/day and lasts for 1.7 years then declines to end at 5.1 MMSCF/day in the 20th year with the total production of 53.89 MMMSCF. After 1200

Table 3. Petroleum resources in prospect

Program	Resources (MMSCF)		
	P95* (P90**)	P50	P5* (P10**)
FASPU*	65.443	149.087	339.683
MSP**			
- Monte Carlo simulation	103.08	151.73	213.57
- Swanson's Mean	93.51	156.19	232.96

Table 4. Economic analysis

	Production rates $\times 10^6$ cu.ft/day	Total production $\times 10^9$ cu.ft/20years	% of yields compared to total gas	Investment $\times 10^6$ \$	Investor returns IRR, %	Investor's earnings $\times 10^6$ \$	State revenue $\times 10^6$ \$
Before HF	11	55.6	0.37	64.72	4.41	-38.77	25.84
After HF at 1500 barrels	25	93.14	0.62	66.53	24.23	74.42	221.29

**Figure 7. Gas in place, production rate, cumulative production, and pressure versus time plot (before HF)****Figure 8. Gas in place, production rate, cumulative production, and pressure versus time plot (after HF)**

barrels of fluid HF, the gas field starts production of 15 MMSCF/day which lasts for 5 years and then declines to end at 5.85 MMSCF/day with the recovery of 79.02 MMMSCF, as shown in Figures 7 and 8.

Economic Analysis

In the prospect with the gas in place of 150 MMMSCF and the initial pressure of 3200 psia were simulated. Before HF the Khorat sand gas field starts production of 11 MMSCF/day and lasts for the first year then declines to end at 5.2 MMSCF/day in the 20th year with the total production of 55.82 MMMSCF, IRR after tax of 4.11%. After HF, the gas field starts production of 25

MMSCF/day and lasts to 1 year then declines to end at 5.5 MMSCF/day with the recovery of 93.14 MMMSCF. Upon Thailand III legislation with the CAPEX (capital expenditure) of 66.53 MM\$(Million US\$) and the gas price of 6\$/1,000,000BTU, the project earned the profit of 74.42 MM\$, pay out in the 5th year of production (10th years of operation), and IRR after tax of 24.23%. The other economic outcomes are shown in Table 4.

Discussion

The assessment indicated the most likely probability to find the Khorat sand gas field

with the reserve of 150 Bcf (billion cu.ft.). The Khorat sand gas fields, will need to be fracked with HF when the IRR is less than 10%. In the NE Thailand and Thai III, before HF the Khorat sand gas field starts production of 11 MMSCF/day and lasts for the first year then declines to end at 5.2 MMSCF/day in the 20th year with the total production of 55.82 MMMSCF, IRR of 4.41%. After 1500 barrels of fluid HF, the gas field starts production of 25 MMSCF/day and lasts to 1 year then declines to end at 5.5 MMSCF/day with the recovery of 93.14 MMMSCF, IRR of 24.23%.

Conclusions

The Khorat sand gas fields' production schedule, as in this model, is much more suitable for NGV production rather than for power generation. The gas fields can be developed commercially (IRR=15-20%) with HF, and the value added NGV production can also make the Khorat sand gas field become profitably developed. The innovation of new technology, cost cutting methods, and efficient operation should promote the petroleum activities and increase the indigenous NGV gas supply in the NE.

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