SCIENTIFIC CONTRIBUTIONS OIL AND GAS
Vol. 39, Number 2, August 2016: 2 of 5

RESEARCH AND DEVELOPMENT CENTRE FOR OIL & GAS TECHNOLOGY
LEMIGAS

Journal Homepage:http://www.journal.lemigas.esdm.go.id

SHALE AS HYDROCARBON RESERVOIRS

BATUAN SERPIH SEBAGAI RESERVOIR HIDROKARBON

Adi Junira[1] and Andy Setyo Wibowo[2]

[1]PT FERG Geosains Indonesia
[2]"LEMIGAS" R & D Centre for Oil and Gas Technology
Jl. Ciledug Raya, Kav. 109, Cipulir, Kebayoran Lama, P.O. Box 1089/JKT, Jakarta Selatan 12230 INDONESIA
Tromol Pos: 6022/KBYB-Jakarta 12120, Telephone: 62-21-7394422, Faxsimile: 62-21-7246150
Email: andysw@lemigas.esdm.go.id,

First Registered on April 15th 2016; Received after Correction on July 29th 2016
Publication Approval on: August 31st 2016

ABSTRAK

Produksi hidrokarbon dari batuan serpih menjadi tantangan baru pada kegiatan eksplorasi dan eksploitasi minyak dan gas bumi dunia. Karakteristik batuan serpih sangat berbeda dengan batuan reservoir pada umumnya sehingga batuan reservoir serpih diklasifikasikan sebagai unconventional reservoir. *Permeabilitas yang cenderung sangat kecil (kurang dari 0,1 mD) dan porositas yang relatif rendah (kurang dari 10%) menjadi kendala utama untuk memproduksi hidrokarbon yang terakumulasi di batuan serpih. Namun demikian, teknologi pengeboran horizontal dan* hydraulic fracturing *terbukti efektif untuk menstimulasi aliran fluida pada reservoir berpermeabilitas rendah seperti batuan reservoir serpih sehingga mendorong berkembangnya eksplorasi hidrokarbon pada batuan reservoir serpih. Oleh karena itu, pengetahuan akan karakteristik batuan serpih dan teknologi hydraulic fracturing menjadi sangat penting untuk manajemen* unconventional reservoir. *Tulisan ini mengulas teknologi yang banyak diterapkan serta tantangan yang ada dalam pengembangan* unconventional reservoir.
Kata Kunci: batuan reservoir serpih, mekanika batuan, hydraulic fracturing

ABSTRACT

Nowadays, shale plays a role as hydrocarbon producing rock. Due to its "unusual" properties as a reservoir, shale is classified as an unconventional reservoir. Among these properties are the relatively low permeability (0.1 mD or less) and the relatively low porosity (10% or less). The relatively low permeability had been the main obstacle to extracting the hydrocarbon held by shale in the past. Nevertheless, the technologies of horizontal drilling and hydraulic fracturing have proven to be effective in stimulating a liquid flow in low permeability reservoirs such as a shale layer which has encouraged the hydrocarbon exploration in the oil shale industry. This paper is intended to provide an overview of technologies implemented in the current oil shale reservoir along with their challenges summarized from available sources in a concise manner.
Keywords: shale reservoir, mechanical properties, hydraulic fracturing

I. INTRODUCTION

Conventionally, shale is a source rock where hydrocarbon was "cooked" before being expelled to more porous and more permeable formation called reservoir rocks of sandstone or carbonates. It was then realized that the remaining hydrocarbon in shale which are not expelled to other more porous and permeable rock formations can produce oil by using the correctly implemented technologies to overcome the relatively low permeability of shale, namely horizontal drilling and hydraulic fracturing.

As a reservoir, shale rock does not have a trap characterization as conventional reservoirs do but the hydrocarbons are held by the impermeable nature of shale. In other words, shale plays different roles usually assigned to different rock formations at the same time, i.e. : source rock, reservoir rock, and seal rock. In addition to that, a shale reservoir does not have gas water contact or oil water contact as conventional reservoirs do.

Normally, a shale reservoir extends in a wide area with relatively high heterogeneity compared with that of conventional reservoirs. Some parts of the shale reservoir that are more favorable in hydrocarbon production which are called “sweet spots”. Note that the geological sweet spots are not necessarily also the economic sweet spots (Ahmed 2015). For instance, the reservoir parts that have favorable geological properties and unfavorable stress magnitude and direction are geological sweet spots but are not economic sweet spots because they cannot be produced economically despite their geological advantages. Therefore, a challenge in developing a shale reservoir is to identify its sweet spots.

Another challenge in developing a shale reservoir is how to accurately calculate its reserves. The traditional material balance reserves calculation usually applied to conventional reservoirs produces inaccurate results when applied to shale reservoirs with stress-sensitive behavior (Dou et al. 2015). However, due to the difficulty to determine the average reservoir pressure, material balance method should never be used in reserves calculation of a shale reservoir (Holditch, 2006).

II. METHODHOLOGY

Hydraulic Fractures Design

Horizontal well technology is used in shale reservoirs to broaden the contact areas between the reservoirs and the wells. These contact areas should be broadened further by introducing the artificial fractures created by increasing wellbore pressure hydraulically in an operation called hydraulic fracturing. The obtained fractures which are called hydraulic fractures are then kept open after the wellbore pressure is lowered to the level before the hydraulic fracturing operation either with or without grained material called proppant. This proppant acts as a barrier to the hydraulic fractures aperture closing due to stresses in the formation. In many cases, proppant is simply sand or, in high pressure conditions, specially designed ceramic beads.

In order for the shale to fail and for hydraulic fractures to be created, the hydraulic pressure should be higher than tensile strength of the shale at the corresponding stresses acting on the shale. Once the shale fails, the fracture is then propagating away from the wellbore, with shape determined by the mechanical properties of the shale, the stresses acting on the shale, and the occurrence of the natural factures in the shale.

The mechanical properties of shale can be described with Young’s modulus and Poisson’s ratio. Shale with relatively high Young’s modulus and relatively low Poisson’s ratio is a “brittle” shale while shale with relatively low Young’s modulus and relatively high Poisson’s ration is a “ductile” shale. Brittle shale translates the hydraulic pressure increase into cracks and fractures while ductile shale translates the hydraulic increase into plastic deformation. Brittle shale also tends to have fracture surfaces with relatively higher roughness in addition to less possibility of “proppant embedment”, a phenomenon where the proppant “adsorbed” into the fracture surfaces. The high roughness of the fracture surfaces results in a high conductivity of the fractures (Jansen et al. 2015). These advantages make the brittle parts the geological sweet spots in developing the shale reservoir.

During hydraulic fracturing, hydraulic fractures are propagated with the direction perpendicular to the direction of the minimum stress orientation which is the least resisting force acting in the shale. Therefore, in order to obtain long hydraulic fractures, the perforation orientation should not deviate significantly from the maximum stress. The incorrect perforation orientation will force the fracture propagation to stop early which results in shorter hydraulic fractures (Sepehri et al. 2015). In some cases, the maximum stress can inflict shear displacement of the two fracture surfaces which results in the fracture surfaces are against the parts that do not fit with one another. The misaligned fracture surfaces do not need proppant to keep the fracture aperture open provided that the mechanical properties of the shale are sufficient to prevent plastic deformation of the shale.

Naturally, shale can have fractures created due to tectonic forces or chemical dissolution. The occurrence of these natural fractures affects the direction and geometry of the hydraulic fractures. The least favorable natural fractures direction is parallel to the minimum stress because these natural fractures will act as barriers to the propagating hydraulic fractures which have the direction perpendicular to the minimum stress (Zhang et al. 2015). This will result in relatively short extension of the created hydraulic fractures which means the portion of the

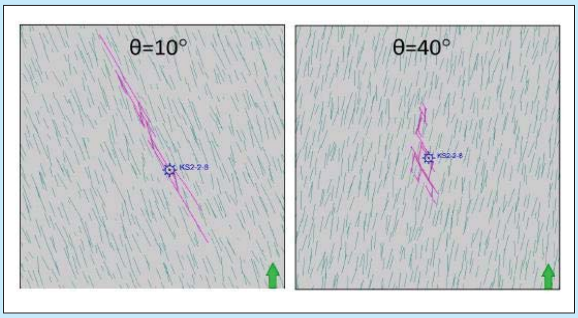

Figure 1
Hydraulic fractures in different natural fractures orientations (Source: Zhang et al. 2015)

shale reservoir covered by the hydraulic fractures will be less than originally intended (Figure 1).

The natural fractures can have some degree of permeability which enable them to act as a flow path of hydrocarbon to the well provided that their apertures are not filled by materials which act as barriers to the flow. In this case, the higher the natural fractures concentration is, the easier the hydrocarbon flows. However, the direction of the natural fractures also plays a role in the success of a hydraulic fracturing operation as mentioned above. Therefore, in selecting the best parts of a shale reservoir to fracture hydraulically, the direction of the natural fractures must also be considered.

In determining the hydraulic fractures spacing, the so-called "stress shadow" should be taken into account. Stress shadow is a condition where the stress around the hydraulic fractures has different magnitude and direction than those of the stress away from the hydraulic fractures. The hydraulic fractures can only form beyond the volume of rock with the stress shadow which means that the minimum hydraulic fractures spacing depends on the width of the stress shadow (Okahialam et al. 2015).

The hydraulic fracture conductivity, which is defined as the multiplication of the width of a hydraulic fracture and its permeability, should be optimized in order to avoid unnecessary cost related to the creation of unusable fracture conductivity (Jansen et al. 2015). This is because after a certain point, the hydraulic fracture conductivity increase will not add more production from the shale reservoir. The limit of the production increase due to the hydraulic fracture increase is related to the matrix permeability of the shale reservoir.

III. RESULTS AND DISCUSSION

A. Hydraulic Fracturing

In most hydraulic fracturing operations, fluid used to transmit the pressure to break the formation is basically water with some additives added to modify the water properties so that they are compatible with the fracturing operations. Among the additives is the friction reducing additive. This additive, described by its name, reduces the friction experienced by the hydraulic fracturing fluid so that it flows downhole and into the fractures with less pressure decrease. The water modified by the friction reducing additive is called "slickwater".

Another common additive used in hydraulic fracturing operations is the gelling additive which thickens the hydraulic fracturing fluid so that it is able to transport the solid proppant downhole and into the fractures while preventing the proppant settlement to the bottom of well.

Generally, hydraulic fractures created instantly as the tensile strength of the formation at the prevailing stresses exceeded by the pressure transmitted by the hydraulic fracturing fluid. Nevertheless, the hydraulic fractures can also be created by applying pressure lower than the tensile strength of formation provided that the time during which the pressure is applied is long enough to inflict the formation failure (Bunger et al., 2015). This kind of failure called static fatigue.

The hydraulic fractures that are intended to drain a shale reservoir should not extend into an undesired formation. The undesired formation can be an aquifer which will create an environmental issue if the chemically-modified hydraulic fracturing fluid enters the aquifer, in addition to the problems during hydrocarbon production related to high water cut. Fracture localization principles should be implemented in order to prevent this undesired extension of the hydraulic fractures. Basically, the method to localize hydraulic fractures is by restricting the pressure transmitted by the hydraulic fracturing fluid at a specific level, in accordance with the strength of the shale reservoir and the fracture barriers around the shale reservoirs. The fracture barriers can be formations with higher strength than that of the shale reservoir or formations with natural fractures (or cleats) which enable them to absorb the pressure transmitted by the hydraulic fracturing fluid such as coal.

The fluid used in a hydraulic fracturing operation will flow back into the well once the applied pressure is lowered at the end of the hydraulic fracturing operation. This fluid backflow can bring various substances or particles into the well. The substances or particles can create a water treatment issue if the water cannot be injected back to the subsurface which is the simplest and easiest method in many cases. The only method to handle the water that cannot be injected to subsurface is by treating it before releasing it to the surface water body. In some cases, the proppant which is originally intended to stay inside the fractures flows back into the well along with the water backflow. To prevent this proppant backflow, some kind of resin is usually applied to the proppant grains.

B. Stress-Sensitive Parameters

Subsurface formations have what is termed effective stress which is the difference between the overburden stress and the pore pressure. The overburden stress is relatively constant because the overburden thickness is also constant. As the pore pressure decreases, for instance during production, the effective stress will increase. The increase in effective stress results in a change in pore geometry (Shaoul et al. 2015). As the pore geometry changes, the open spaces of the pores available for fluid flow will also change, usually they shrink. Consequently, this will result in the decrease of the permeability of the formation in addition to the decrease in the porosity of the formation.

Another consequence of the increase of the effective stress is the closing of the horizontal hydraulic fractures which occur at the depth of less than 2,000 ft since the relatively thin overburden inflicts relatively little vertical stress (Jin et al. 2015). This closing of the hydraulic fractures also reduces the available spaces available for flow which in turn will reduce the permeability of the formation.

The constantly changing properties of shale formations during production should be taken into account in calculating reserves and forecasting future production of shale reservoirs for instance, in analyzing and interpreting well test data of shale formations (Shaoul et al. 2015).

C. Producing Hydrocarbon From Shale

Due to the relatively expensive technologies required to develop shale reservoirs, the shale hydrocarbon reserves can only be economical at relatively high oil and gas prices. This also means that, generally speaking, the profit of shale hydrocarbon reserves is relatively low compared with that of conventional hydrocarbon reserves. The common approach in producing hydrocarbon from a shale reservoir is by exploiting its sweet spots first before moving to the less favorable parts of the shale reservoir. The sweet spots affect the economics of a shale hydrocarbon development due to its direct contribution to the cash flow.

The rapid production decline of shale reservoirs should also be considered in developing a shale reservoir. The rapid production decline dictates that in order to maintain a relatively flat production rate, new wells must always be drilled across the shale reservoirs. Additionally, not all hydraulic fractures contribute to the hydrocarbon production from shale reservoirs (Ahmed 2015).

Despite its “unfavorable” nature, shale reservoirs hold vast amounts of hydrocarbon which are technically producible. In line with the growing demand for hydrocarbon, shale reservoirs will play a more significant role in the future. The challenge in developing shale reservoirs now is how to produce shale hydrocarbon reserves more cheaply and safely.

IV. CONCLUSIONS

Shale hydrocarbon reserves should be calculated by taking into account the difference between shale reservoirs and conventional reservoirs. The common approach in producing hydrocarbon from a shale reservoir is by exploiting its sweet spots first before moving to the less favorable parts of the shale reservoir.

The shape of hydraulic fractures in shale reservoirs is determined by the mechanical properties of the shale, the stresses acting on the shale, and the occurrence of the natural fractures in the shale. The optimum fracture conductivity should be taken into account in designing the hydraulic fractures in order to avoid unnecessary expenditure. Pressure restriction is the key to localize hydraulic fractures so that they do not extend to the undesired formations. Permeability and porosity are stress-sensitive parameters in shale reservoirs which change along with the reservoir pressure change during production.

Shale reservoirs hold vast amounts of technically producible hydrocarbons and the challenge in developing shale reservoirs now is how to produce hydrocarbon reserves more cheaply and safely.

REFERENCES

Aditya Khanna and **Andrei Kotousov.** (2015) : Controlling the Height of Multiple Hydraulic Fractures in Layered Media, *SPE paper 176017-PA*, *Society of Petroleum Engineers Journal*.

Andrew P Bunger and **Guanyi Lu.** (2015) : Time-Dependent Initiation of Multiple Hydraulic Fractures in a Formation with Varying Stresses and Strength. *SPE paper 171030-PA*, *Journal of Petroleum Technology*, Vol. 20, Issue 06, 185 - 196.

Eric C Bryant, Jongsoo Hwang, and **Mukul M Sharma.** (2015) : Arbitrary Fracture Propagation in Heterogeneous Poroelastic Formations using a Finite Volume-Based Cohesive Zone Model. *SPE paper 173374 presented at the SPE Hydraulic Fracturing Conference* 2015, The Woodlands, Texas, USA, 3 – 5 February.

Frac Focus, Hydraulic Fracturing: The Process, viewed 21 August 2015, from https://fracfocus.org/hydraulic-fracturing-how-it-works/hydraulic-fracturing-process.

Fuxiang Zhang, Kaibin Qiu, Xiangtong Yang, Jun Hao, Xuefang Yuan, Jeffrey Burghardt, Hongtao Liu, Jianyi Dong, and **Fang Luo**. (2015) : A Study of the Interaction Mechanism between Hydraulic Fractures and Natural Fractures in the KS Tight Gas Reservoir, *SPE paper 174384-MS presented at the EUROPEC 2015*, Madrid, Spain, 1 – 4 June.

Ikenna Okahialam, Mei Yang, Dnyaneshwar B Shinde, Vivek Sahai, Aura Araque-Martinez, and **Rakesh Rai.** (2015) : Completion Optimization Under Constraints - An Eagle Ford Shale Case Study, *SPE paper 174057-MS presented at the Western Regional Meeting*, Garden Grove, California, USA. 27 – 30 April.

Jay Sepehri, Mohamed Y Soliman, and **Stephen M Morse.** (2015) : Application of Extended Finite Element Method (XFEM) to Simulate Hydraulic Fracture Propagation from Oriented Perforations, *SPE paper 173342-MS presented at the Hydraulic Fracturing Technology Conference*, The Woodlands, Texas, USA. 3 – 5 February.

J R Shaoul, A Ayush, J Park, and **C J de Pater.** (2015): The effect of Stress Sensitive Permeability of Post-Fracture Welltests in Tight Gas and Unconventional Reservoirs, *SPE paper 174187 presented at the European Formation Damage Conference and Exhibition*, Budapest, Hungary, 3 – 5 June.

Junjing Zhang, D Zhu, and **A D Hill.** (2015) : Water-Induced Fracture Conductivity Damage in Shale Formations. *SPE paper 173346-MS presented at the* SPE *Hydraulic Fracturing Technology Conference*, The Woodlands, Texas, USA, 3 – 5 February.

Kyongsu Kim, Sungkyu Ju, Jongchan Ahn, Hyundon Shin, Changhoon Shin, and **Jonggeoun Choe.** (2015): Determination of Key Parameters and Hydraulic Fracture Design for Shale Gas Production, *SPE paper 174187 presented at the* 25th *International Ocean and Polar Engineering Conference*, Kona, Big Island, Hawaii, USA, 21 – 26 June.

Menglu Lin, Shengnan Chen, Wei Ding, Zhangxin Chen, and **Jinze Xu.** (2015) : Effect of Fracture Geometry on Well Production in Hydraulic-Fractured Tight Oil Reservoirs. *SPE paper 167761-PA Journal of Canadian Petroleum Technology*, Vol. 54, Issue 03, 183 – 194

R Mayer, R Taylor, and **I Mahe**. (2015), Bringing Geoscience into Shale Development. *Paper OMC-2015-356 presented at the 12th Offshore Mediterranean Conference and Exhibition*, Ravenna, Italy, 25 – 27 March.

Stephen A Holditch. (2006) : “Tight Gas Sands”, *SPE paper 103356-JPT, Journal of Petroleum Technology*, Vol. 58, Issue 06, 86 - 93.

T Jansen, D Zhu, and **A D Hill.** (2015) : The Effect of Rock Mechanical Properties on Fracture Conductivity for Shale Formations, *SPE paper 174384-MS presented at the Hydraulic Fracturing Technology Conference*, The Woodlands, Texas, USA. 3 – 5 February.

US Environmental Protection Agency, The Process of Hydraulic Fracturing, viewed 21 August 2015, from http://www2.epa.gov/hydraulicfracturing/process-hydraulic-fracturing.

Usman Ahmed. (2015) : Optimized Shale Resource Development: Transforming Unconventional to Conventional Technologies, *Paper OMC-2015-221 presented at the Offshore Mediterranean Conference and Exhibition*, Ravenna, Italy, 25 – 27 March

Xiangji Dou, Liao Xinwei, Zhao Tianyi, Chen Zhiming, Ren Weiyan, and **Zhang Rui**. (2015) : “Analysis on Traditional Reserve Estimation Methods in Stress-sensitive Gas Reservoir: Error Analysis and Modification”, *SPE paper 178284-MS presented at the Nigerial Annual International Conference and Exhibition*, Lagos, Nigeria, 4 – 6 August.

Xiangji Dou, Xinwei Liao, Tengfei Hou, Tianyi Zhao, Chen Zhiming, Weiyan Ren, and **Rui Zhang.** (2015) : Fracture Optimization for Multi-stage Fractured Horizontal Well with Time & Stress-sensitive Parameters. *SPE paper 178286-MS presented at the Nigeria Annual International Conference and Exhibition*, Lagos, Nigeria, 4 – 6 August .

Xiaochun Jin, Subhash N Shah, and **Jean-Claude Roegiers.** (2015). “An Integrated Petrophysics and Geomechanics Approach for Fracability Evaluation in Shale Reservoirs”. *SPE paper 168589-PA presented at the SPE Hydraulic Fracturing Technology Conference* 2014, The Woodlands, Texas, USA, 3 – 5 February.