

Hydraulic Fracturing Special Double Issue

Editorial

Preface

Before embarking on a special issue on hydraulic fracturing, the publisher and editors of the *Journal of Sustainable Energy Engineering* (JSEE) thought it best to preface the issue with a short description of what to expect in the proceeding papers. Following our “E-Cubed” approach, namely looking at global energy sustainability from an Energy-, Economic-, and Environmental-based view, and where those areas dovetail together, it is our responsibility to provide this three-pronged approach to the engineering of energy sustainability. It is not, however, as an apolitical journal, our goal to provide any political papers whatsoever on the economic viability of the technology with regard to the technology’s impact on the global economy, or the environmental effects of the technology. We encourage our authors and editors to offer their technical findings and personal views in our articles and editorials respectively. Having said that, this issue, in particular, is focused solely on the technological aspects of hydraulic fracturing, from our E-Cubed approach.

Though there are social, economic, and environmental issues surrounding hydraulic fracturing, some of which could be addressed in the pages that follow, it is not the scope of this issue to delve into those, other than how new technology may affect them and vice versa. Energy industry’s focus is to provide energy, with whatever technology deemed necessary (including hydraulic fracturing,) hopefully with an eye towards their potential downside. Though this is an important issue which should not be ignored, the papers herein will not offer views on this problem. We would encourage anyone interested in these issues to submit papers on them for future issues, or to propose a special issue on the topic for a later publication. We also believe that it is the energy industry’s duty to continue moving towards global energy sustainability, and, with that vision constantly in mind, we offer this contribution to the scientific literature as to how hydraulic fracturing, one of the most hotly contested leaps in technology in the history of modern oil well drilling, can move toward that goal.

Introduction

Hydraulic fracturing of ultra-low and low permeability reservoirs has become the hottest energy-related topic within the oil and gas community as well as the

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general public. Together with horizontal drilling, hydraulic fracturing had a transformative impact on the global **energy** and **economic** outlook. Furthermore, the **environmental** impact of hydraulic fracturing, real or perceived, has been the subject of much debate. Thus, Hydraulic Fracturing is a perfect topic for a special issue for Journal of Sustainable Energy Engineering (JSEE,) with its E-Cubed focus on the trilogy of, Energy, Economy and Environment.

This special issue includes several papers that cover all aspects of hydraulic fracturing with a special focus on filling the existing technology gaps that may have limited optimum and safe utilization of hydraulic fracturing worldwide. The general challenge of understanding unconventional reservoirs is not limited to any specific technical discipline. Below, some of these gaps and the challenges they have created are discussed.

Production Pattern

In our view, the biggest technical challenge in hydraulic fracturing is finding the mechanism that can account for the relatively robust flow of oil and gas from ultra-low permeability unconventional reservoirs. The orthodox reservoir engineering theories and production decline models fail to account for the high initial and rapid fall-off of production from fractured horizontal wells. There is a great deal of uncertainty and often downright contradiction in existing common industry beliefs and fracturing concepts.

The initially high and subsequent rapid decline of production from hydraulically fractured horizontal wells is generally attributed to opening and activation of an existing network of natural fractures that are assumed to be linked together by the induced hydraulic fractures. Based on this model, a number of numerical simulations have attempted to explore the interaction between the hydraulic and natural fractures. On the face of it, this appears to be a simple and reasonable model. But closer scrutiny and deeper analysis of the subject gives pause to accepting this theory. First, cores recovered from some of these reservoirs usually show a competent formation that is occasionally intersected by randomly oriented very narrow discrete natural fractures. These cores show a very different picture of the formation than what is assumed in some numerical models. Often times these natural fractures are filled with secondary deposits that bind together their two faces. Even if one assumes the natural fractures to have a higher permeability than the formation, their very narrow widths and disconnected distribution minimize their production contribution. If one were to assume that the natural fractures are in fact connected to each other in a network, then the role of the hydraulic fracture and its contribution becomes one of transmitting the fluid produced through the natural fractures to the wellbore. This model of fluid flow does not justify the general industry trend of reducing the spacing between created hydraulic fractures, which has been as small as 20–30 feet in some recent treatments.

Stress computations around an induced hydraulic fracture show that, except for a narrow region around the extending hydraulic fracture tip, the high pressure inside the fracture increases the normal stresses acting on natural fracture faces, which then results in preventing their activation/opening, or at a minimum, narrowing of their aperture (assuming an open natural fracture). Creating multiple simultaneous fractures, as is often practiced in the popular Plug and Perf system, increases the normal stresses and closing effect of the hydraulic fracture. Reducing the spacing between fractures further exacerbates this effect. Thus, if natural fractures are going to contribute to production, at least some of them need to be open and inter-connected before fracturing. What contradicts this hypothesis is the observation that these formations are nearly unproductive before fracturing, and that even long term build-up tests in them does not yield useful data for reservoir engineering computations. This observation in fact contradicts another fracturing model proposed by some investigators that injection of fluid at low rates (a few barrels per minute) simply activates and extends the existing natural fractures, and that the main hydraulic fracture is created after we exceed injection rates of several barrels per minute. It is very difficult to reconcile the contradiction between the extremely low natural productivity of these reservoirs with the theory that we can inject fluid into them at low rates without fracturing them.

Some recent studies have also suggested alternative models such as those with fluid diversion/connectivity enhancement through activation of bedding planes. These models need to be thoroughly investigated and existing modeling workflows need to be improved as necessary. In our view, activation of natural fractures is a reasonable mechanism that may account for some of the production profile of ultra-low permeability reservoirs. But the models proposed so far have fallen short of satisfying a rigorous examination of their results. Moreover, alternative mechanisms need to be either proven or invalidated so that we can use proper physical basis for future model development and refinement. A better understanding of the flow mechanism in fractured horizontal wells goes a long way towards giving us a path to optimization of the entire process. In this effort we need to keep an open mind and be ready and willing to explore outside our normal "playgrounds". Darcy's law and conventional reservoir engineering models may need to be replaced with other models more suitable for describing the flow behavior in ultra-low permeability reservoirs. Thus, we need is more fundamental research!

Geomechanics

In spite of our extensive exposure to unconventional reservoirs, we have very limited knowledge of the physical and mechanical behavior of these reservoirs. Some of the behaviors attributed to these reservoirs have very little or no sound technical foundation. Among these one can list the oft-stated assumptions of equal horizontal in-situ principal stresses, formation ductility, presence of natural fractures, and more. For example, the assumption of equal horizontal in-situ principal stresses is

used to justify the hypothesis that opening a network of interconnected natural fractures is responsible for production of unconventional reservoirs. But this hypothesis is not backed by actual direct measurement of in-situ stresses to justify its validity. It is needed to justify activation and extension of interconnected and intersecting natural fractures at different orientations. In essence, each of the two assumptions of equal stresses and natural fracture opening are justified by the other one!

Similarly, the justification for attributing brittle or ductile behavior to the formation is based on log-derived determinations of formation lithology and its mineral composition, or its mechanical constants. But in reality, the best way to establish the point is through laboratory testing of rock samples and observing their failure mode. Similarly, review of structural geology can provide insight about fracture behavior, as long as the results are augmented with additional supporting data. But citing a structure that may have been formed millions of years ago is not a strong indication of how present day fractures will behave. As an example, during a fracturing operation in Alberta, Canada, we have recorded the intersection of a hydraulic fracture created during only one stage of a horizontal well with an existing vertical abandoned well. Extrapolating the data, it was concluded that the hydraulic fracture was extending along an E-W direction. This was contrary to the general local belief that structural geology of the Canadian Rockies will cause hydraulic fractures to have a NE-SW orientation. Similarly, studies in the Permian Basin in West Texas show that while the current stress state within Wolfcamp formation is normal, a significant proportion of pre-existing natural fractures are strike-slip in nature. Based on the geological history of the site, these differences can occur due to many reasons. Explanations could include temporal changes in the stress state over geologic time scales (due to accumulation and release of significant strain), regional tectonic activity causing reactivation of basement faults and associated faulting in the overburden layers, etc.

Once again, going to basics may be the shortest route to characterizing these reservoirs. This means laboratory testing, direct measurement of stresses (not by logging), and reducing the level of speculative and wishful engineering!

Fracture Growth Pattern

Theories of hydraulic fracturing have played a pivotal role in guiding the industrial growth of the process. At the same time, industrial application of hydraulic fracturing has exposed significant differences between theory and practice. For example, fractures created in horizontal wells are known to be longer than predicted by existing fracture design models, so much so that these models are seldom used in routine fracturing operations. Many fractures in horizontal wells are known to have extended more than 1000 ft. (sometimes even a mile!) and intersected adjacent wells, causing fluid and proppant movement into the intersected well. The frequency of this occurrence has been high enough that offset wells are routinely shut-in during fracturing.

The discrepancy between model predictions and actual results has made trial-and-error the main tool for design of hydraulic fractures. While this is a necessary step even for a well-proven theory, heavy reliance on it reduces the efficiency of operations, and increases the cost of progress (something the industry can ill afford at this time). Another difference has been in fracturing pressure variations. For example, fracturing theory predicts that stress shadow created by existing stages of fracturing in a horizontal well should increase the treatment and shut-in pressures of each successive stage. Field data does not consistently support this, even in treatments where several million pounds of proppant has been injected into closely spaced fractures in a single wellbore.

One would expect that adding tens of thousands of cubic feet of proppant volume would cause a consistent increase in the prevailing stresses and fracturing pressure, but this is not what we actually see. Same discrepancy exists in the stage-to-stage shut-in pressure variations. Much of our analysis of fracturing treatments is based on shut-in pressure variations, including determination of the minimum principal stress, fracture closure time, formation permeability, and more. Again, creation of each fracture and injecting thousands of cubic feet of sand is expected to routinely increase the prevailing minimum principal stress from stage to stage. This should manifest itself in higher treatment and shut-in pressures. But actual field data often differs with this expectation. The explanation offered for these significant discrepancies is fracture “complexity”. While this is an adequate explanation from “rank-and-file”, in the long run it is unacceptable from “experts”.

Microseismic Monitoring and Mapping

Microseismic mapping results have been one of the sources for some of our assumptions and confusion regarding fracture behavior. These results often show scattered seismic events generated by the extending fracture. In fact, it is the scattered nature of these events and attempts to find a simple rational pattern for them that has motivated some to hypothesize activation of a network of orthogonal natural fractures as the main source for productivity of unconventional reservoirs. Without a doubt, microseismic mapping technology has been an effective tool for estimation of fracture orientation in horizontal wells and as such has made significant contribution to the effective application of hydraulic fracturing for production enhancement. At the same time, over-simplification of its results, ignoring its inherent present limitations including uncertainties, and creation of unreasonable expectations for commercial gains has sometimes overshadowed its benefits. Microseismic mapping has the potential to become a valuable data source for real-time fracture monitoring and control. To reach this point, its results need to be interpreted using realistic fracture behavior. Use of microseismic monitoring would help better understand the induced seismicity phenomena and put the associated risk in the proper perspective. It is crucial that microseismic interpretation moves beyond the traditional “dots – in – the – box” approach of today to

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more holistic understanding of induced seismicity using additional processing or interpretation tools. Examples include moment tensor inversion, estimation of secondary parameters such as strain behavior and predictive modeling of expected flow behavior, direct imaging of passive emissions (emission tomography or reverse time imaging), etc. to name a few.

Completion Diagnostics

It is a well understood fact that many of the perforations shot during hydraulic fracturing operations do not make any significant contribution towards overall production. Moreover, as the well is brought into production, the behavior of perforations in terms of contribution to overall flow varies significantly. In other words, perforations that were contributing a lot towards initial flow may not necessarily contribute much later on. Understanding the “how” and the “why” of these observations is critical in improving future frac treatments and optimizing productivity of wells in question. Some suggested mechanisms attempting to answer these questions include proppant bridging and partial screen-out effects or stress shadowing. Significant work, both theoretical and quantitative modeling as well as lab based and field based experiments are needed to help us answer these questions. Moreover, traditional methods aimed at fracture diagnostics such as interpretation of treatment pressure for optimal fracture design do not work for long lateral completions and there is a need to either modify existing techniques or to develop newer ones which can tackle the complexities involved.

Economy, Safety and Environmental Issues

Other topics of interest to the industry include continuous monitoring of hydraulic fracturing to ensure safe operation, and case histories demonstrating responsible operation with attention to public concerns. Likewise we seek technical papers with special focus on economic impacts of hydraulic fracturing operations and comparative studies on optimizing hydraulic fracturing operational parameters.

In summary, our remarkable success with the application of hydraulic fracturing should be a motivator for better understanding of the process and diligence in filling the technology gaps and science-based reasoning to debate the safety of hydraulic fracturing that could serve as springboards for even more spectacular results. This special issue is hoped to be a step towards that objective. We also would like to thank Dr. Ali Daneshy, Daneshy, Editor-in-Chief, of the *Hydraulic Fracturing Journal* for his important contributions to the original planning for this special issue and this editorial.

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