Highlights of the 2017 ARMA Hydraulic Fracturing Workshop

ARMA Technical Committee on Hydraulic Fracturing

The ARMA Technical Committee on Hydraulic Fracturing (TCHF) held its second hydraulic fracturing workshop on June 25th in San Francisco, California. The goal is to clarify fundamental physics involved in hydraulic fracturing and demonstrate model validity and diversity to capture them.

The workshop drew wide attentions after announcement. It received 13,300+ views within the first week of post on LinkedIn. In San Francisco, over 90 participants representing 70 organizations from 13 countries attended the workshop.

The workshop consisted of two sessions: a morning session of lab and field findings and an afternoon session of model runoffs. The deliveries are available to Hydraulic Fracturing Community (HFC) members at the ARMA TCHF website (http://armarocks.org/sample-page/committees/technical-committee-on-hydraulic-fracturing-tchf-2/). These include:

1. Workshop agenda;
2. Highlights (this document);
3. Presentations and posters;
4. Case descriptions of model runoff;
5. Summaries of model runoff; and,
6. Attendee list, attached as appendix.

Fig. 1. The Organizing Committee and TCHF members (from left to right): Bill Carey, Sau-Wai Wang, Mukul Sharma, Thomas Doe, Gang Han, Ahmad Ghassemi, Joe Morris, Xiaowei Weng.

Morning Session: Lab and Field Findings

Table 1 listed 12 invited speakers from four national laboratories, seven universities, and three industry affiliates in the lab and field session [Refs 1-11]. Investigations from various labs, a 1450-meter deep mine, Marcellus, and Vaca Muerta fields revealed various aspects of the fracturing physics.

Speakers	Affiliations	Topics
Bezalel Haimson/ Moo Lee	University of Wisconsin-Madison/ Sandia National Lab	HF for in-situ stress measurements
Curtis Oldenburg	Lawrence Berkeley National Lab	HF in a deep mine: highlights from the kISMET project
Tom Doe	Golder Associates	Heterogeneity and topography in HF stress measurements
Romain Prioul/ Elizaveta Gordeliy	Schlumberger	Lab experiments to validate HF simulators
Ahmad Ghassemi	University of Oklahoma	Experimental Studies of Geothermal Stimulation by HF
Bruno Goncalves/ Herbert Einstein	New Jersey Institute of Technology/ Massachusetts Institute of Technology	HF monitoring with image and acoustic emission
Andrew Bunger	University of Pittsburgh	Rock breakage mechanism promoting multiple HFs
Jeffrey Burghardt/ Stergey Stanchits	Pacific Northwest National Lab/ Schlumberger	HF initiation and propagation in heterogeneous rock
Murtadha Al Tammar/ Mukul Sharma	University of Texas at Austin	Pore pressure effect on HF growth
Diana Gomez Rodriguez/ Robert Gracie	University of waterloo	Cohesion and toughness in a transparent rock analogue
Bill Carey	Los Alamos National Lab	Fracture permeability and evolution in Marcellus shale
Hamid Pourpak	Total	Vaca Muerta case study

Table 1. Programs of the Lab and Field Session

More specifically, Dr. Bezalel Haimson opened the session with a comprehensive review of applying hydraulic fracturing technique to measure the in-situ stresses [1], whose heterogeneity depends on variable rock elastic properties [3]. These techniques were applied to characterize stresses at the kISMET site in a 1450m deep mine [2]. With ten organizations from national labs, universities, and service providers, the test facility is to advance stress field characterization, hydraulic fracture creation, monitoring, induced seismicity, as well as pre-and post- fracturing simulations.

Based on the reviews of a series of lab experiments with artificial materials or rocks under realistic field conditions, Dr. Romain Prioul identified rock heterogeneity and lab-field scalability as the responsible for the difference between experiments and models [4]. Dr. Jeff Burghardt proposed a methodology to address the lab scalability for a tight gas reservoir. A complex fracture pattern was observed in a true-triaxial big block test with natural fractures [8].

Tested with 13” cubic granite rocks in a true triaxial apparatus, Dr. Ahmad Ghassemi from University of Oklahoma revealed multiple mechanisms involved in hydraulic fracture propagation, including tensile, shear slip and dilation, mixed mode, etc. [5]. Through imaging and acoustic emissions of fracturing with different preset flaw configurations, Dr. Bruno G. Silva from New Jersey Institute of Technology

identified the fracture mechanisms could be tensile or shear dominant depending on the vertical loads [6]. Dr. Mukul Sharma and his team from University of Texas at Austin demonstrated the importance of pore pressure on fracture propagation through controlled injection experiments. Dr. Andrew Bunger from University of Pittsburg achieved lower fracture breakdown pressures due to "static fatigue", a phenomenon rock fails in a time-delayed manner at the loads insufficient to induce instantaneous failure [7].

Several efforts focused on fracture permeabilities in natural and induced fractures. For Marcellus shales, Dr. Bill Carey from Los Alamos National Lab found the in-situ stresses play a more important role in determining the permeability of natural fractures than subsequent reactivation or changes in effective stress [10]. For Vaca Muerta shale, Dr. Hamid Pourpark from Total demonstrated significant variations of the fracture permeabilities with different confining stresses, fluids, and proppants [11].

These investigations advanced the understandings of physics involved in hydraulic fracturing. The findings laid down a foundation for the modeling session, which demonstrated model capacity to capture recognized physics.

Afternoon Session: Model Runoffs

The afternoon session presented model runoffs to capture the physics. Total 20 fracturing models participated seven benchmark case studies with the standardized input and output requirements.

Several TCHF members participated and prepared the test cases, including Drs. Mukul Sharma, Sau-Wai Wong, Xiaowei Weng, Joe Morris, Ahmad Ghassemi, John McLennan, Gang Han, et al. Special thanks to the valuable suggestions from modelers such as Deepen Gala, Mike Smith, Egor Dontsov, Leonard Cruz, Pengcheng Fu, Shawn Maxwell, Mark McClure, Uno Mutlu, Guanshui Xu, Hooman Hosseinpour, et al.

From simple to complex, the benchmark cases include

Case 1: Single fracture in homogeneous, elastic media.
Case 2: Single fracture in layered, elastic formations.
Case 3: Single fracture in homogeneous, poroelastic and thermoelastic media.
Case 4: Single fracture in elasto-plastic media (low cohesion, low Young's Modulus).
Case 5: Single fracture interacting with natural fractures and discontinuities (elastic, poroelastic).
Case 6: Single fracture in layered elastic media with complex fluids (non-Newtonian, compressible).
Case 7: Multiple competing fractures from perforation clusters (stress shadow effects).

The simplest Case 1 compares the numerical results with analytical solutions. Cases 2 to 5 highlights the effect of rock complexity on fracture initiation and propagation. Case 6 evaluates the role of complex fluids such as CO_2 and foams. Case 7 studies the impact of stress interference between fractures. Based on input variations, the seven cases are further divided into 30 subcases. The details are described in a separate document [12].

Table 2 lists the 16 participants and 20 models. From legacy 2D, pseudo 3D, planar 3D, to fully coupled 3D, the state-of-art models represent a variety of methods such as analytical solutions, Finite Element (FEM), Finite Difference (FDM), Boundary Element (BEM), Finite Volume (FVM), Discrete Element (DEM), Finite-Discrete Element (FDEM), etc.

Name	Affiliation	Model/Method
Mukul Sharma	University of Texas at Austin	EFrac and Multi-Frac
Ahmad Ghassemi	University of Oklahoma	GeoFrac
Pengcheng Fu	Lawrence Livermore National Lab	Geos
Xiaowei Weng	Schlumberger	Mangrove and Planar3D
Tobias Hoeink	Baker	MFrac and Argos
Shawn Maxwell	Itasca	XSite and 3DEC
Egor Dontsov	University of Houston	EP3D
Guanshui Xu	FrackOptima	FrackOptima
Michael Smith	NSI Technologies	StimPlan
Mark Cottrell	Golder Associates	FracMan
Mark McClure	McClure Geomechanics	ResFrac
Robert Caulk	University of California in San Diego	DEM
Yarlong Wang	Petro-Geotech Inc	U_FRAC
Jing Zhou	Idaho National Lab	DEM
Nancy Chen	University of Calgary	FEM
Uno Mutlu	Rockfield	Elfen_TGR

Table 2. List of participants and models in the benchmark efforts.

The results of each model, as well as the comparisons among models [13], are documented in the workshop deliveries. In general, all participants successfully demonstrated their model validity to capture various physics. We did observe model difference for each case studied. The difference arises from the fact that each model has different assumptions, theoretical backgrounds, numerical approaches, physics incorporated, etc. One should keep in mind and appreciate these differences when select the fit-for-purpose fracturing models.

Acknowledging the models diversity, we have emphasized that the exercise is NOT a show for model superiority. Rather, the intent is to demonstrate the model validity to capture the recognized physics.

References

1. Bezalel Haimson, and Moo Lee, 2017. Hydraulic Fracturing for In Situ Stress Measurements – Method Development and Field Tests at the University of Wisconsin-Madison. The 2nd ARMA Hydraulic Fracturing Workshop, San Francisco, CA, June 25th.
2. Curt Oldenburg, and Pat Dobson, 2017. Hydraulic Fracturing in a Deep Mine: Highlights from the kISMET Project. The 2nd ARMA Hydraulic Fracturing Workshop, San Francisco, CA, June 25th.
3. Thomas Doe, 2017. Heterogeneity in Hydraulic Fracturing Stress Measurements. The 2nd ARMA Hydraulic Fracturing Workshop, San Francisco, CA, June 25th.
4. Romain Prioul, Lisa Gordeliy, and Andrew Bunger, 2017. On the Role of Laboratory Experiments to Validate Hydraulic Fracturing Simulators. The 2nd ARMA Hydraulic Fracturing Workshop, San Francisco, CA, June 25th.

5. Lianbo Hu, Zhi Ye, and Ahmad Ghassemi, 2017. Reservoir Stimulation: Hydraulic Fracturing, Shear Slip, and Mixed-Mode Fracture Propagation. The 2nd ARMA Hydraulic Fracturing Workshop, San Francisco, CA, June 25th.
6. Bruno Gonçalves da Silva, and Herbert Einstein, 2017. Image and Acoustic Emission Monitoring of Hydraulic Fracturing. The 2nd ARMA Hydraulic Fracturing Workshop, San Francisco, CA, June 25th.
7. Andrew Bunger, Guanyi Lu, Qiao Lu, Romain Prioul, Elizaveta Gordeliy, and Gallyam Aidagulov, 2017. Time Dependent Initiation of Hydraulic Fractures: Rock Breakage Mechanism Promoting Multiple Hydraulic Fractures. The 2nd ARMA Hydraulic Fracturing Workshop, San Francisco, CA, June 25th.
8. Jeff Burghardt, 2017. Hydraulic Fracture Initiation and Propagation in Heterogeneous Rock. The 2nd ARMA Hydraulic Fracturing Workshop, San Francisco, CA, June 25th.
9. Diana Gomez Rodriguez, Maurice B. Dusseault, and Robert Gracie, 2017. Cohesion and Fracture Toughness in a Transparent Annealed Rock Analogue. The 2nd ARMA Hydraulic Fracturing Workshop, San Francisco, CA, June 25th.
10. Bill Carey, and Luke Frash, 2017. Fracture Permeability and Evolution of Marcellus Shale. The 2nd ARMA Hydraulic Fracturing Workshop, San Francisco, CA, June 25th.
11. Kun Su, Yonantan Sanz Perl, Atef Onaisi, Hamid Pourpark, and Sandrin Vidal-Gilbert, 2017. Experimental Study of Hydromechanical Behavior of Fracture of Vaca Muerta Gas Shale. The 2nd ARMA Hydraulic Fracturing Workshop, San Francisco, CA, June 25th.
12. ARMA Technical Committee on Hydraulic Fracturing, 2017. Benchmark Cases for Hydraulic Fracturing Models. The 2nd ARMA Hydraulic Fracturing Workshop, San Francisco, CA, June 25th.
13. Gang Han, Mukul Sharma, Sau-Wai Wang, Ahmad Ghassemi, and Joe Morris, 2017. Model Benchmark Highlights. The 2nd ARMA Hydraulic Fracturing Workshop, San Francisco, CA, June 25th.

Appendix: Attendee List

First Name	Last Name	Affiliations
Abdulwahab	Abdullah	King Fahd University of Petroleum & Minerals
Alireza	Agharazi	MicroSeismic Inc
Murtadha	Al Tammar	The University of Texas at Austin
Omar	AlDajani	MIT
Florian	Amann	ETH Zürich
Ellie	Ardakani	ESG Solutions
Ali	Azad	Shell
Jie	Bai	Halliburton
Tore Ingvald	Bjørnarå	NGI
Kinga	Bobek	Polish Geological Institute - NRI
Chia Weng	Boon	MMC-Gamuda KVMRT(T) Sdn Bhd
Andrew	Bunger	University of Pittsburgh
Jeffrey	Burghardt	Pacific Northwest National Laboratory
Jiujie	Cai	University of Calgary

James	Carey	Los Alamos National Laboratory
Daniel	Carter	Saudi Aramco Energy Ventures
Robert	Caulk	University of California, San Diego
Rick	Chalaturnyk	University of Alberta
Shengnan	Chen	University of Calgary
Dmitry	Chuprakov	Schlumberger
Leonardo	Cruz	Baker Hughes
Thomas	Doe	Golder Associates
Egor	Dontsov	University of Houston
Maurice	Dusseault	University of Waterloo
Francis	Elisabeth	Saudi Aramco
Deepen	Gala	The University of Texas at Austin
Jun	Ge	Energy & Environmental Research Center
Ahmad	Ghassemi	Univerity of Oklahoma
Ivan	Gil	BP
Deepak	Gokaraju	MetaRock Laboratories, Inc.
Bruno	Goncalves da Silva	New Jersey Institute of Technology
Jesse	Hampton	New England Research
Bezalel	Haimson	University of Wisconsin-Madison
Gang	Han	Aramco Services Company
Tobias	Hoeink	Baker Hughes
Hooman	Hosseinpour	Golder Associates Inc.
Nai-Chung	Hu	Gulfport Energy
Robert	Hurt	Pioneer Natural Resourses
Bo-An	Jang	Kangwon National University
Hyun-Sic	Jang	Kangwon National University
Marek	Jarosiński	Polish Geological Institute - NRI
Charles	Kang	McClure Geomechanics LLC
James	Kessler	Occidental Petroleum Corporation
Olga	Kresse	Schlumberger
John-Paul	Latham	Imperial College London
Moo	Lee	Sandia National Laboratories
Qiuyi	Li	MIT
Qiao	Lu	University of Pittsburgh
Shawn	Maxwell	Itasca IMaGE
Mark	McClure	McClure Geomechanics
Anahita	Modiriasari	Purdue University
Joseph	Morris	Lawrence Livermore National Laboratory
Ovunc	Mutlu	Rockfield Global Technologies America
Neal	Nagel	OilField Geomechanics LLC
Asiri	Obeysekara	Imperial College London
Curtis	Oldenburg	Lawrence Berkeley National Laboratory
Radomir	Pachytel	Polish Geological Institute - NRI
Anthony	Peirce	University of British Columbia
Caleb	Pollock	Pioneer Natural Resouces
Hamid	Pourpak	Total

Romain	Prioul	Schlumberger-Doll Research
Erick Slis	Raggio Santos	Petrobras
Hee-Sung	Riu	Kangwon National University
Adolfo	Rodriguez	OpenSim Technology LLC
Mats	Rongved	Norwegian University of Science and Technology
Alexei	Savitski	Shell International E&P, Inc.
Mukul	Sharma	The University of Texas at Austin
Mao	Sheng	China University of Petroleum at Beijing
Kaustubh	Shrivastava	The University of Texas at Austin
John	Smith	Fifth Creek Energy
Michael	Smith	NSI Technologies LLC
Hiroki	Sone	University of Wisconsin-Madison
Roberto	Suarez-Rivera	W.D. Von Gonten Laboratories
Zhuang	Sun	The University of Texas at Austin
Jan	ter Heege	TNO
Kenji	Ueda	INPEX Corporation
Luca	Urpi	ETH - SED
Herbert	Wang	NSF
Shugang	Wang	Chevron
Yarlong	Wang	Petro-Geotech Inc.
Xiaowei	Weng	Schlumberger
Sau-Wai	Wong	rybkarock
Ruiting	Wu	Chevron
Guanshui	Xu	University of California at Riverside
Umali	Yasidu	Hokkaido University
Yanguang	Yuan	BitCan Geosciences & Engineering Inc.
Fengshou	Zhang	Tongji University
Peidong	Zhao	The University of Texas at Austin
Jing	Zhou	Idaho National Laboratory
Haiyan	Zhu	Southwest Petroleum University