The 2016 ARMA Hydraulic Fracturing Workshop

ARMA Technical Committee on Hydraulic Fracturing

Highlights

The ARMA Technical Committee on Hydraulic Fracturing (TCHF) held its first hydraulic fracturing workshop on June 24th in Houston, TX. Attendance at the sold-out event was capped to encourage discussion, participation, and candor. In total there were 79 attendees representing 56 organizations from six continents.

The workshop consisted of three 2-hour sessions focusing on the physics involved in hydraulic fracturing processes such as initiation, propagation, and closure. Each session featured three speakers in the first hour, and opened the floor for discussions in the second. As many as 10 discussion participants prepared 5-minute presentations and shared their understandings in each fracturing process. The meeting agenda is attached with this highlight.

The workshop deliveries are available to Hydraulic Fracturing Community (HFC) members at an ARMA website (http://armarocks.org/sample-page/committees/technical-committee-on-hydraulic-fracturing-tchf-2/hydrolic-fracturing-workshop-houston-2016/). These include:

1. The highlights (this document);
2. Presentations from invited speakers and discussion participants;
3. Extended papers from invited speakers;
4. Agenda, attached as appendix I; and,
5. Attendee list, attached as appendix II.

The following write-up summarizes the discussion sessions.

Group Photo of TCHF members (from left to right): Mark Mack, Mukul Sharma, John McLennan, Joe Morris, Xiaowei Weng, Sau-Wai Wong, Gang Han, Maurice Dusseault, Ahmad Ghassemi, Jon Olson.

Session 1: Fracture Initiation

Hari Viswanathan/Esteban Rougier (Chair); Maurice Dusseault (Discussion Lead)

Three major issues related to fracture initiation were discussed:

- Longitudinal fractures vs transverse fractures. Operator experience and much field data showed hydraulic fractures started as longitudinal and turned into transverse at some distance (1-2 ft) away from the wellbore. In some tectonic (compressive stress) fields, e.g. Sichuan Basin in China, high pore pressure led to the development of horizontal instead of vertical fractures from horizontal wells. Simulation of this process is important as it has implications for high breakdown pressure and large injection pressure drop near the wellbore.
- Perforation complexity. Traditionally perforations were viewed as an aid to the development of transverse fractures from the wellbore. Some evidence from unconventional fields like Fayetteville confirmed plug-and-perf to be effective to generate transverse fractures. However, data from other fields such as Eagle Ford suggested that perforations failed to induce transverse fractures. Laboratory studies with big block tests showed perforation channels were often missing in a high compressive stress environment. Some participants believed perforation damage itself was significant enough to inhibit the formation from easy breakdown during injection (i.e. the plastic damage induces larger local stresses that inhibit breakdown). The bigger and deeper penetrations might introduce more rock damage.
- Time-dependent fracture initiation. Field monitoring data showed that fractures at the toe of horizontal wells were more difficult to initiate. Once initiated, the toe fractures were likely to be much smaller than the heel ones. Time-dependent rock behaviors such as creep were proposed to incorporate into fracture interference modeling efforts.

There were also discussions on cyclic loading/unloading on fracture initiation and propagation, limited flowback of injected water due to fissured layers and matrix osmosis, loss of connectivity near the wellbore due to creep in shale and soft rocks, etc. These issues introduce additional physical processes and present a challenge to modeling fracturing initiation.

Session 2: Fracture Propagation

Xiaowei Weng (Chair); Sau-Wai Wong (Discussion Lead)

Discussions were focused on four major topics, including:

- Fracture interference. Stress shadow effects are important and depend on the spacing and behavior of earlier induced fractures. The shear displacement induced by the earlier fractures can affect the propagation efficiency for the latter ones. Comparing to propped fractures, fractures that have only been pressurized have less influence on later induced fractures. Both lab and simulations showed that adjacent fractures could diverge (i.e. repel) or converge (i.e. attract). These observations have significant impacts on the optimization of simul-frac, zipper-frac, or refrac operations.

- Scale of heterogeneity and anisotropy. The considerations of rock fabric and its heterogeneity in modeling efforts were discussed at length. The scale at which rock fabric heterogeneity needs to be considered was important. While it is not practical to model every layer or natural fracture in field, data available in the near wellbore region can help explore the impact of rock fabric on fracture height growth. The anisotropies of mechanical and flow properties, in-situ stresses, and toughness also have major influences on fracture trajectory both near the wellbore and away from the wellbore. 3D fracture simulations could help explain some phenomena observed in the field such as asymmetric growth and inclined path.
- Natural fractures. Outcrop studies and lab experiments showed that induced fractures could turn, arrest, pass through, or jump offset when approaching natural fractures, depending on fracture properties and in-situ stress contrasts. Simple 2D models were shown to capture certain features of these patterns. However, more realistic 3D models were also presented that could potentially capture fracture front segmentation and fracture interactions such as crossing or jumping offset. Interface properties such as permeability and strength are important to carry out 3D modeling of fracture propagation and complexity development; yet, because of challenges in testing real fractured rock, these data are rarely available.
- Propagation criteria and mechanisms. The models based on Linear Elastic Fracture Mechanics (LEFM) and Cohesive Zone Model (CZM) were demonstrated. Even though rock toughness, friction loss, and leak-off all play roles in fracture propagation, the contribution from each factor varies in different stages of propagation. Lab or field data is necessary to calibrate and verify whether propagation is dominated by toughness, fluid viscosity, or leak-off.

Questions were raised to verify fracture modeling results with field and lab observations: should propagating fractures be viewed as a single fracture or multiple branches? Was the overestimate of fracture length due to model inadequacy, incompleteness, or lack of poroelastically coupled fluid leak-off in models?

Session 3: Fracture Closure

Joe Morris (Chair); Neal Nagel (Discussion Lead)

In this session, the presentations and discussions were on pressure analysis after shut-in (e.g. DFIT) and proppant transport. More specifically,

- DFIT analysis. Diagnostic Fracture Injection Test (DFIT) or other types of injection/fall-off tests pump a limited amount of fluid to create small fractures bypassing near-wellbore stress alterations. Through interpreting pressure response after shut-in, these tests have long been used to estimate the minimum in-situ stress, pore pressure, or even formation permeability. For unconventional rocks, operators suggested 1-10 bbls of water was enough to create suitable, small fractures. Methods for interpreting pressure fall-off varied based on different assumptions. Some believe the traditional G-function method is sufficient as long as the shut-in period is long enough. Others used joint (natural fracture) closure equations (e.g. SPE 124745) and split fracture closure into mechanical and hydraulic processes. While different methods yield different estimates of in-situ stresses, field data are not conclusive at this time and the discussion at the workshop did not reach unanimous agreement.

- Proppant transport. Different models such as continuum-based FDE/FEM and particle-based DEM were presented to simulate proppant flowing, settling, turning, or arching. Fracturing properties such as opening and roughness and those of proppants such as size distributions and surface irregularities could have significant impacts on proppant placement. Lab experiments and simulations showed that the proppants tended to settle down in the lower part of the hydraulic fracture. However, there was some discussion that field production indicates that the stimulated surface area is often well connected back to the well, despite proppant settlement. The standard API cell test was deemed inadequate for unconventional reservoirs. Lack of lab and field data challenged model validations.

Summary

After hours of knowledge-sharing and often heated discussions, technical challenges and questions for the Hydraulic Fracturing Community were summarized in the closing remark. These include

- Longitudinal vs. transverse fractures: Why do longitudinal fractures often occur?
- Bigger and denser vs. smaller and fewer perforations: Does perforating have a negative effect on fracture initiation?
- Toe vs. heel fractures: Why do fractures at the heel appear to be better developed?
- Converging vs. diverging adjacent fractures: Can models really predict whether one or the other phenomenon takes place?
- Lab, wellbore vs. field scales: Can heterogeneity, natural fractures, fracture toughness be upscaled and effectively characterized for model inputs?
- Rock toughness vs fluid transport and leak-off: Can lab tests and field data help verify and quantify fracture propagation behaviors?
- Traditional vs. new DFIT analyses: How is fracture closure impacted by its surface mechanical characteristics and how does this affect the selection of closure pressure for the minimum in-situ stress?
- Proppant flowing vs. settling: Where do proppants go?

The challenges are clear. While model development has been thriving in recent years, they are more or less faced with similar shortages of genuine calibrations and verifications. In consequence the industry largely has not accepted the “new models” as means of optimizing hydraulic fracture design, or as means of interpreting microseismic or post-fracture stage performance. Lab investigations and field observations become critical to fill in the gap. These subjects will be important for future TCHF workshops.

Appendix I: The 1st TCHF Hydraulic Fracturing Workshop Agenda

8:00 – 8:15 Opening Remarks

8:15 – 10:15 Session I: Fracture Initiation

Chair: Hari Viswanathan/Esteban Rougier

Overview of Fracture Initiation
Bob Barree (Barree and Associates): Consideration of Breakdown Conditions of Directional Wells
Esteban Rougier (Los Alamos National Lab): FDEM analysis of Borehole Fracture Initiation Processes
Robert Gracie (U of Waterloo): Self-consistent in Fracture Simulation: Initiation, Propagation, and Material Models
Group Discussions (led by Maurice Dusseault)

10:15 – 10:30 Coffee Break

10:30 – 12:30 Session II: Fracture Propagation

Chair: Xiaowei Weng

Overview of Fracture Propagation
Mark Mack (Itasca): The effects of stress changes and natural fractures on hydraulic fracture interactions
Ahmad Ghassemi (Oklahoma University): Impact of fracture interactions, rock anisotropy and heterogeneity on hydraulic fracturing - Some insights from numerical simulations
Jon Olson (UT Austin): Hydraulic fracture complexity: what do we know and where are we going?
Group Discussions (led by Sau-Wai Wong)

12:30 – 13:30 Lunch Break

13:30 – 15:30 Session III: Fracture Closure

Chair: Joe Morris

Overview of Fracture Closure
Joe Morris (Livermore): Mechanics of proppant-formation interactions during fracture closure
Dave Cramer (ConocoPhillips): Reexamining DFIT interpretation methods for determining in-situ stress
Alexei Savitski (Shell): Influence of near wellbore tortuosity upon pump-in/flowback test interpretation
Group Discussions (led by Neal Nagel)

15:30 – 16:00 Conclusions

Appendix II: Attendee List

	First Name	Last Name	Company Name
1	Ahmed	Abou-Sayed	Advantek Waste Management Services LLC
2	Bo	Yu	Agapito Associates, Inc
3	Gang	Han	Armaco Services Company
4	Tobias	Hoeink	Baker Hughes
5	Robert	Hurt	Baker Hughes
6	Robert	Barree	Barree & Associates, LLC
7	Bill	Begnaud	BHP Billiton
8	Jessica	Avila	Chevron
9	Eunhye	Kim	Colorado School of Mines
10	David	Cramer	Conoco Phillips
11	deepak	adhikary	CSIRO, Australia
12	Wolfgang	Deeg	Devon Energy Corporation
13	Jun	Ge	Energy & Environmental Research Center
14	Haseeb	Zia	EPFL
15	Mahdi	Haddad	FracGeo
16	Arman	Khodabakhshnejad	FracGeo
17	Ahmed	Ouenes	FracGeo
18	Josh	Camp	Halliburton
19	Hai	Huang	Idaho National Laboratory
20	Mark	Mack	Itasca Houston Inc
21	Byungtark	Lee	Itasca Houston Inc
22	Fengshou	Zhang	Itasca Houston Inc
23	Li	Zhuang	Korea Institute of Civil Engineering and Building Technology
24	Joseph	Morris	Lawrence Livermore National Laboratory
25	James	Carey	Los Alamos National Laboratory
26	Luke	Frash	Los Alamos National Laboratory
27	Esteban	Rougier	Los Alamos National Laboratory
28	Hari	Viswanathan	Los Alamos National Laboratory
29	Stephen	Morgan	Massachusetts Institute of Technology
30	Mark	McClure	McClure Geomechanics LLC
31	Alireza	Agharazi	MicroSeismic Inc
32	Ehsan	Ghazvinian	Mine Design Engineering
33	Kathy	Kalenchuk	Mine Design Engineering
34	Mats	Rongved	Norwegian University of Science and Technology (NTNU)
35	James	Kessler	Occidental Petroleum Corporation
36	Neal	Nagel	OilField Geomechanics LLC
37	Derek	Elsworth	Penn State Univ
38	Marek	Jarosiński	Polish Geological Institute - NRI
39	Emmanuel Oshiokhayame	Umole	POWER HOLDING COOPERATION OF NIGERIA
40	Adam	Bere	Rockfield
41	Uno	Mutlu	Rockfield
42	Mathew	Ingraham	Sandia National Laboratories
43	Moo	Lee	Sandia National Laboratories
44	Safdar	Abbas	Schlumberger
45	Olga	Kresse	Schlumberger
46	Xiaowei	Weng	Schlumberger
47	Bona	Park	Seoul National University
48	Alexei	Savitski	Shell
49	Xu	Li	Shell
50	Sau-Wai	Wong	Shell
51	Andreas	Bauer	SINTEF Petroleum Research

52	Matt	Dycus	SM Energy Company
53	ANDREA	RUSSO	SRK CONSULTING (CHILE)
54	Kan	Wu	Texas A&M University
55	Ali	Rezaei	Texas Tech University
56	Jon	Olson	The University of Texas at Austin
57	Yongcun	Feng	The University of Texas at Austin
58	Xiaorong	Li	The University of Texas at Austin
59	Ken	Gray	The University of Texas at Austin
60	Ripudaman	Manchanda	The University of Texas at Austin
61	Mukul	Sharma	The University of Texas at Austin
62	Hamid	Pourpak	Total EP
63	Jing	Du	Total EP
64	Ken	Glover	Trican Well Service
65	Ahmad	Ghassemi	Univerity of Oklahoma
66	Frederic-Victor	Donze	University Grenoble Alpes
67	Egor	Dontsov	University of Houston
68	Zach	Agioutantis	University of Kentucky
69	Raj	Kallu	University of Nevada
70	Jan	Cornet	University of Oslo
71	Andrew	Bunger	University of Pittsburgh
72	Melvin B	Diaz	University of Science and Technology
73	Maurice	Dusseault	University of Waterloo
74	Robert	Gracie	University of Waterloo
75	Hiroki	Sone	University of Wisconsin-Madison
76	Shunde	Yin	University of Wyoming
77	Robert	Fulks	Weatherford
78	Mojtaba	Pordel Shahri	Weatherford
79	Roberto	Suarez-Rivera	W D Vongonten Lab