Barracuda Applications in Oil and Gas Industry

From fracking to biomass conversions, many processes possess similar traits and objectives

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INTRODUCTIONS

- Energy industry is going through unforeseen challenges and needs infusion of new technologies that goes beyond conventional thinking and technologies.
- Particle-laden flows in energy industry can be large in scale and commercial-scale predictions are necessary for successful applications.
- Conventional CFD methods are proven difficult to achieve the goals.
- Two novel applications for Barracuda will be discussed:
  - Oil sand transport and erosion – solid settling and re-entrainment in viscous liquid flows is a first for MP-PIC model
  - Hydraulic fracturing in unconventional reservoirs – high concentration sand pumping into large reservoir fractures represents a challenge for other approaches

Oil sand transport and erosion

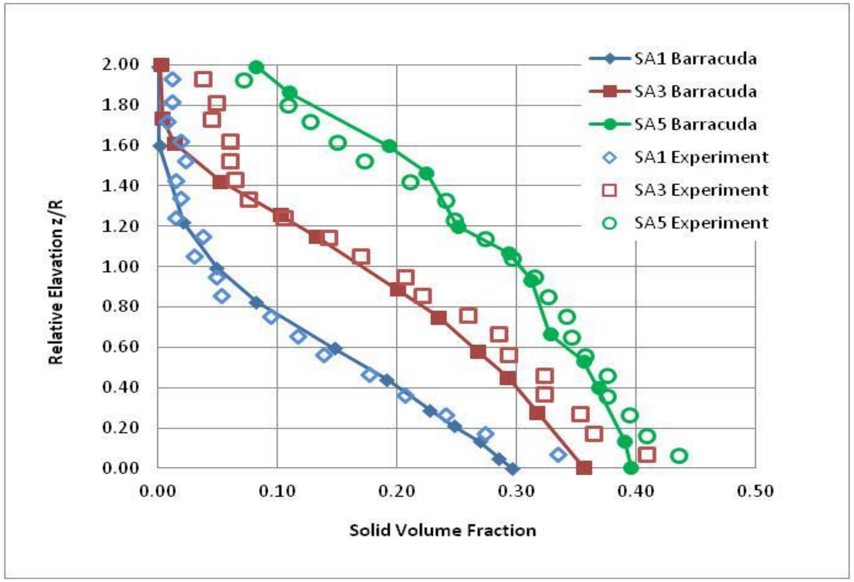
Dense slurry transport has always been difficult to do with erosion effects. MP-PIC approach provides a unique capability not found in Eulerian-Granular models

Introductions

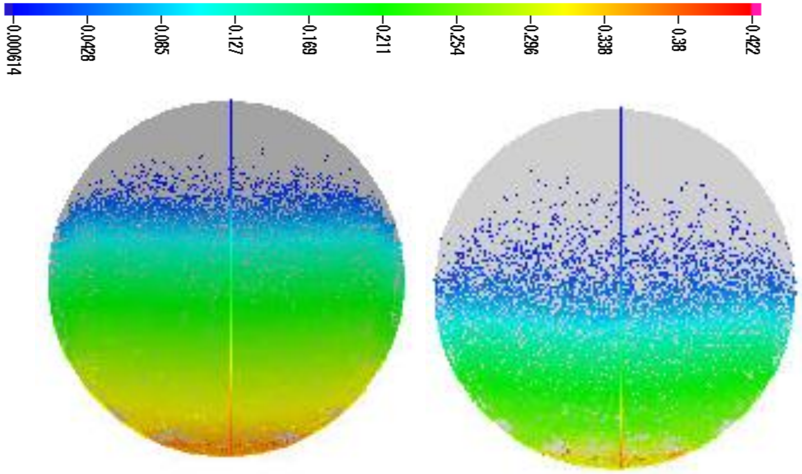
- Oil sand business were a big part of Shell’s oil production before 2016, but has been sold entirely and no longer in Shell’s portfolio.
- High content of sand solids present a unique challenge for operations and modeling.
- Erosion and sand entrainment are the main concerns.
- No good models available for both erosion and high concentration slurry transport.
- Eulerian Granular model lacks good erosion model and particle size distribution is difficult and expensive to have.
- DEM model can do the work but the cost is high and impractical.
- Barracuda provides a unique combination of speed and capability unparalleled by other approaches.
- Solid/liquid interactions need better interpretation.

Model fit

- By tweaking the particle normal stress model, excellent data fit were found using Ps=40 and β=1 as shown.
- However, with mixture velocity reduced by half to 0.83 m/s, no sand bed formation was found - in contradiction to SRC PipeFlow’s prediction of a critical deposition of 1.28 m/s



Steady-state sand concentration profiles



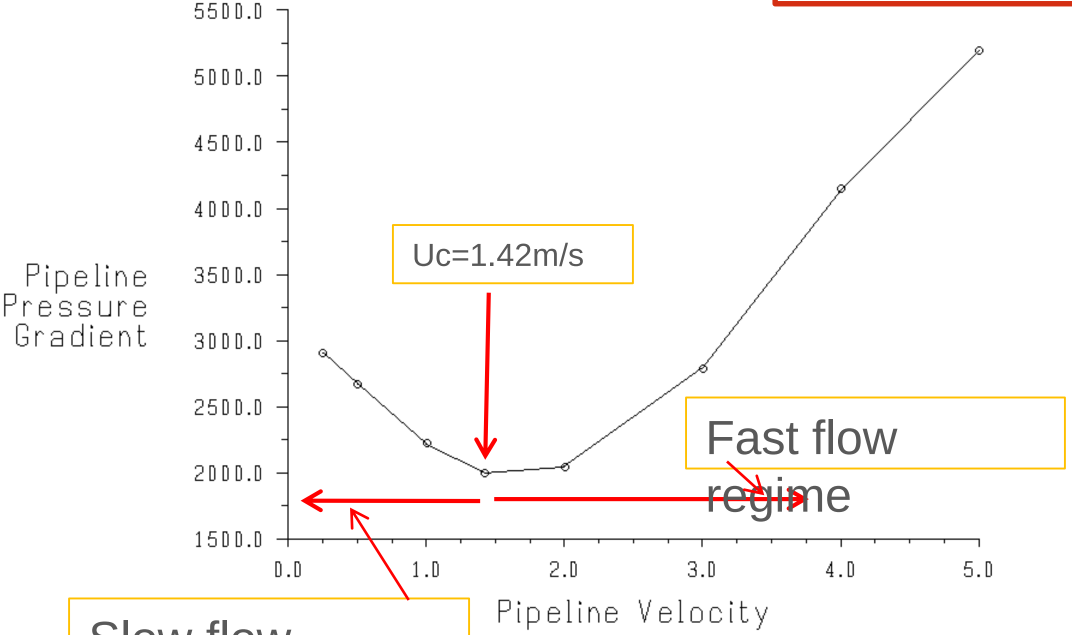
SA3 SA1

Steady state sand concentration contours

SRC Pipeflow Engineering Model Validations

- Pressure gradient variation obtained from SRC

Phenomenon:
When U>Uc, dp/dx increases as pipeline velocity increases;
When U<Uc, dp/dx increases as pipeline velocity decreases;

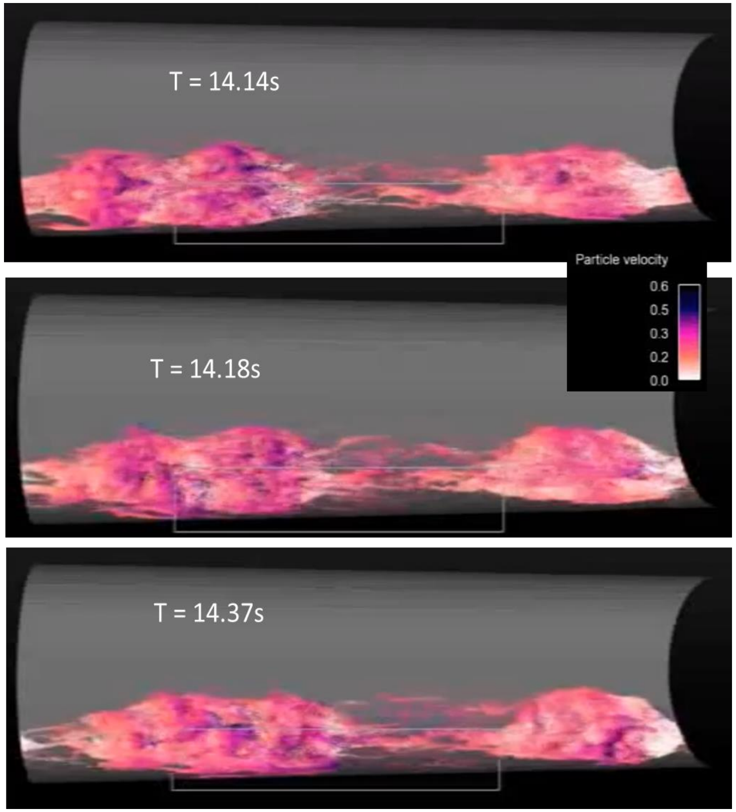


Uc=1.42m/s

Fast flow regime

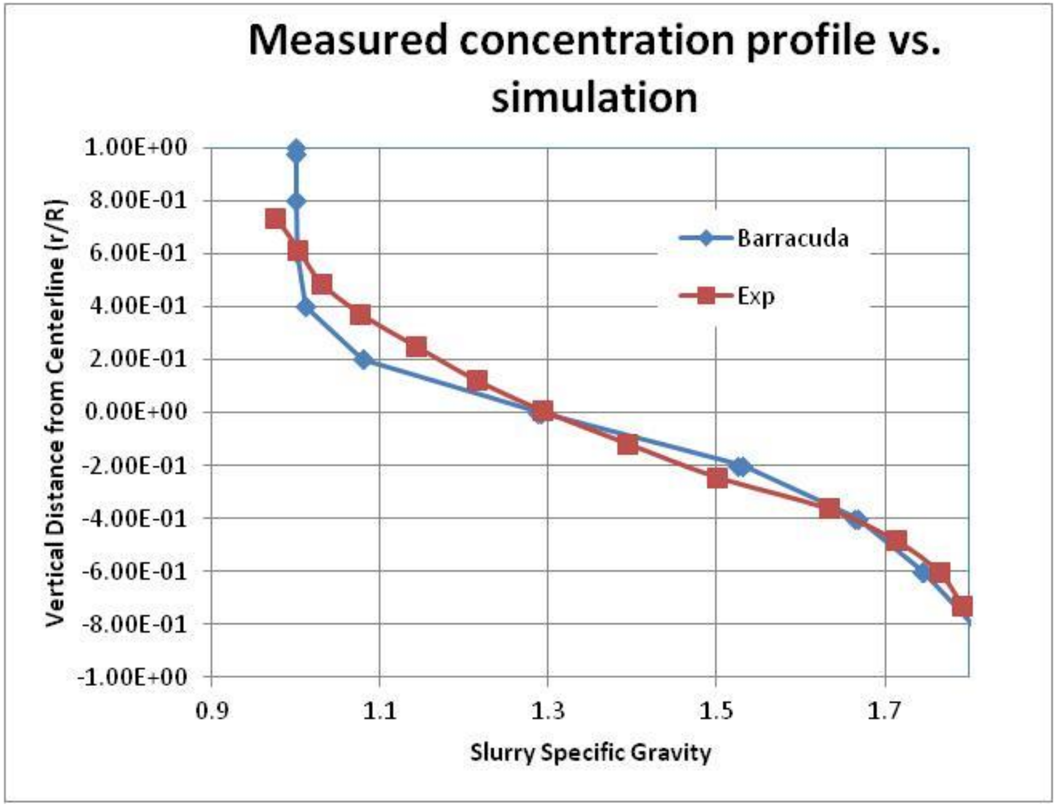
Slow flow regime

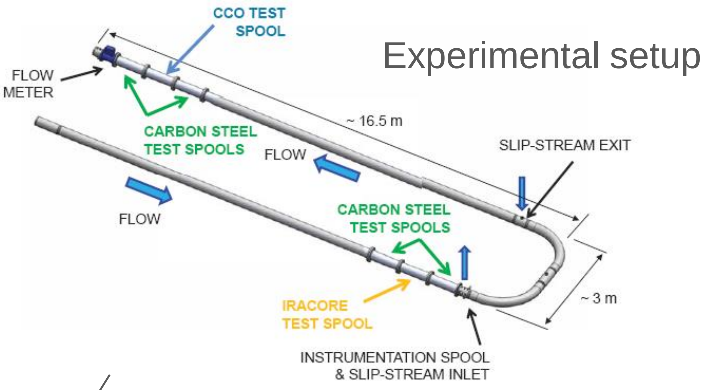
Minimal Solid Entrainment Velocity – LES/DEM

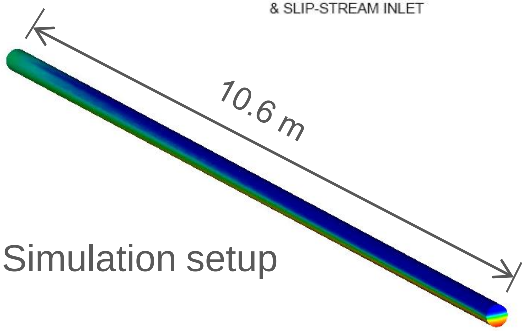


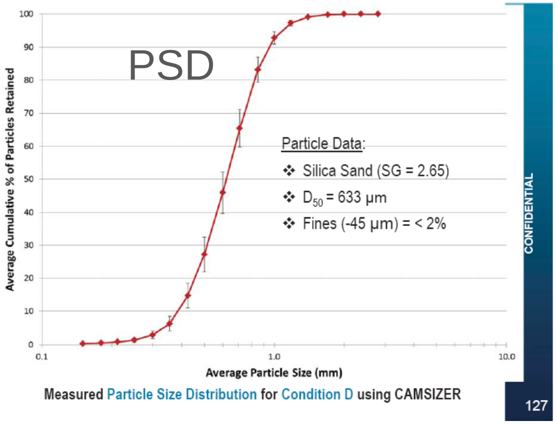
- Modeling of particle entrainment – LES/DEM
- ~20 MM cells + 20 MM particles + DNS drag laws…

SAND CONCENTRATION PROFILE VALIDATION




Experimental setup


Simulation setup

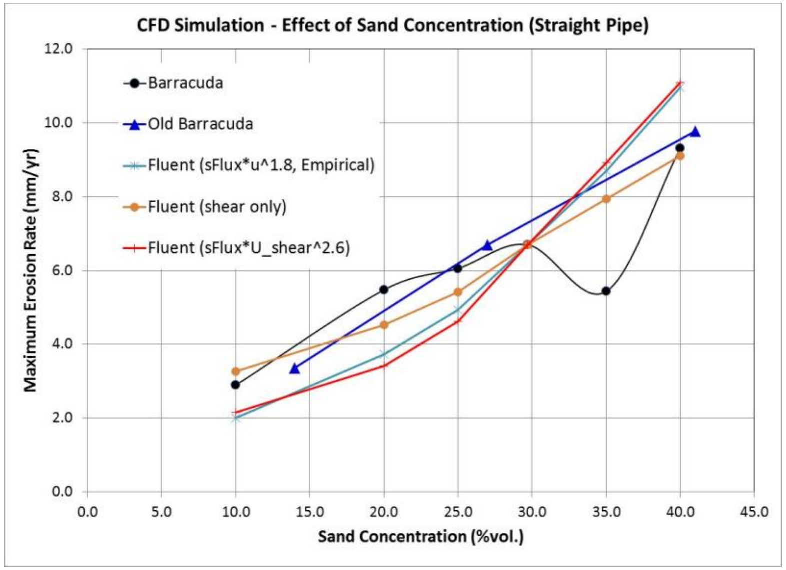

PSD

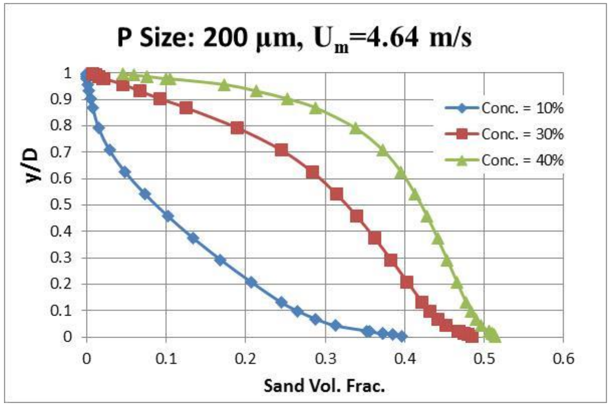
Particle Data:
- Silica Sand (SG = 2.65)
- D_{50} = 633 μm
- Fines (-45 μm) = < 2%

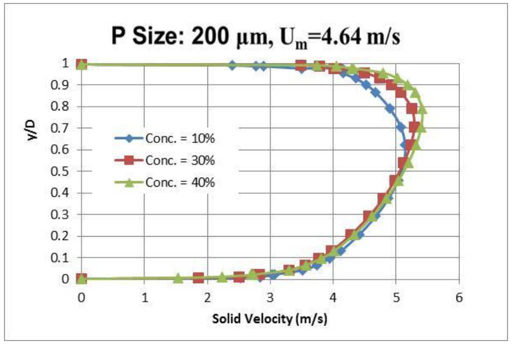
Measured Particle Size Distribution for Condition D using CAMSIZER

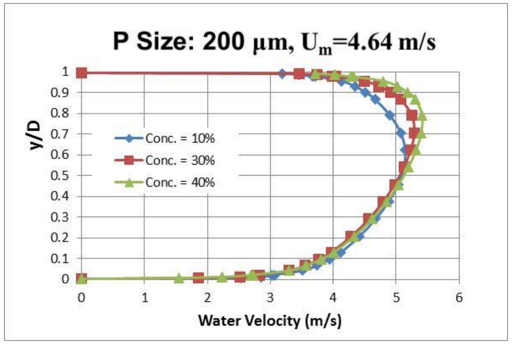
- Pipe ID: 7.625”
- Experiment setup – loop
- Model setup – straight pipe

RESULTS – SOLID CONCENTRATION VS. EROSION RATE


CFD Simulation - Effect of Sand Concentration (Straight Pipe)


P Size: 200 μm, U_m=4.64 m/s


P Size: 200 μm, U_m=4.64 m/s


P Size: 200 μm, U_m=4.64 m/s

- The effect of solid concentration on erosion is shown here.
- Solid volume concentration ranges from 10 to 40%
- A near linear trend is observed from 25% to 40%, and the overall trend is also close to linear in accordance with published work
- The calibration point is at 4.64 m/s, 30% solid concentration with 200 μm particles
- The figures on the top right shows the profiles of solid concentration, velocity and water velocity along the pipe vertical centerline

CONCLUSIONS

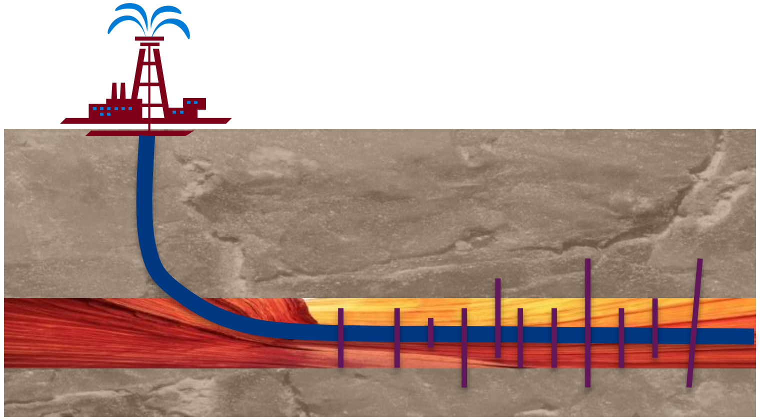
- High concentration slurry flow requires combination of speed and accurate solid collision model to satisfy experimental data.
- Solid pressure terms need modification to predict solid concentration profiles in experiments.
- Scale-up results can be excellently matched.
- Erosion predictions are satisfactory as well in Barracuda v14.
- New version of Barracuda failed to get correct trend in high solid concentration and velocity.
- New model developed for Eulerian-Granular erosion rate implemented in Fluent to compensate the need based on Barracuda v14 predictions.

HYDRAULIC FRACTURING

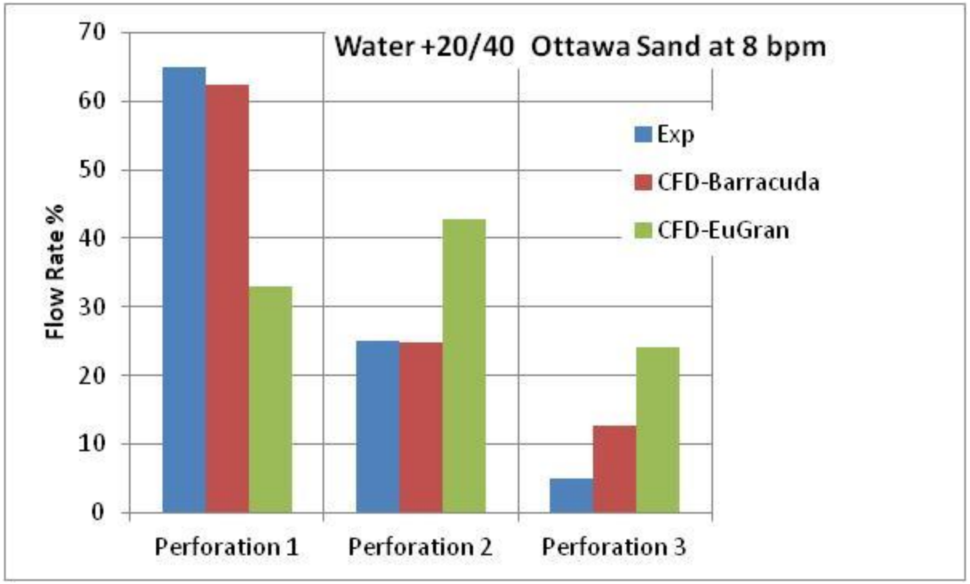
Unconventional reservoir requires new capabilities to predict well performance

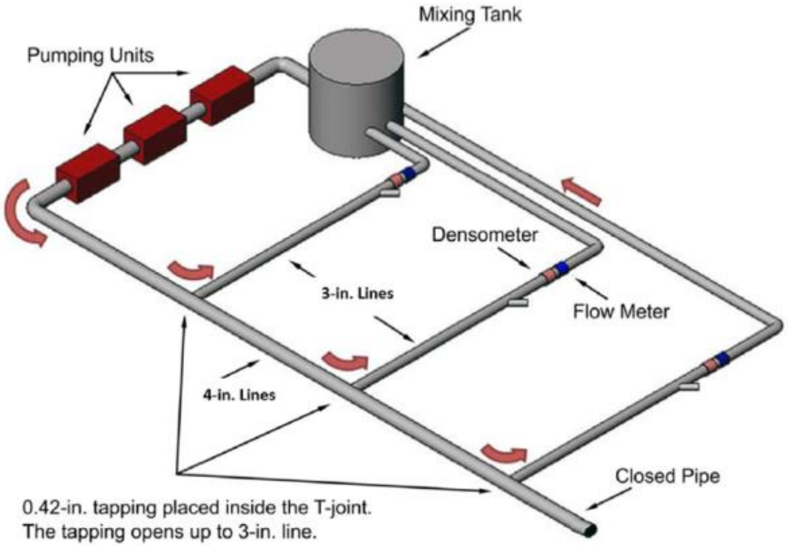
CHALLENGES

- Unknown downhole pressure
- Lab results cannot repeat downhole conditions
- Difficult to replicate the high flow rates used in the field in the lab’
- Incorrect flow regime can result in different proppant distribution
- Field measurement only reflects total flow
- Long pipes between perforations – numerically unfeasible
- Long simulation time



VALIDATION WITH LAB EXPERIMENT



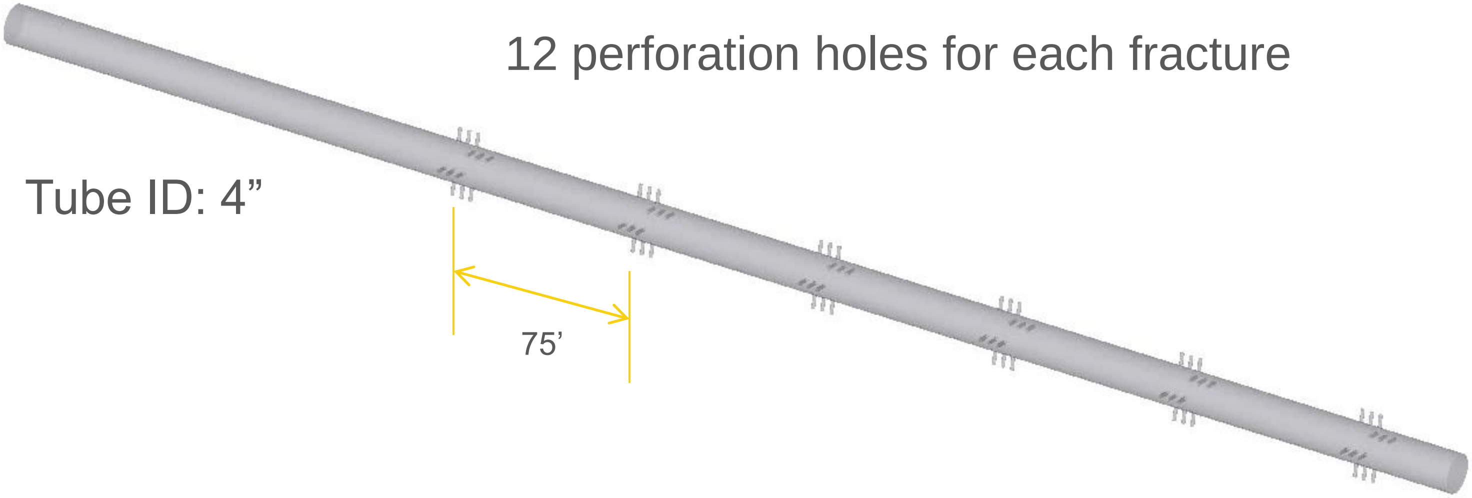


*SPE Paper #163852, Crespo *et al*., 2013

- **Equal liquid flow** among three perforations
- Highly skewed sand flow reproduced by Barracuda at low flow rates
- Eulerian-Granular flow model predicted much more even sand flow distribution
- Sand profile and pressure drop are validated in earlier works.
- Experimental data not normalized properly (sum<100%), simulation match should be even better if errors corrected

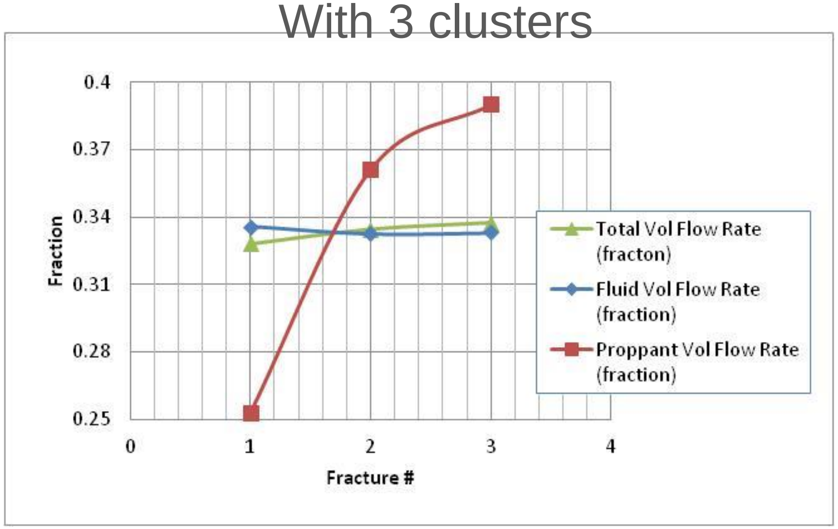
MODEL PARAMETERS

- Geometry
- Number of clusters and perforation hole # in each cluster
- Carrier fluid viscosity
- Outlet conditions due to fracture pressure – uneven flow distribution due to boundary conditions

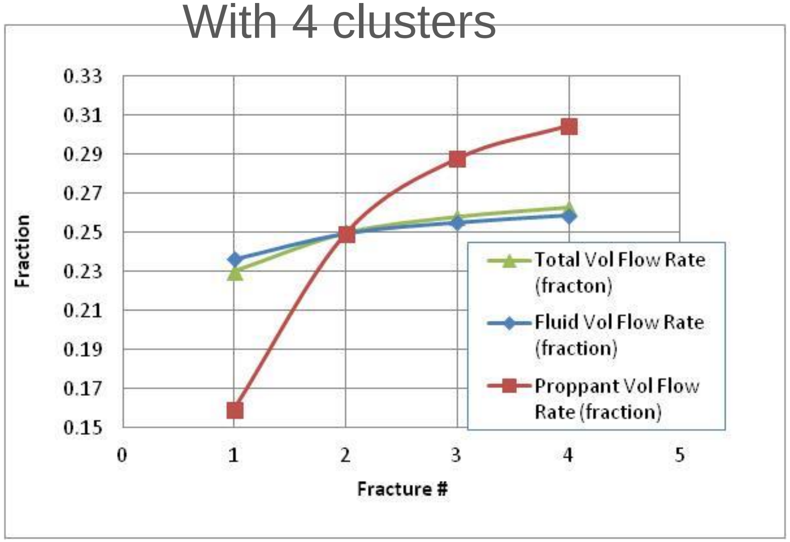


FLOW DISTRIBUTIONS VERSUS # OF FRACTURES/CLUSTERS – PERFORATION HOLES

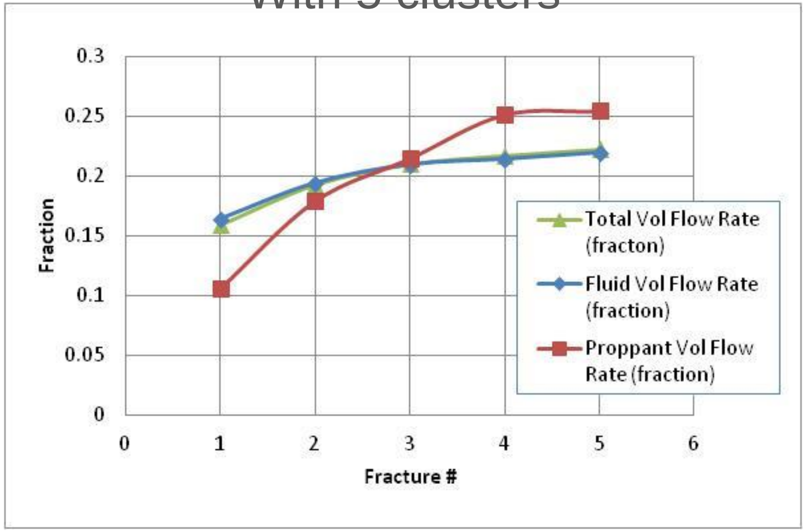
With 3 clusters



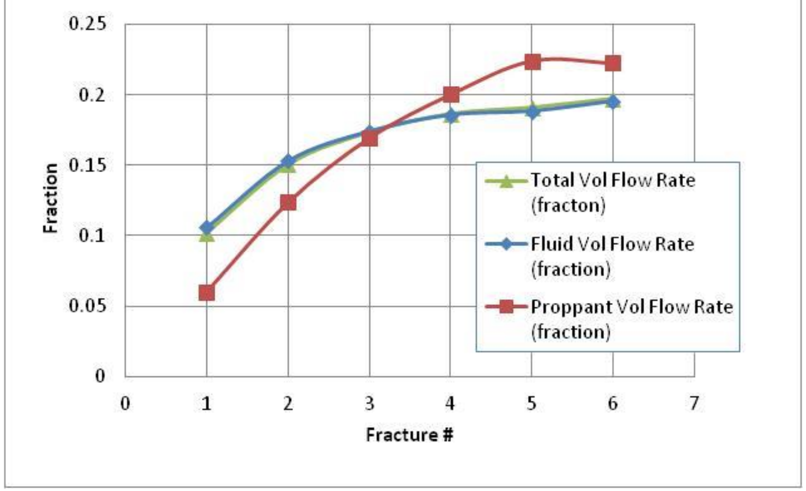
With 4 clusters



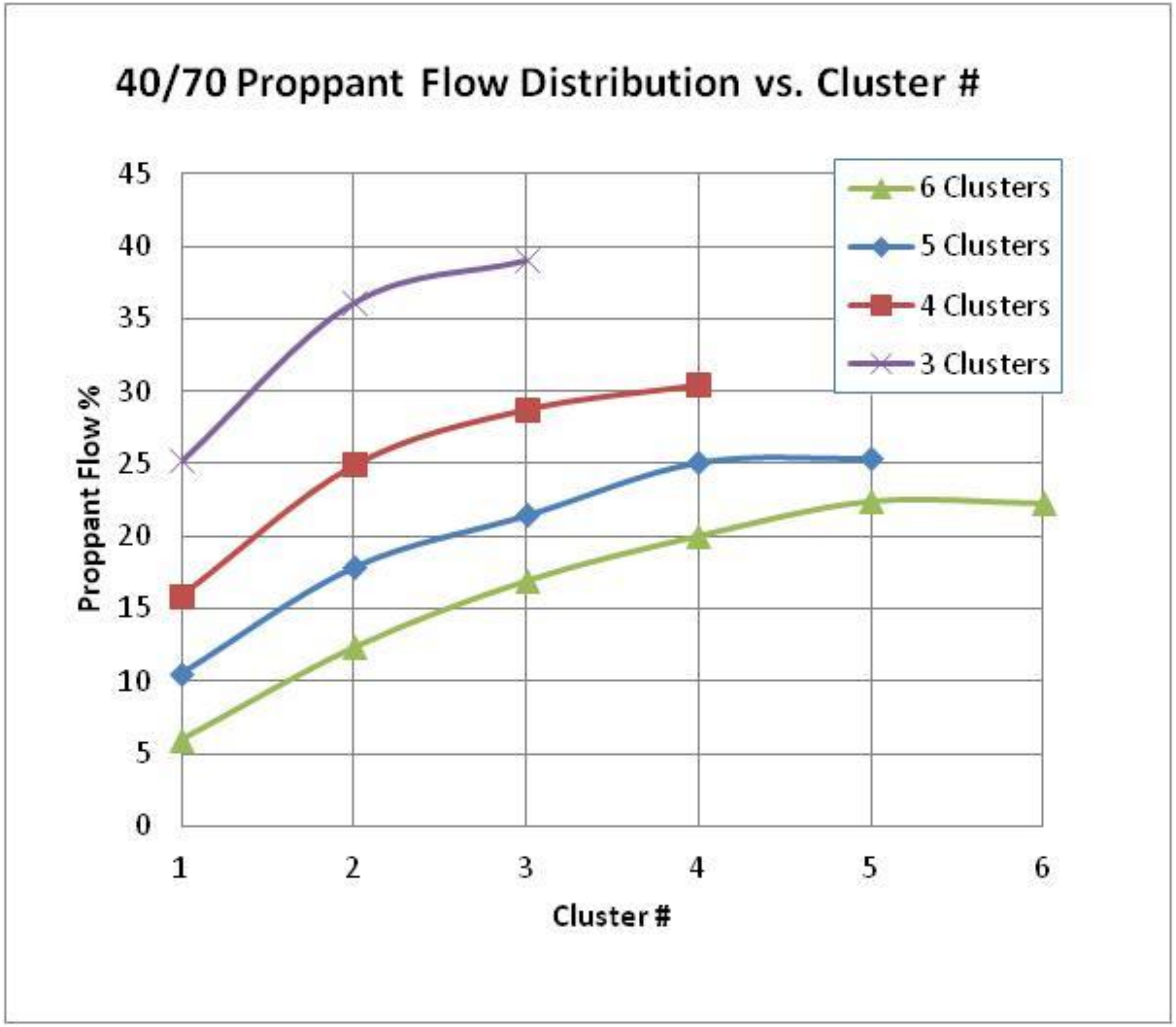
With 5 clusters



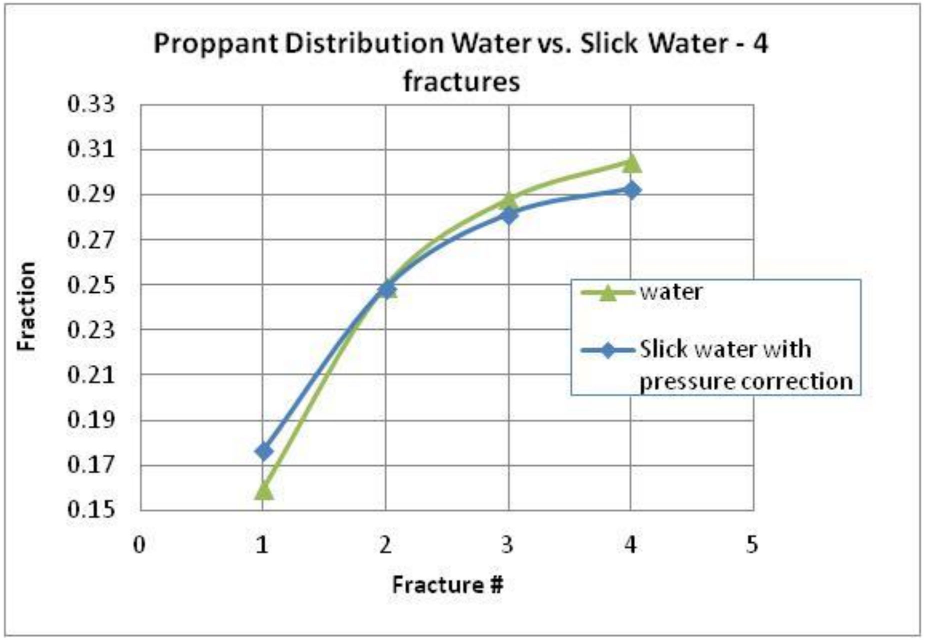
With 6 clusters



PROPPANT DISTRIBUTIONS VERSUS # OF FRACTURES/CLUSTERS – PERFORATION HOLES



SLICK WATER EFFECTS ON PROPPANT DISTRIBUTION IN THE CASE OF 4 CLUSTERS

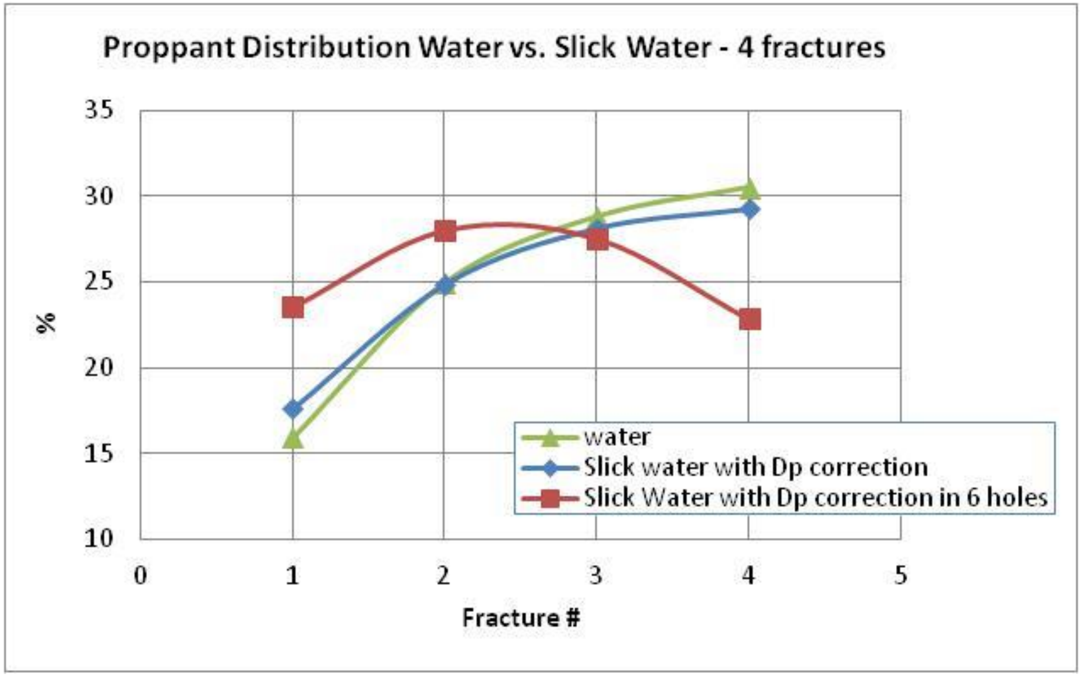


- Proppant distribution is not significantly affected by carrier fluid properties between water and slick water
- Slick water:
  - Viscosity = 2cp
  - dP reduced by a factor of 0.45 with 2.5 ppg proppants

COMPARATIVE CASES STUDIED WITH 12 AND 6 PERFORATION HOLES WITH SLICK WATER AND dP CORRECTION

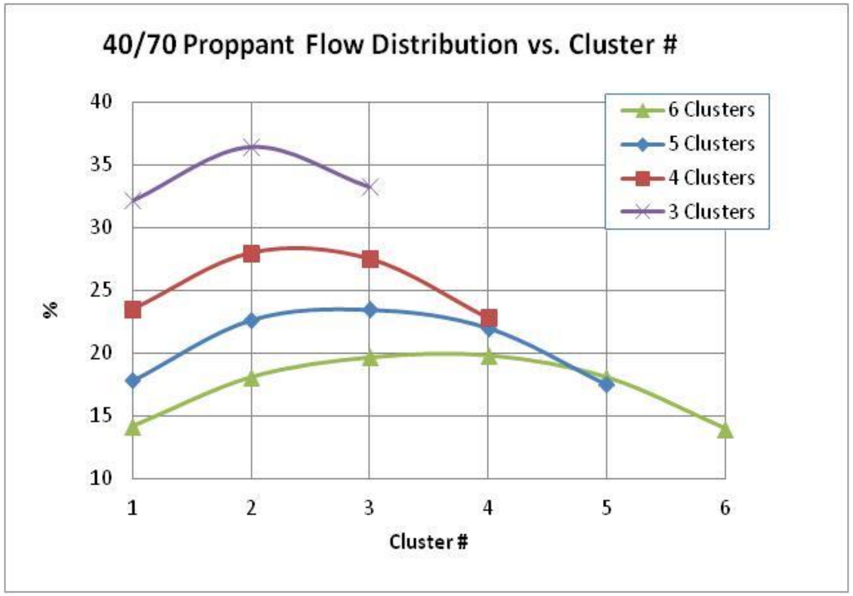
- Three cases compared:
  - Water with 12 perforation holes in each cluster
  - Slick water with 12 perforation holes in each cluster
  - Slick water with 6 perforation holes in each cluster
- Each case with 3, 4, 5 and 6 clusters compared
- Perforation hole ID: 3/8”
- For slick water with proppants the Dp was corrected with a factor of 45%
- Slick water viscosity 2 cp
- Proppant concentration 2.5 ppg
- Flow rate: 75 BPM

PROPPANT DISTRIBUTIONS WITH 4 CLUSTERS

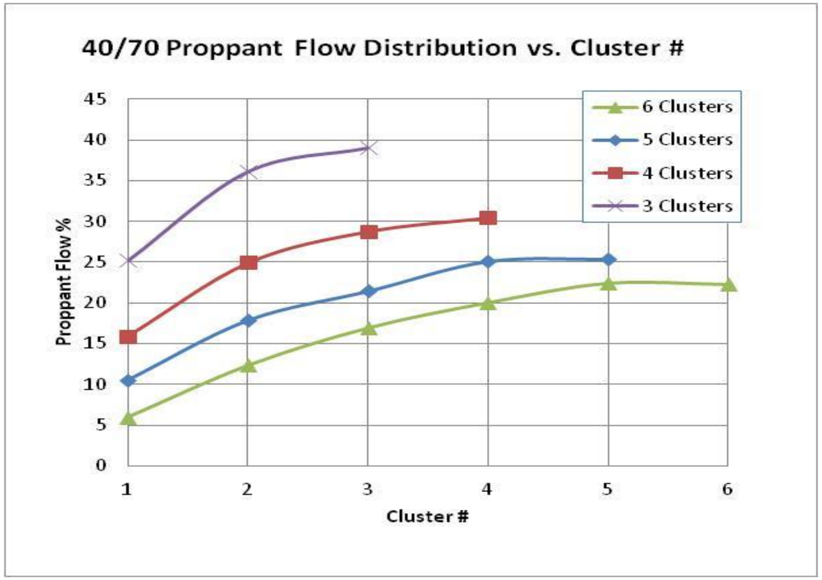


- Proppant distribution comparison for three cases
- Difference between water and slick water is insignificant
- With 6 instead of 12 perforation holes, the increased pressure greatly even out the proppant distribution

PROPPANT DISTRIBUTIONS WITH 6 AND 12 PERFORATION HOLES



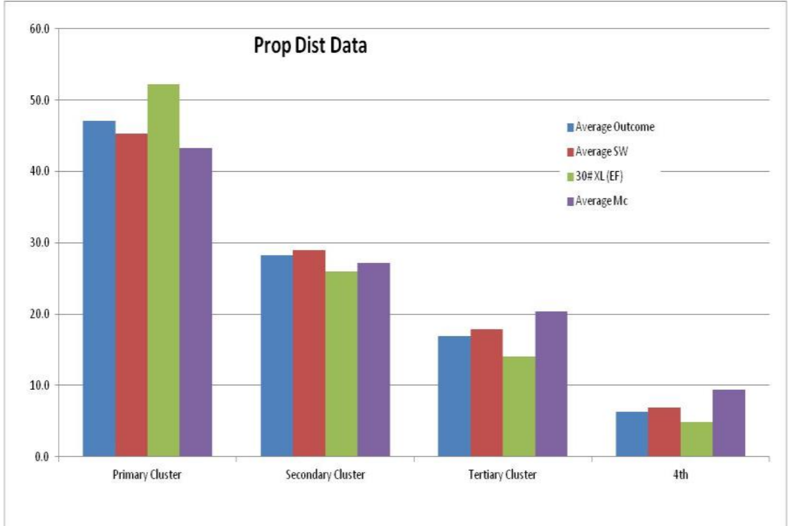
6 holes



12 holes

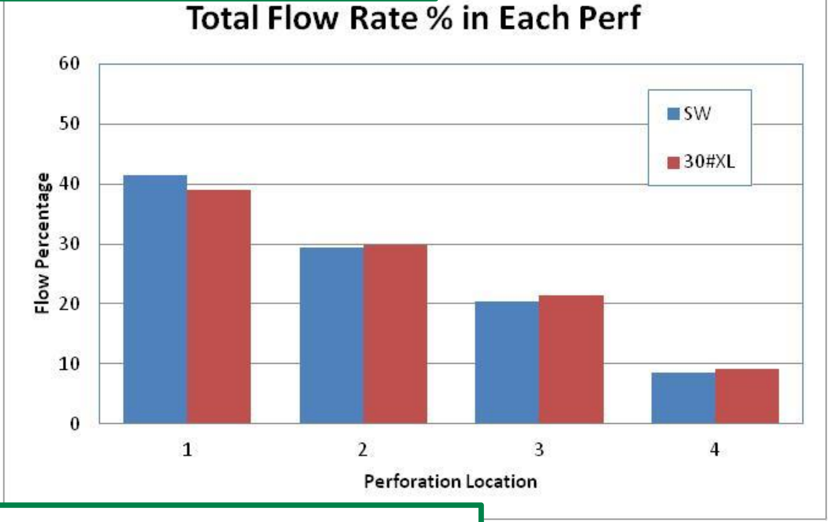
- Proppant distribution comparison for three cases
- Difference between water and slick water is insignificant
- With 6 instead of 12 perforation holes, the increased pressure greatly even out the proppant distribution

FLOW DISTRIBUTION DATA FROM THE FIELD USING DTS

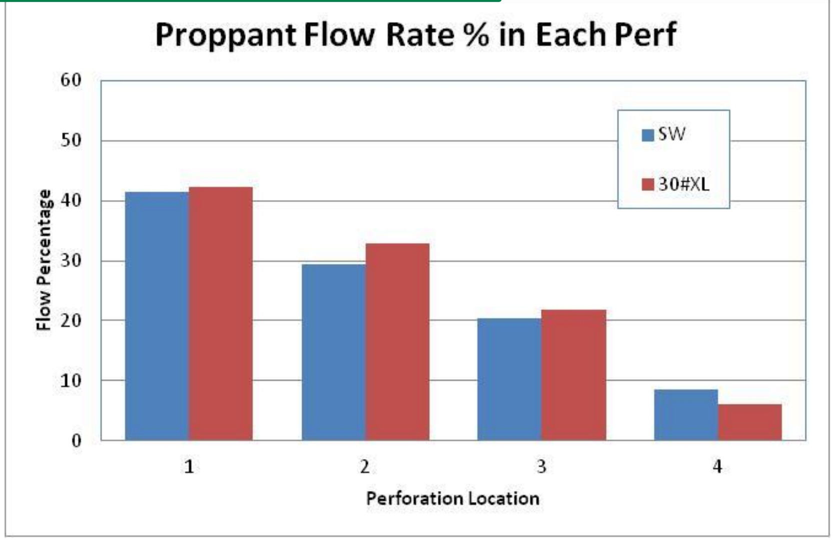


Field data using DTS/DAS

Simulation Results – Total Flow %



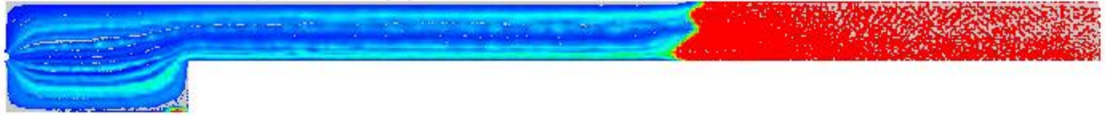
Simulation Results – Proppant Flow %



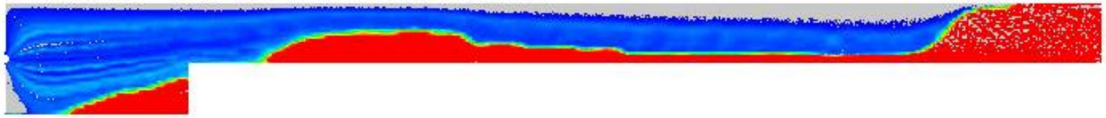
- Data used to calibrate Barracuda flow simulation by adding pressure loss coefficient to mimic flow distribution.
- It can seen that once flow is calibrated, both total flow and proppant shows similar distributions regardless of SW or XL (gel) used as carrier fluid!

PROPPANT DISTRIBUTION VS. FLOW RATES AND PROPPANT DENSITY - EXAMPLE

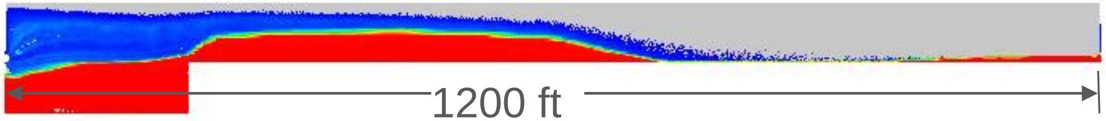
18.75 bpm, Proppant SG=1.0, t = 3600s



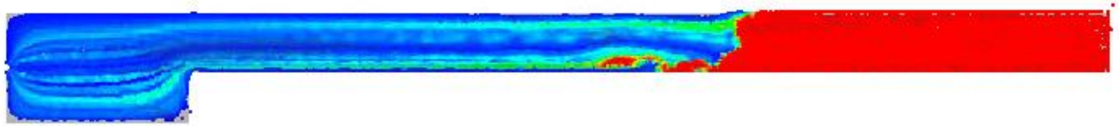
18.75 bpm, Proppant SG=1.35, t = 3600s



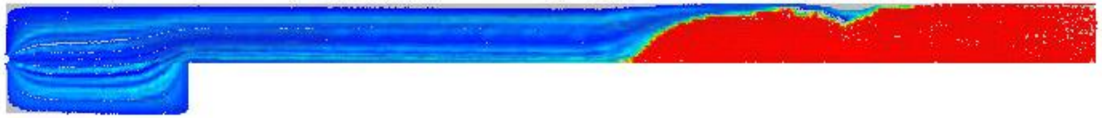
18.75 bpm, Proppant SG=2.65, t = 3600s



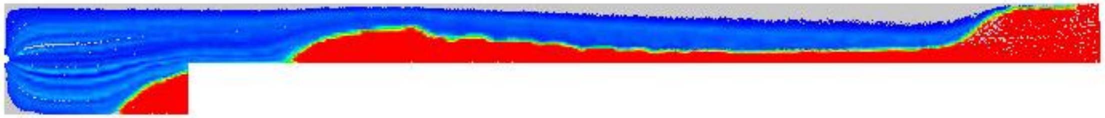
75 bpm, Proppant SG=1.0, t = 900s



75 bpm, Proppant SG=1.35, t = 900s



75 bpm, Proppant SG=2.65, t = 920s



- Varying pumping rate and density have significant impact on proppant distribution in the fracture
- Other factors are important as well:
  - Fluid density and viscosity
  - Proppant size, density and shape (drag)
  - Proppant coating

❖Red color indicates packing limit

❖Grey color indicates liquid only

*SPE Paper #151607, Tsai *et al*. 2013

CONCLUSIONS

- Complete liquid/particle fluidization model for slurry transport has been developed and applied to oil and gas operations.
- Model optimization through published data.
- Some phenomenon are proven difficult to model and better methods should be used.
- Large-scale fracking applications can be modeled effectively with Barracuda and results can be useful for decision making.
- GPU acceleration greatly enhanced the model speed (from 1-2 weeks to 1-2 days) and allows realistic optimization for commercial operations