Use of Fly Ash as a Proppant in Fracking of Unconventional Oil & Gas Wells

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University of Kentucky Center for Applied Energy

Curtis Willie, Jim Crenshaw

Enhanced Solutions Services

KOGA Annual Meeting 6/27/2024

Our Partners: Enhanced Solutions Services

More than 80 years of combined oil and gas experience

About ESS

Founded in 2017, ESS is a premiere technical and engineering partner. The company serves as trusted advisor for operators across multiple basins globally, as well as researching and advising on Oil & Gas-related technologies.

Curtis Wilie
Chief Operating Officer

Mr. Wilie is an oilfield veteran with over 40 years of experience in global technology leadership roles.

Curtis started with Halliburton as a field engineer in 1980, ultimately serving as global chief technical advisor for tools and testing before joining Shell in 2002. There, he built Shell's global deepwater well evaluation team, then moved on to become the global director of Shell's deepwater technology portfolio.

Jim Crenshaw
Chief Petroleum Engineer

Mr. Crenshaw has more than 40 years of global operations experience with both major oilfield service companies and private equity-backed start-ups.

During a career spanning five continents, he held numerous senior management and board positions. In these roles, he focused on operations, engineering and development, as well as roll-out and implementation of new technologies focused on both drilling and completions.

Outline of Presentation

- Background, how we got here
- Fly Ash as a Proppant: General Properties
- Advantages of Fly Ash Proppants
- Early Field Trials and Demonstrations
- Commercial Deployment
- Bringing the Technology Home: Ongoing Research
- Summary

Background: how we got here

- UK Program
  - Research on technology for the recovery and classification of fly ash from active ponds. 2014-2015 via SBIR and State funding.

- Enhanced Solution Services (ESS) formerly Metis.
  - Purchased old oil wells.
  - Initiated field trials, 2017.

The NuForm Materials Classifier/Thickener Technology

Designed to be:
Simple
Inexpensive
Flexible
Transportable

The NuForm Materials Classifier/Thickener Technology

AEP Cardinal Pond, Brilliant, Ohio 2014-2015

Field trials of Classifier/Thickener Technology with Sphere One.

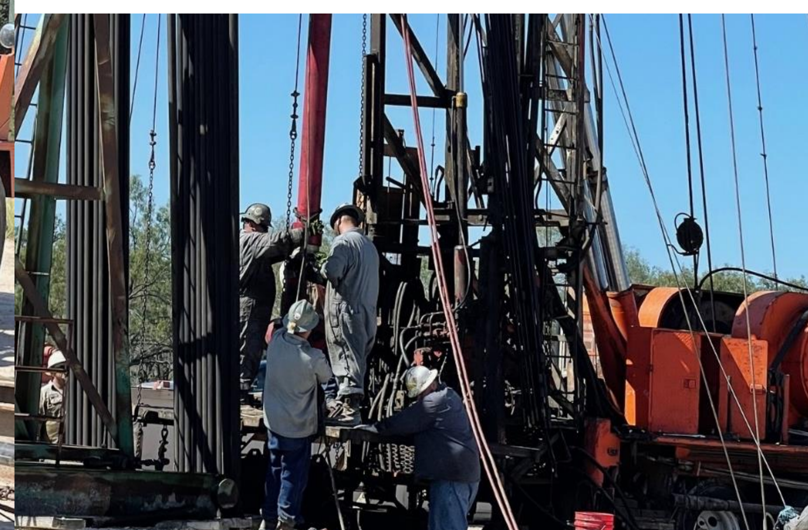
Completed Plant

Dredge

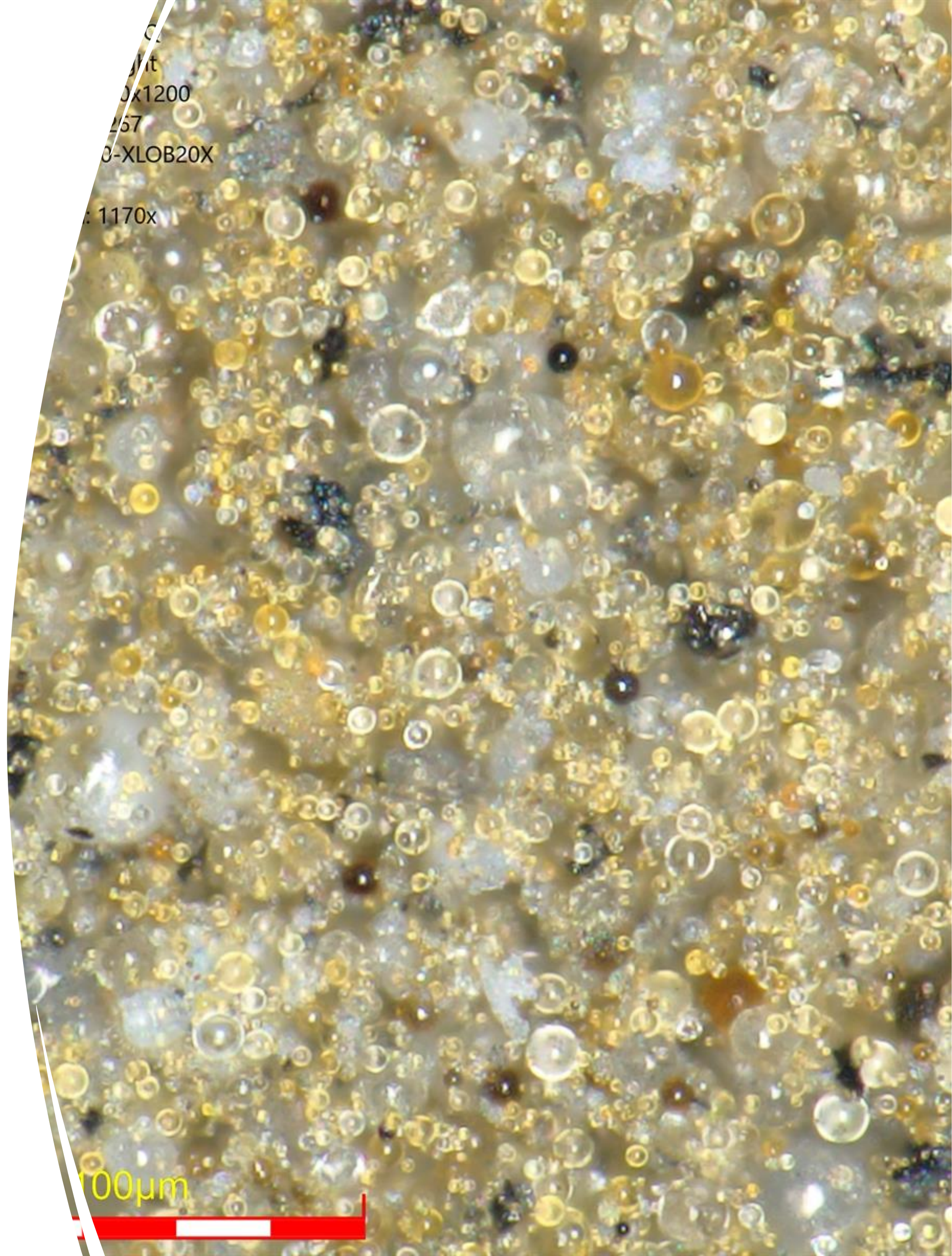
AEP Cardinal Pond, Brilliant, Ohio

Pilosa No. 3 Well-First Fly Ash Frac 2017

Pilosa No. 3 Well-Make Over 2022



Fly Ash as a Proppant: General Properties

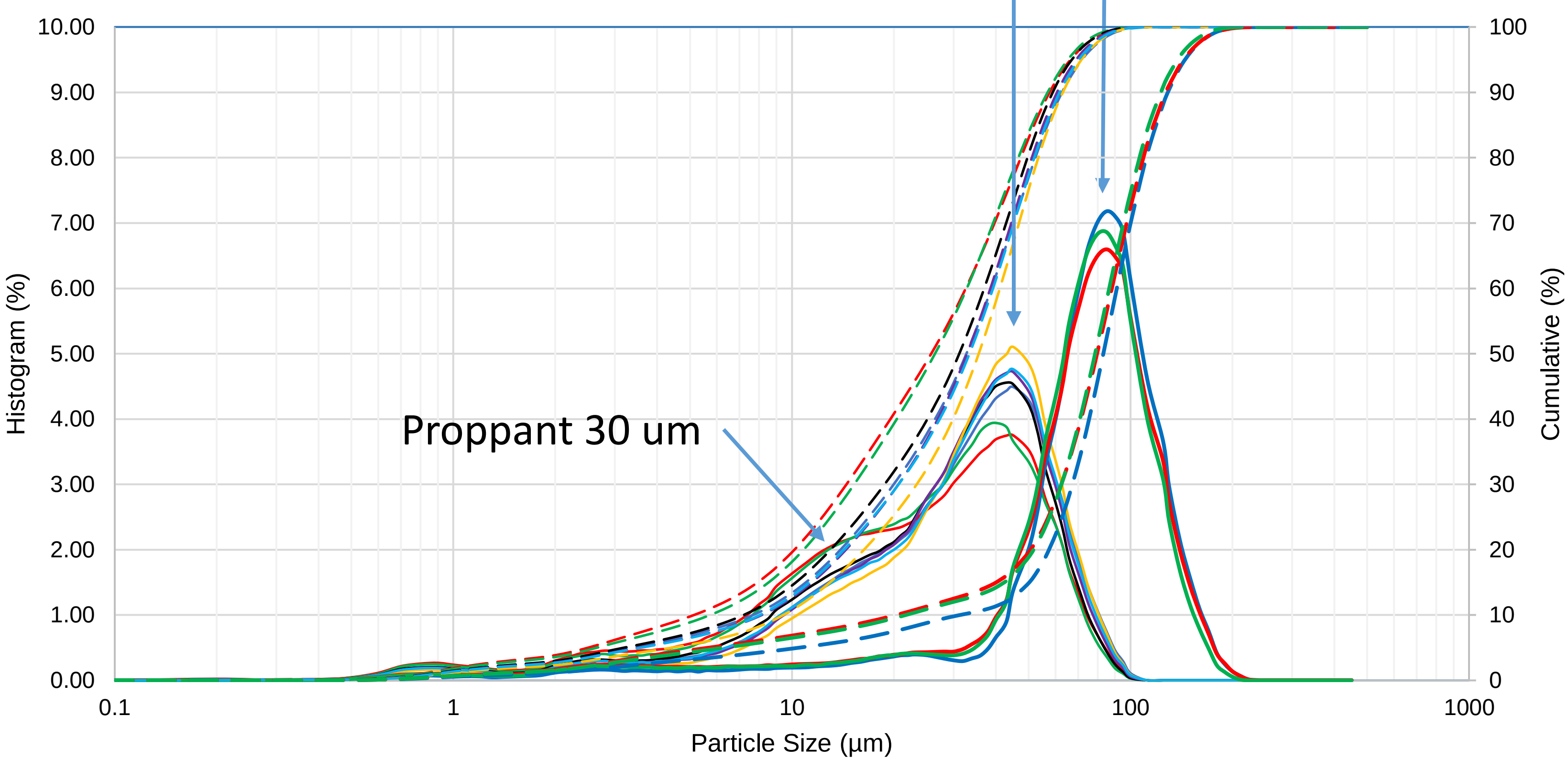


ISO 13503-2 Proppant Tests

- 4. Standard Sampling
- 5. Storage
- 6. Sieve Analysis
- 7. Proppant Sphericity and Roundness
- 8. Acid Solubility.
- 9. Turbidity.
- 10. Procedures for determining proppant bulk density, apparent density and absolute density.
- 11. Proppant crush-resistance test.
- 12. Loss on ignition of resin-coated proppant.

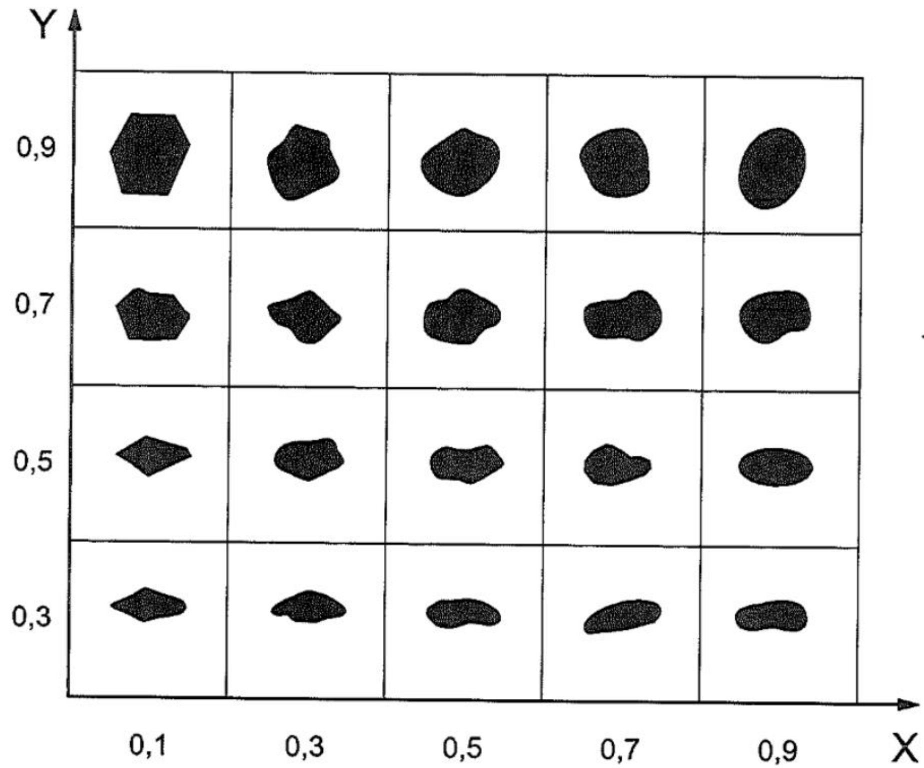
Ash Particle Size From Pond: Laser Data

Low Settling Velocity
0.3-0.4 cm/s vs
47 cm/s for 20 x 40 mesh quartz sand



Manipulating particle size distribution from ponded ash

7. Sphericity and Roundness



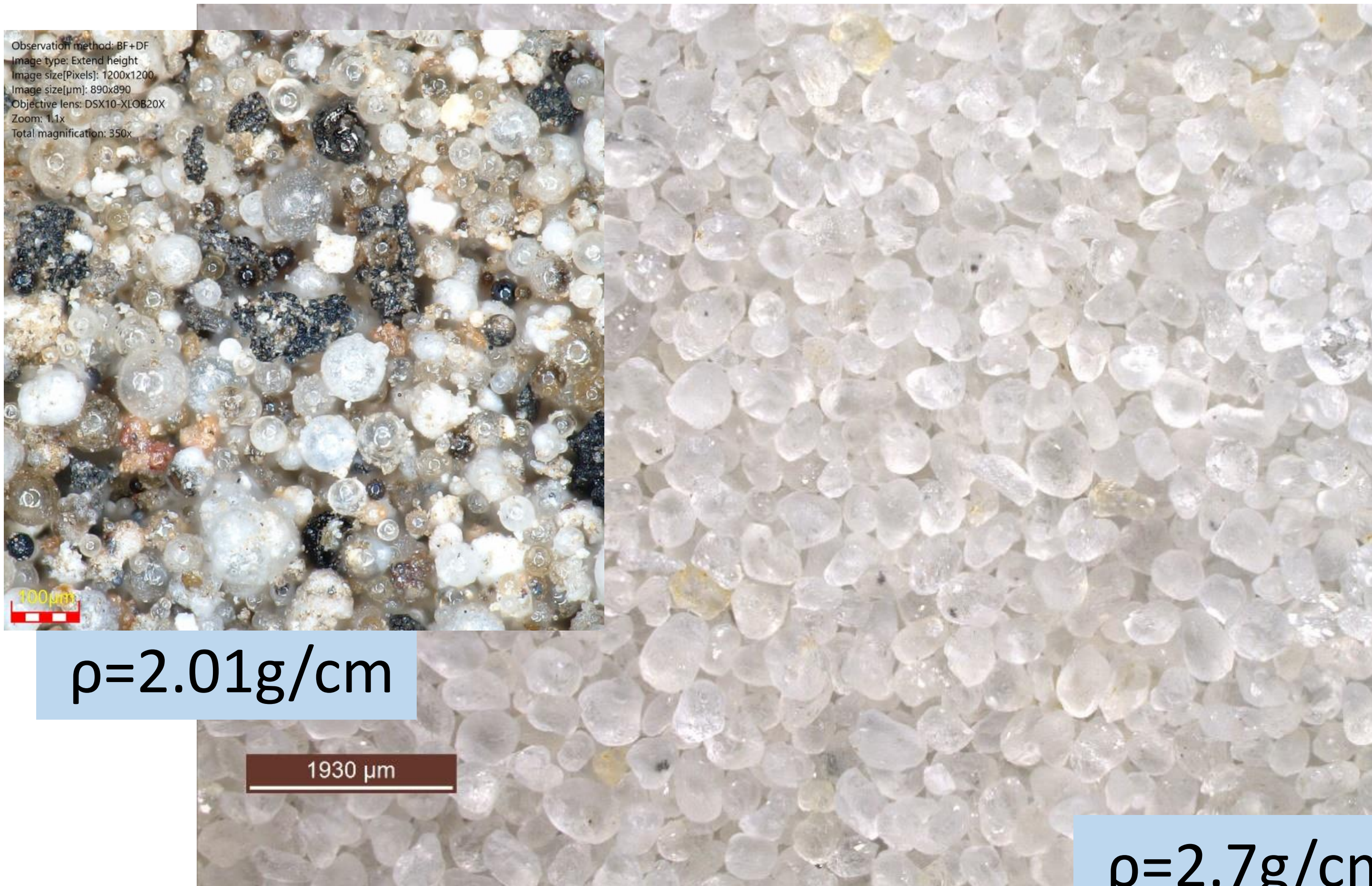
Key

X roundness

Y sphericity

Figure B.1 — Chart for visual estimation of sphericity and roundness

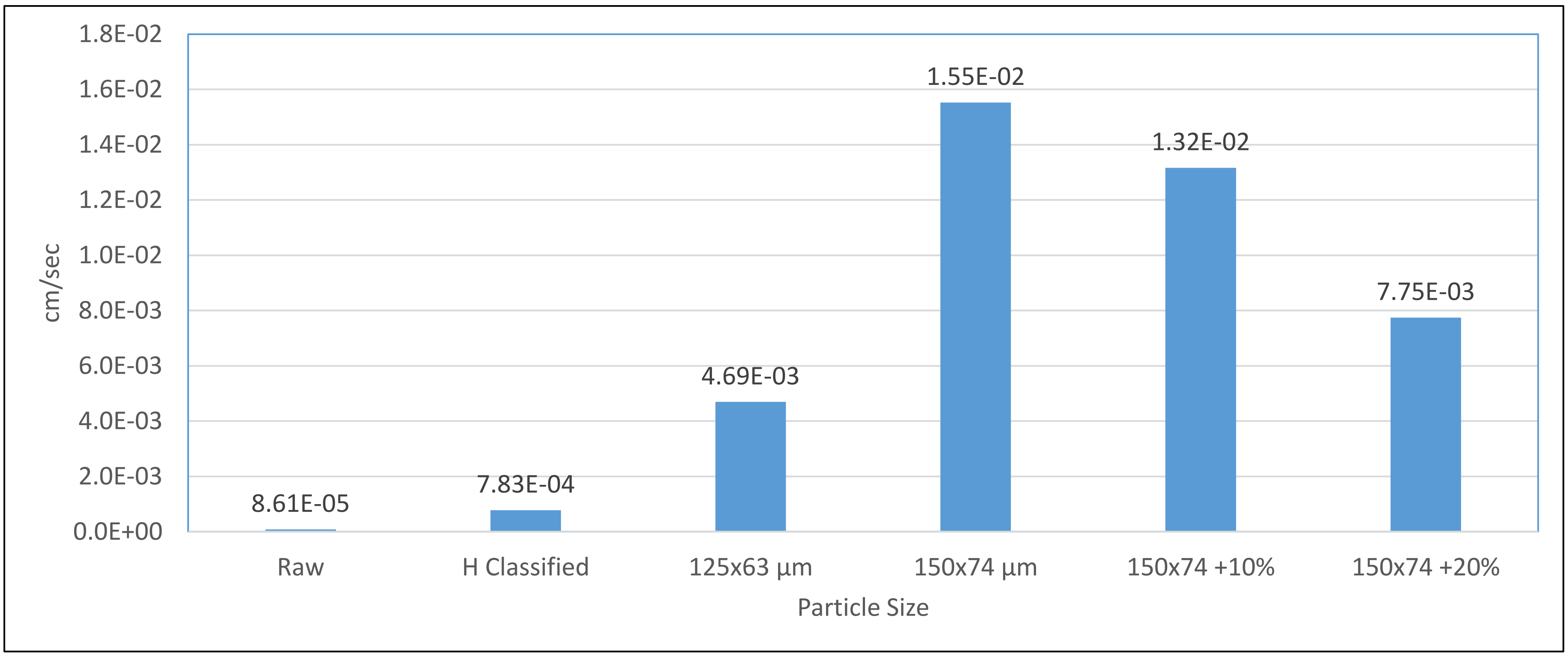
Sphericity and Roundness



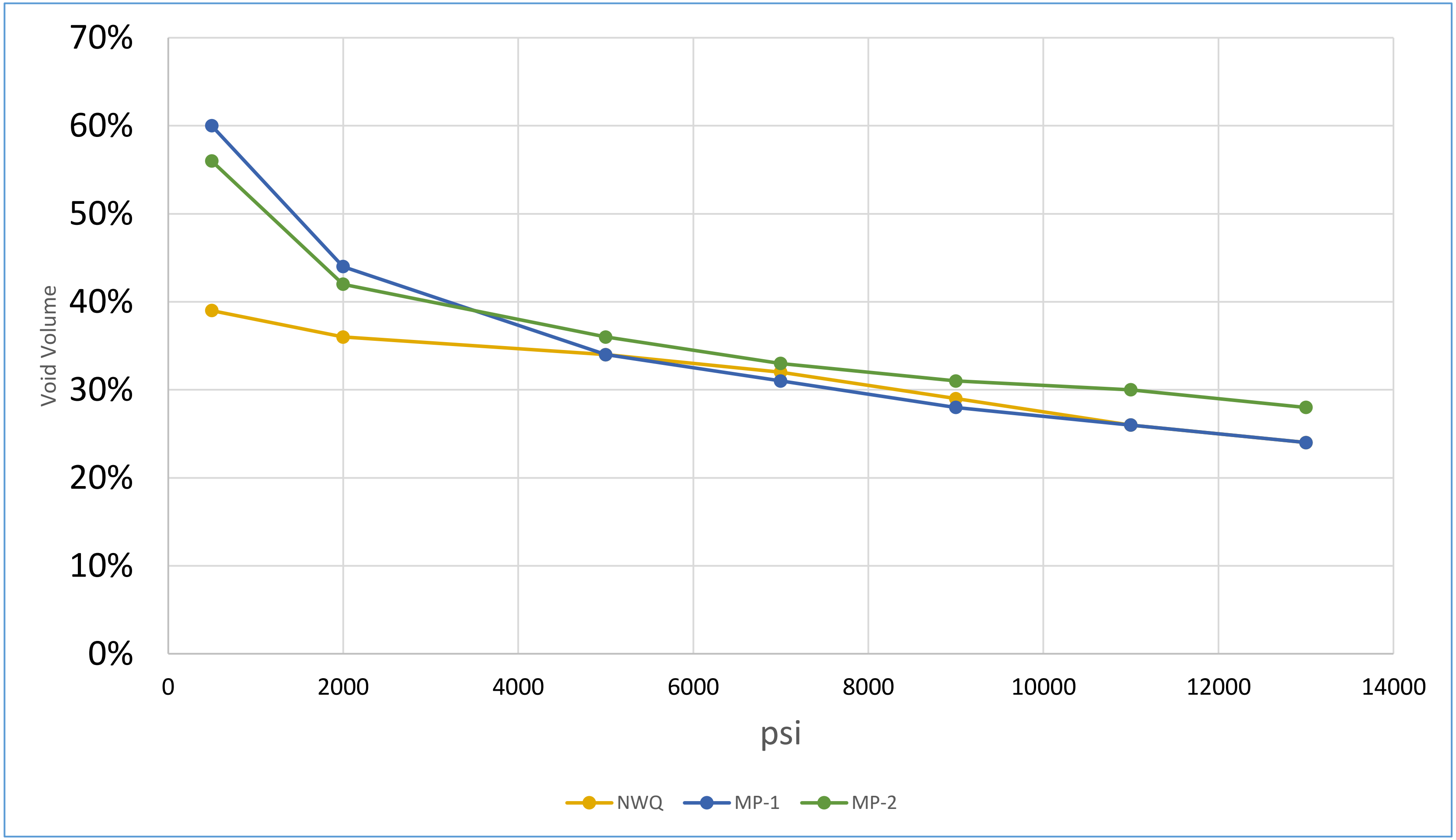
ρ=2.01g/cm

ρ=2.7g/cm

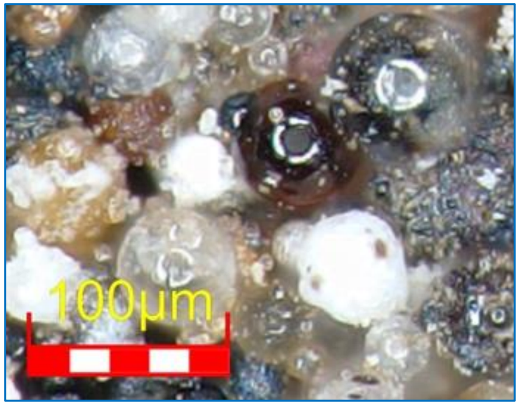
Ash Can be Tailored to Produce a wide range of Hydraulic Conductivity matching the fracture network



Crush Resistance: Ash Maintains High Void Volume at Pressure



Air Classification Coarse Ash



2.01 g/cm^3

Gas bubbles!

Carman-Kozeny equation for flow through a packed bed

$$\frac{Q}{A} = \frac{\Delta p \, \epsilon^3}{\mu L \, 5(1-\epsilon)^2 \, S^2}$$

Q is the volumetric flow rate

A is the face area of the bed

L is the depth of the bed,

Δp is the applied pressure drop

ϵ is the void volume of the bed

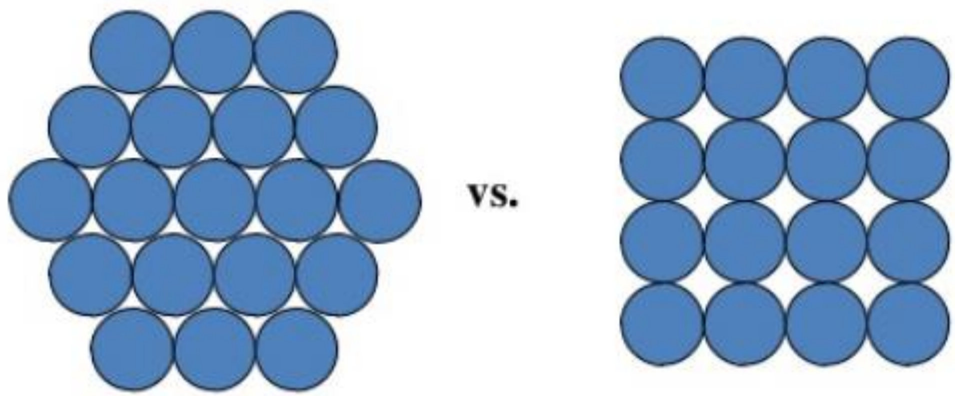
S is the volume specific surface of the bed

μ is the viscosity of the fluid

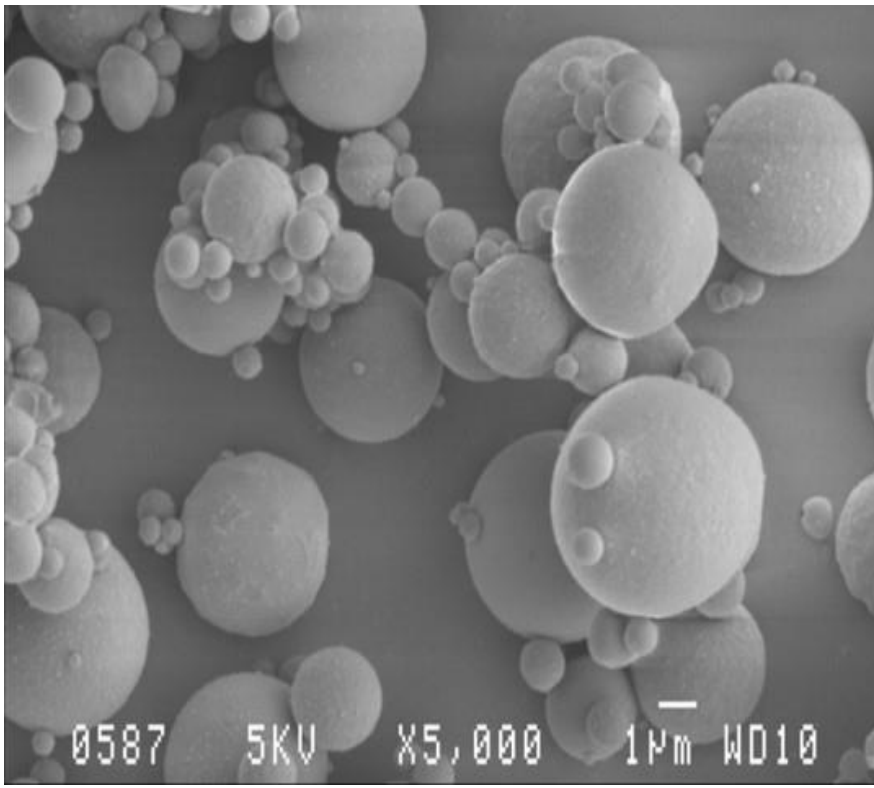
Void Volume (ϵ) and Packing

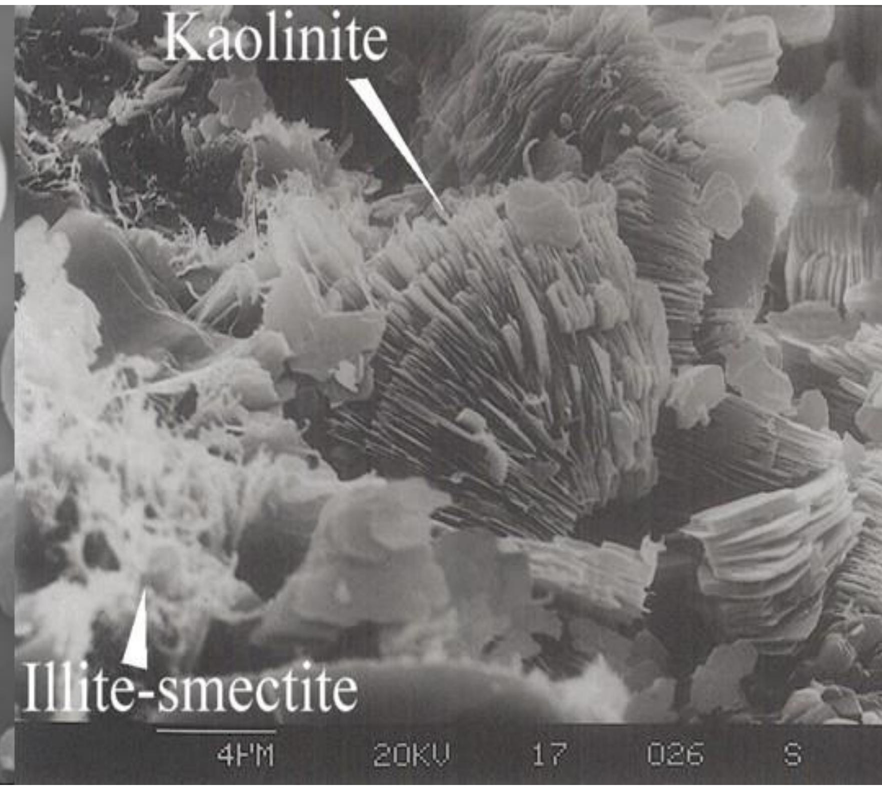
Hexagonal Close Packing D $= \pi\sqrt[2]{18} = 0.74$ ~26% ϵ

Cubic Close Packing D = π/6 = 0.52 ~48% ϵ



Ash Smooth Surface Low Drag

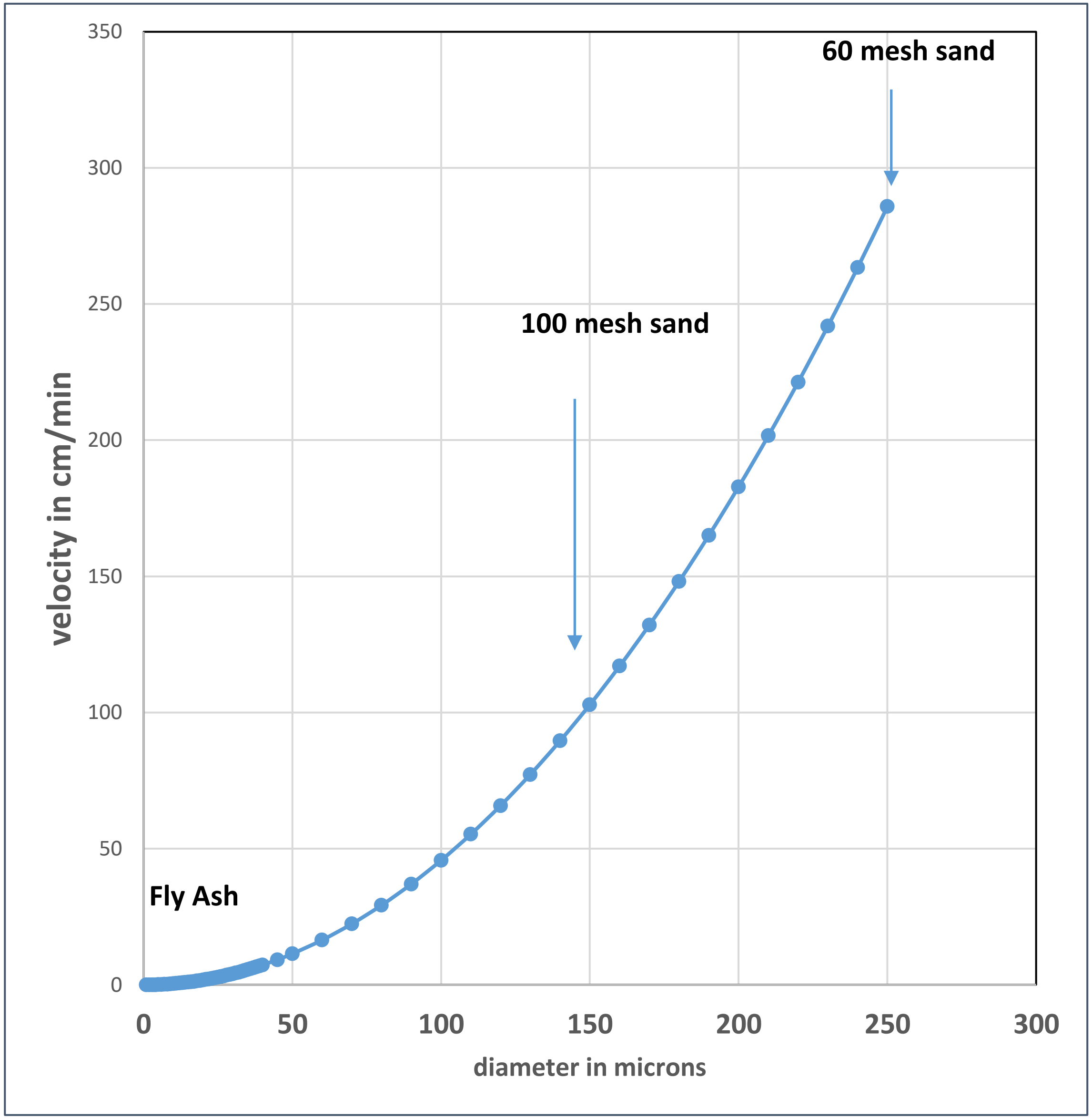




Internal Surface Area, S^2 = Roughness factor relatable to internal drag or friction

Stokes Law Settling: Sand versus Fly Ash

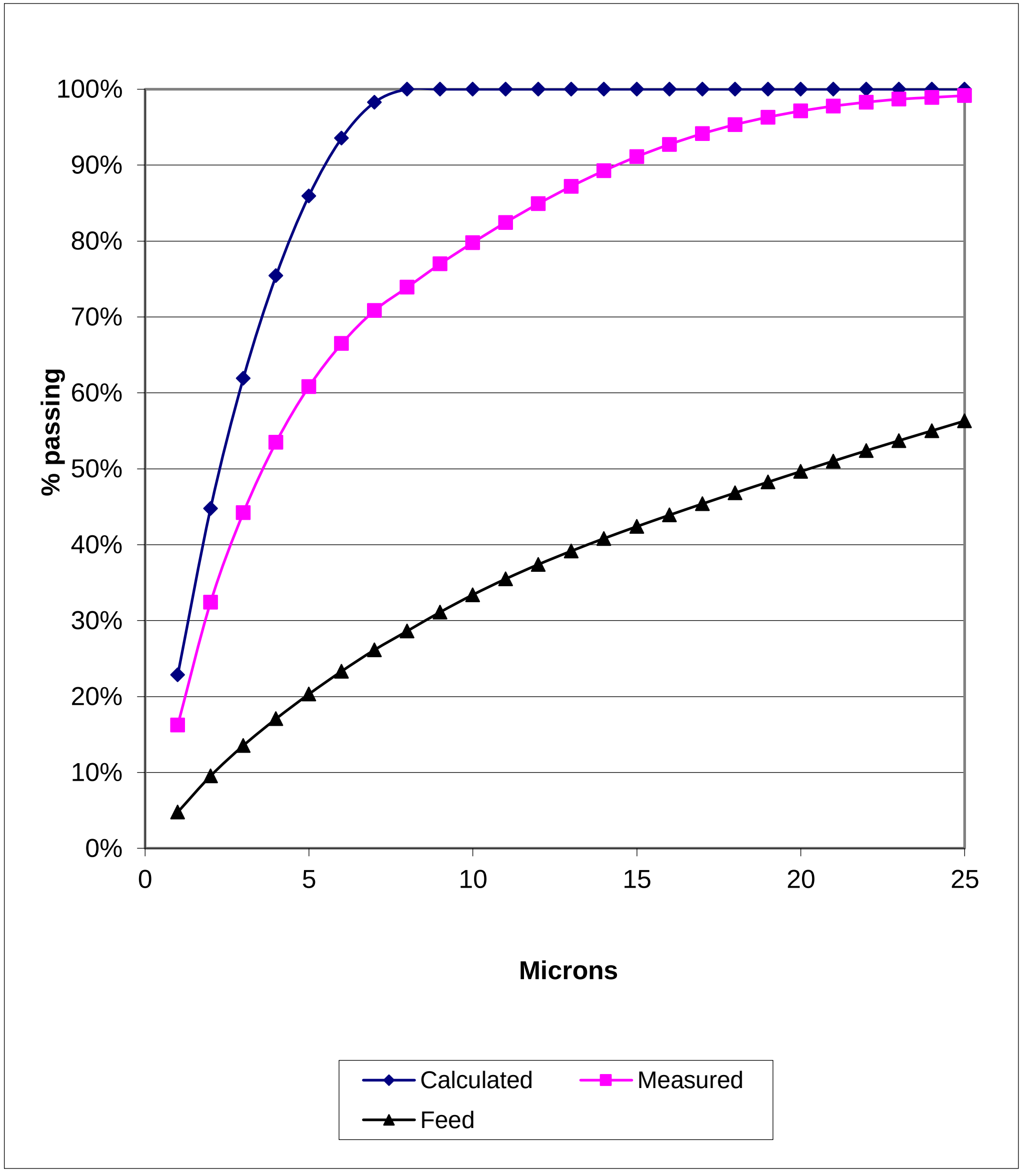
$$Vs=g*D^2*(\sigma p-\sigma w)/18(\mu)$$



Fly Ash Separation and Stokes Law

Stokes Law Assumptions:

- Laminar Flow
- No inertial effects (Reynolds number =zero)
- Spherical particles
- Homogeneous (uniform in composition) material
- Smooth surfaces
- Particles do not interfere with each other.



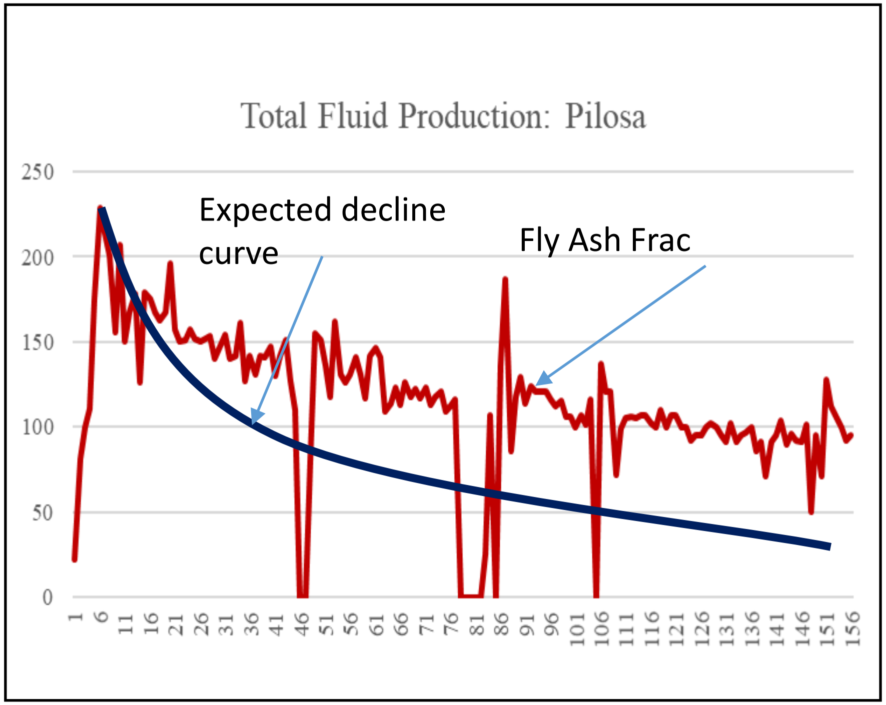
Advantages of Fly Ash as Compared to Conventional Frac Sand

Suspension Characteristics of Fly Ash Proppant is greatly improved versus Conventional Frac Sands

- Low drag almost a perfect Stokes particle resulting in a very fluid slurry
- Lacks surface charges of any kind—Little or no Zeta potential
- Stays in suspension--allows lowered pumping rates
- Does not require polymers, gums or other viscosity modifiers
- Reduced pumping horsepower

Early Field Trials

First Test: Pilosa #3



Job with 150,000 # of Proppant

About the Dar-Stim Process

Commercial Deployment

Operational Background

- First used in 2017
- 20+ different formation types across Texas, Oklahoma, Kansas and Israel
- More than 16 million pounds of coal byproducts utilized to date
- More than 70 wells completed (*50% oil / 50% gas*)
- Majority of the wells were sub-hydrostatic
- 25% of wells were horizontals or highly deviated
- 4 open hole horizontals
- Majority pumped down tubing between 5-12 BPM
- Zero HSE incidents

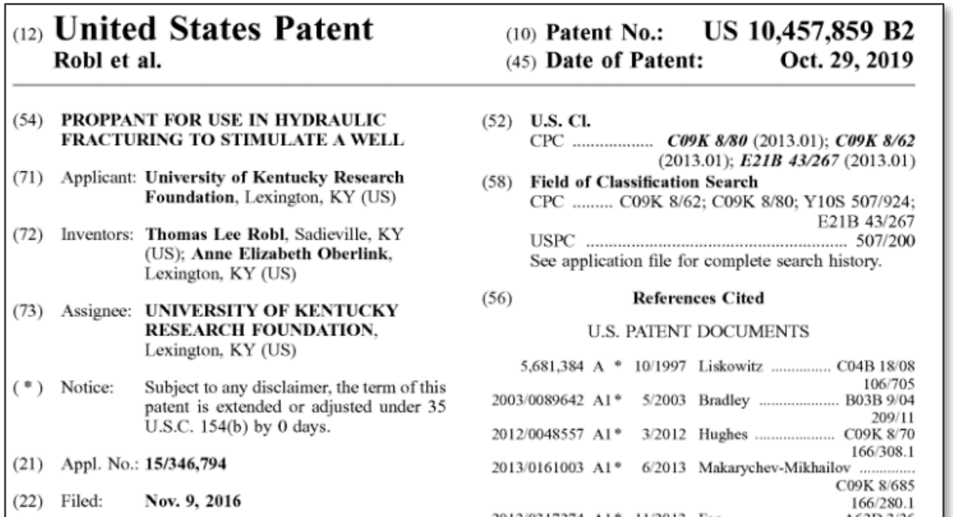
The Patent

The Dar-Stim was developed with our technology partners, the University of Kentucky Center for Applied Energy Research.

The Proppant

ESS enjoys an exclusive supply arrangement that provides us with refined coal combustion byproducts free of heavy metals or other impurities.

The result is a low-cost, low-risk, carbon-neutral solution ideal for both revitalizing marginal wells and enhancing new wells.



(12) **United States Patent**
Robl et al.

(10) **Patent No.: US 10,457,859 B2**
(45) **Date of Patent: Oct. 29, 2019**

(54) **PROPPANT FOR USE IN HYDRAULIC FRACTURING TO STIMULATE A WELL**

(71) Applicant: **University of Kentucky Research Foundation**, Lexington, KY (US)

(72) Inventors: **Thomas Lee Robl**, Sadieville, KY (US); **Anne Elizabeth Oberlink**, Lexington, KY (US)

(73) Assignee: **UNIVERSITY OF KENTUCKY RESEARCH FOUNDATION**, Lexington, KY (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **15/346,794**

(22) Filed: **Nov. 9, 2016**

(52) **U.S. Cl.**
CPC ***C09K 8/80*** (2013.01); ***C09K 8/62*** (2013.01); ***E21B 43/267*** (2013.01)

(58) **Field of Classification Search**
CPC C09K 8/62; C09K 8/80; Y10S 507/924; E21B 43/267
USPC 507/200
See application file for complete search history.

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2013/0161003 A1* 6/2013 Makarychev-Mikhailov C09K 8/685 166/280.1
2013/0317274 A1* 11/2013 Fan A62D 3/36

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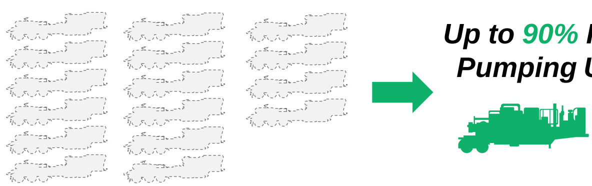
Reduced Cost & Wellsite Footprint

◀ *Typical frac site 35,000hhp*

Dar-Stim job 1,500hhp ▶



Up to 90% Fewer Pumping Units

80% Less Headcount

Stabil lower viscosity fluid results in less horsepower and lower pumping rates--translates directly to fewer pumps and less people on location.

Benefits of a Reduced Footprint

+ Less headcount
+ Lower horsepower
+ Lower fuel charges

= Significant Cost Savings

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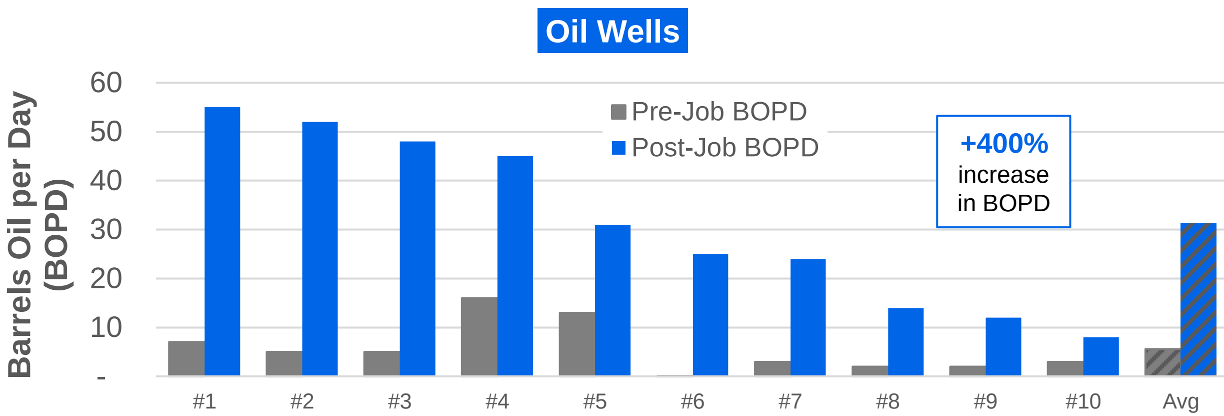
Proven Results – Across Diverse Formations

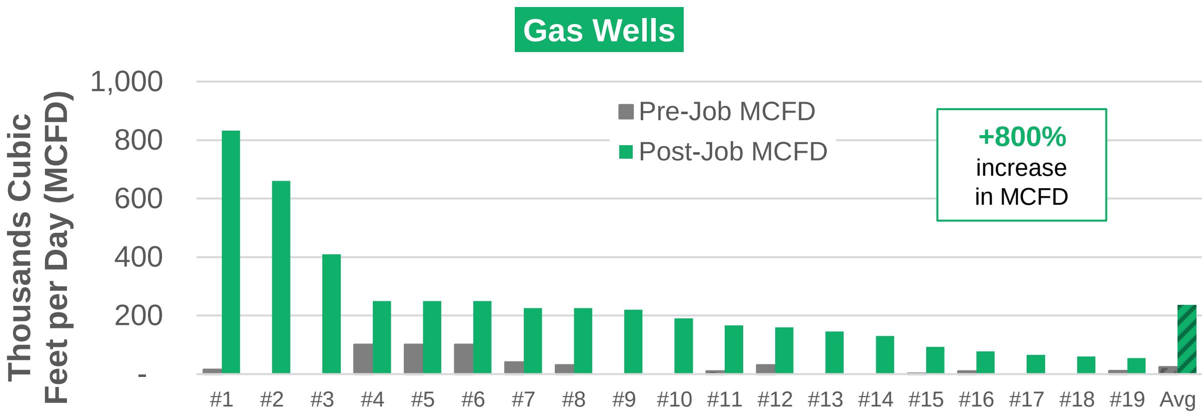
Operational Background

- More than 87 wells completed (*50% oil / 50% gas*)
- 23 different formation types across Texas, Oklahoma, Kansas and Israel
- More than 16 million pounds of coal byproducts utilized
- Majority of the wells were sub-hydrostatic
- 25% of wells were horizontals or highly deviated
- 4 open hole horizontals
- Majority pumped down tubing between 5-12 BPM
- Zero HSE incidents

Formation	Frac Gradient (psi/ft)	Depth Range (ft)	Avg Mass (lbs)
San Miguel	0.41	3,200	400,000
Des Moines Granite Wash	0.4	6,600	150,000
Des Moines Limestone	0.53	6,500	200,000
Spraberry	0.54	5,200	200,000
Wolfcamp	0.55	5,300	550,000
Austin Chalk	0.65	10,600	200,000
Olmos	0.67	7,400	150,000
Barnett Shale	0.68	9,100	200,000
Wilcox	0.72	10,300	100,000
Mohilla	1.0	16,740	180,000
Marble Falls	0.75	5,700	200,000
Forestburg	0.75	7,500	150,000
Escondido	0.84	7,100	200,000
Vicksburg R	0.74	15,172	150,000
Jack Fork	1.0	9,700	650,000
Shallow Eagle Ford Shale	1.1	3,000	250,000

Proven Results – By The Numbers





Dar-Stim typically achieves 3-5x increase in production, with post-job flowback often returned to initial production levels.

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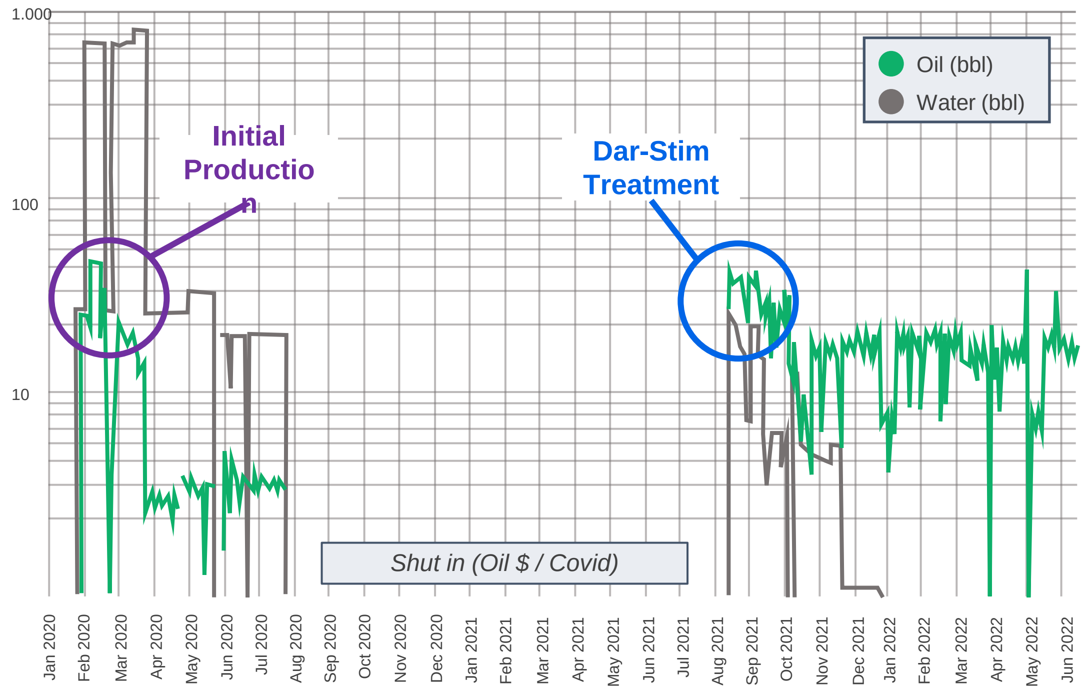
Case Study – Dumas, TX

5x Uplift on Texas panhandle well

1. Operator approached ESS with an underperforming well producing 6 barrels of oil per day
2. ESS executed Dar-Stim in less than 4 hours on location with 1 cement unit
3. Initial flow back of 51 bopd was equal to well "IP"
4. No increase in water production
5. Reservoir pressure returned to virgin pressure levels after treatment
6. Two year later, oil production uplift sustained at 25 bopd – 4x

Operator investment in Dar-Stim paid back in less than two months.



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Dar-Stim Reduced Carbon Footprint

The Ultimate ESG Solution for Stimulation

Repurpose coal ash as proppant

No chemical additives

Lower horsepower **reduces emissions**

Reduced headcount on location

Re-use produced water from formation

Uses up to **70% less water** than existing methods.

Recovers up to **90%** of the pumped water.

Works with **recycled water**

Reduced wellsite footprint

Dar-Stim impacts every step in the value chain, delivering a uniquely carbon negative treatment while simultaneously reducing cost at the wellhead.

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Environmentally "Disruptive" Technology

Reduced water footprint

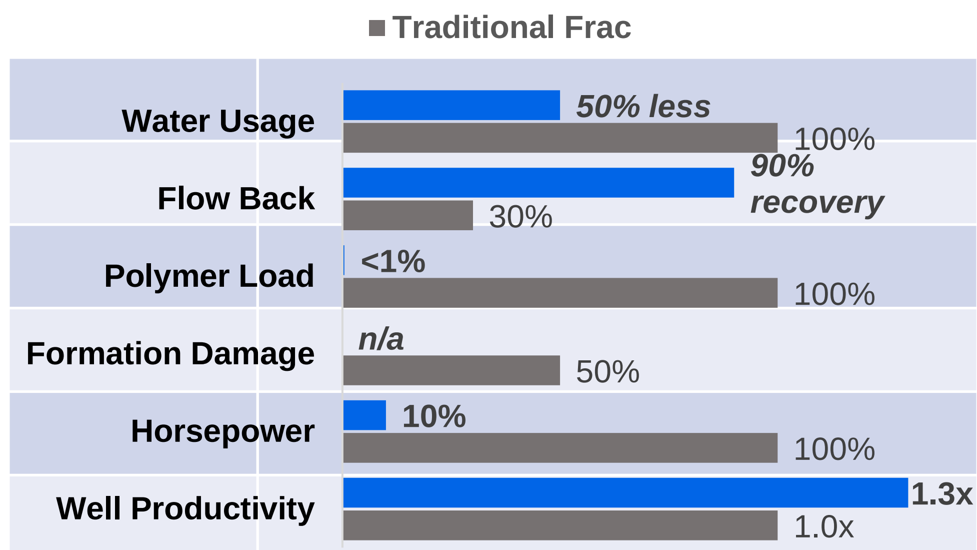
- Works with existing field-produced water
- Increased flowback to treat subsequent wells

Chemical-free

- No polymers or carry agents required
- No biocides or clay stabilizers required

Fewer chemicals downhole mitigates formation damage, resulting in more productive wells

Dar-Stim vs Traditional Frac in Tight Reservoirs



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Bringing the Technology Home:
New Applications for the Beneficial Reuse of Coal Combustion Ash

This work is funded by:
Kentucky Energy and Environment Cabinet,
Office of Energy Policy

Their Support is Gratefully Acknowledged!

TEAM KENTUCKY®
ENERGY AND ENVIRONMENT CABINET

Scope and Objectives

1. Develop New Uses for Coal Ash in Energy Production
   - Proppant for Oil and Gas Production
   - Cement Additive for Oil and Gas Well Plugging and Abandonment
2. Determine the Potential for Improved Performance in Current Usage

Tasks and Milestones

Task 1 – Survey assessment of fly ash properties as a proppant.
Milestone 1.1 – Collect current production and landfilled fly ash from across Kentucky.
Milestone 1.2 – Analyze fly ash samples for chemical, mineralogy, and beneficiation properties.

Task 2 – Assessment and Modification of fly ash a frac proppant.
Milestone 2.1 – Complete pH/conductivity analyses of fly ash.
Milestone 2.2 – Evaluate the effects of different types of surfactants on fly ash proppant slurries.

Task 3 – Fly ash as an aggregate in slurry for plugging and abandonment operations.
Milestone 3.1 – Test and evaluate fly ash-based formulations for well plugging and abandonment.
Milestone 3.2 – Evaluate the effects of different fly ash surfactants on slurry viscosity and strength development.

Task 4 – Educational Webinar: Kentucky Coal Ash Facts and Utilization for Enhanced Energy Production.
Milestone 4.1 – Provide a date and time an end of project Education Webinar on the use of fly ash in Kentucky's oil and gas industry.
Milestone 4.2 – Complete a minimum of four social media posts throughout the length of the project.
Milestone 4.2 – Complete one primary Educational Webinar.

Changes in Chemistry: Major Elements 2023/2024 compared to 1997 and 2002

	Coal S	*1997	**2002
Group 1	<1%	40%	24%
Group 2	1-2%	13%	29%
Group 3	2-3%	27%	8%
Group 4	>3%	20%	38%

	2023-2024	2002**	Difference
	Ave A-F	Group 1	23/24-2002
SiO_2	43.34	57.06	-13.72
Al_2O_3	18.29	27.10	-8.82
Fe_2O_3	19.01	5.02	**13.99**
CaO	8.17	2.37	**5.80**
MgO	0.99	1.11	-0.12
Na_2O	0.67	0.57	0.10
K_2O	2.00	2.41	-0.41
P_2O_5	0.15	0.16	-0.01
TiO_2	0.93	1.59	-0.66
SO_3	2.26	0.14	**2.12**
LOI	2.83	2.85	-0.02

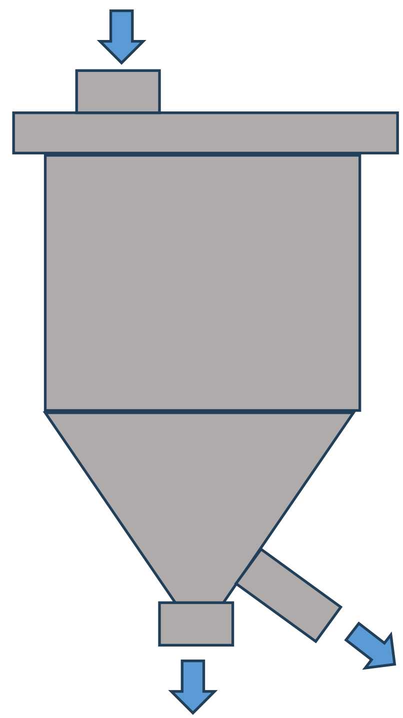
*Hower, J.C. et al., 1998, Fuel, **78**, p 701-712.
Hower, J.C. et al., 2005, Fuel, **84, p 1338-1350.

Beneficiation of Kentucky Fly Ash

- Examine Beneficiation for:
- New Product Development
  - Oil and Gas Well Applications
    - Proppant
    - Improved Well Cements
    - Mud
- Recovery of Heavy Media, Magnetite

Air Classification

20-inch diameter, 1 tph Sturtevant Whirlwind®



Separation Results, Yields, Particle Size, LOI

The World of Coal Ash 2024

Plant	% Yield		Mean Particle Size (D50) µm			% LOI		
	Fines	Coarse	Feed	Fines	Coarse	Feed	Fine	Coarse
A	72%	28%	16.7	12.1	51.4	1.77%	1.91%	2.47%
B	*	*	62.2	36.5	65.9	*	*	*
C	69%	31%	20.7	18.0	52.8	5.54%	5.98%	3.85%
D	93%	7%	13.9	10.4	40.7	3.38%	4.27%	2.14%
E	67%	33%	14.6	10.1	50.0	2.03%	2.72%	1.17%
F	82%	18%	14.3	12.0	43.5	1.43%	1.65%	0.26%

Separation Results Plant E

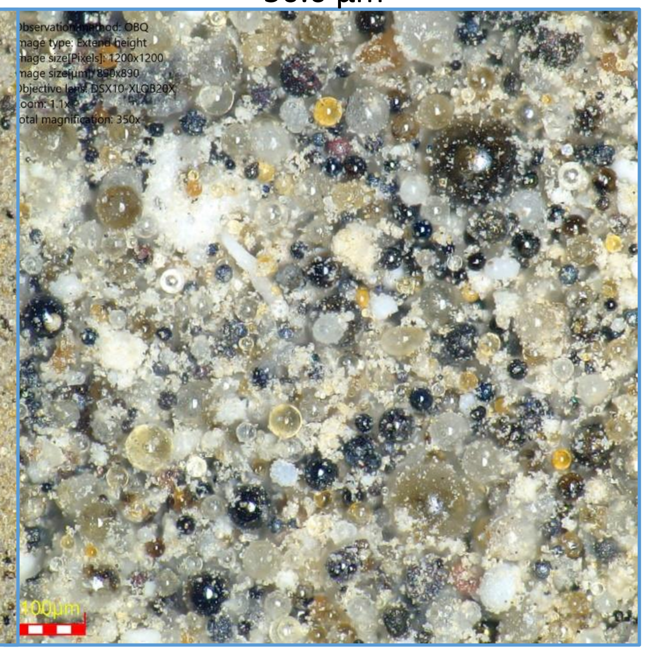
14.6 µm

As Received

10.1 µm

Fines

50.0 µm



Coarse

Summary: Benefits of fly ash derived proppants

- Continuity and connectivity of fractures down to Micro-Darcy's of permeability.
- Elimination of chemical gelling agents
  - Simple or no post frac cleanup.
- Reduced water consumption.
- Lowered horsepower demand and fuel consumption.
- Reduced footprint and subsequent environmental damage.
- Practical elimination of screen outs.
- Enhanced well life and Return on Investment.
- Reduced carbon footprint.
- Works well in very tight formations.

We need to bring this technology home