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Acid Tunnelling Insights from Full-Scale Tests

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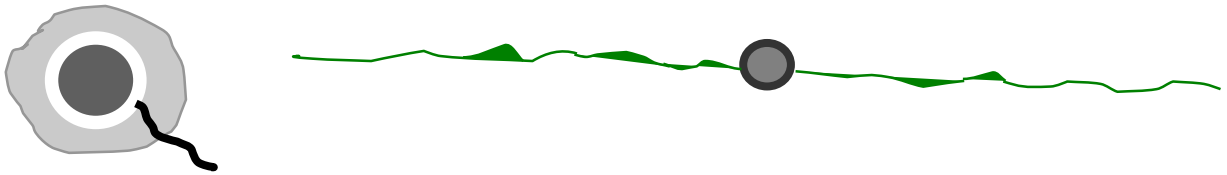
Overview

- What problem is solved?
- Acid tunneling history
  - Previous yard acid tests
  - Field experience
- Laboratory water tests
- Latest full-scale acid tests
- Conclusions

What Problem is Solved?

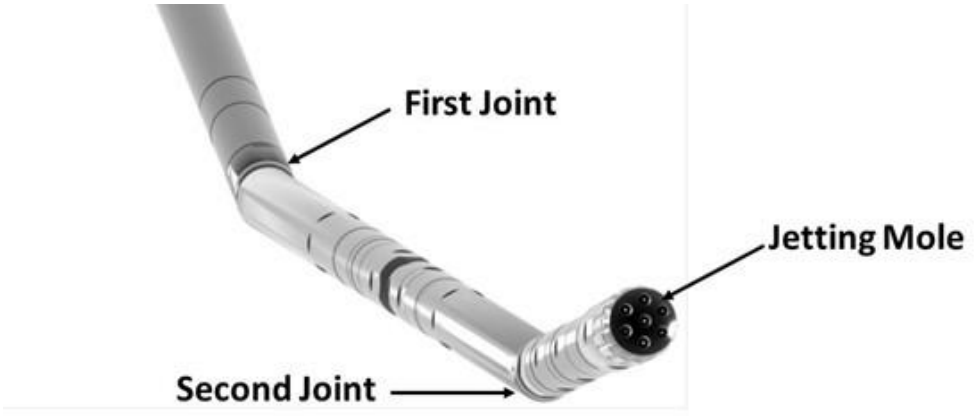
Conventional carbonate acid stimulation methods

Matrix Acidizing … Fracture Acidizing

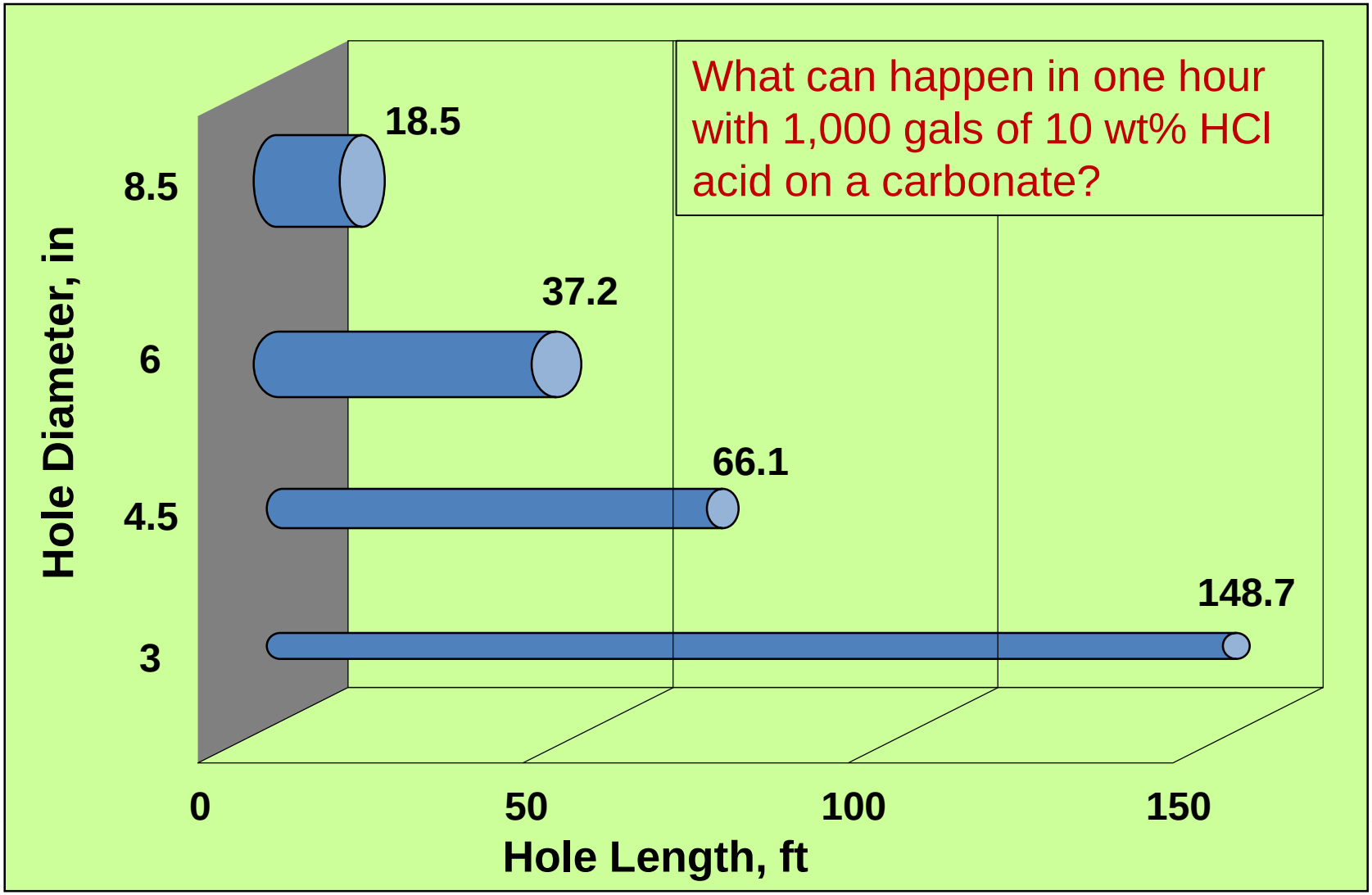


Acid tunneling technology

- Open-hole completions
- Multiple tunnels
- 10-15 wt% HCl acid



Theoretical Acid Tunnelling Construction



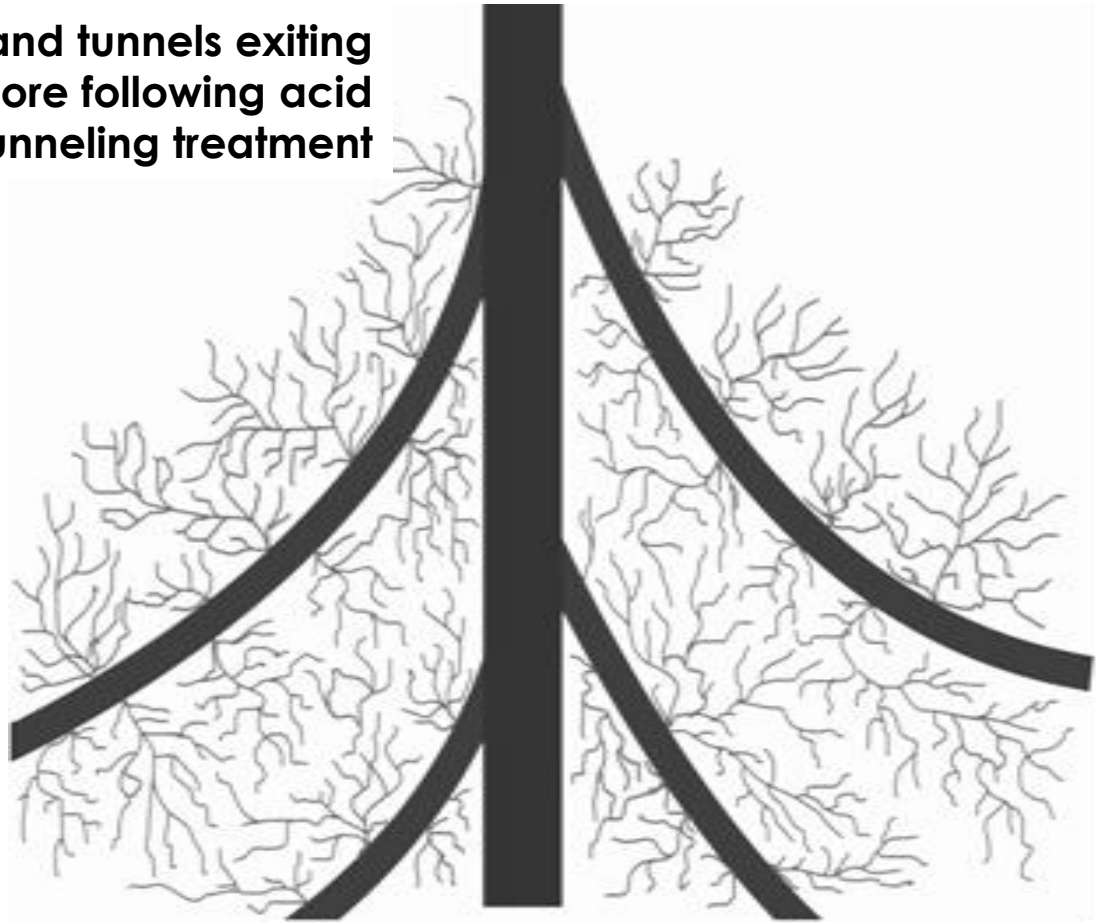
Previous Yard Acid Tests (SPE-74824, 2002)

Previous Yard Acid Tests (Continued)

- Input parameters: acid strength, pump rate, nozzle pressure differential, nozzle design
- Limitations: no casing pressure, ambient temperature
- Key learnings
  - Critical jetting energy and nozzle layout
  - At surface conditions, 2 bpm of 5 wt% HCl acid results to 20ft/hr of 4-in. tunnel (0.17 ft/bbl tunnelling efficiency)

Theoretical Dentritic Structure

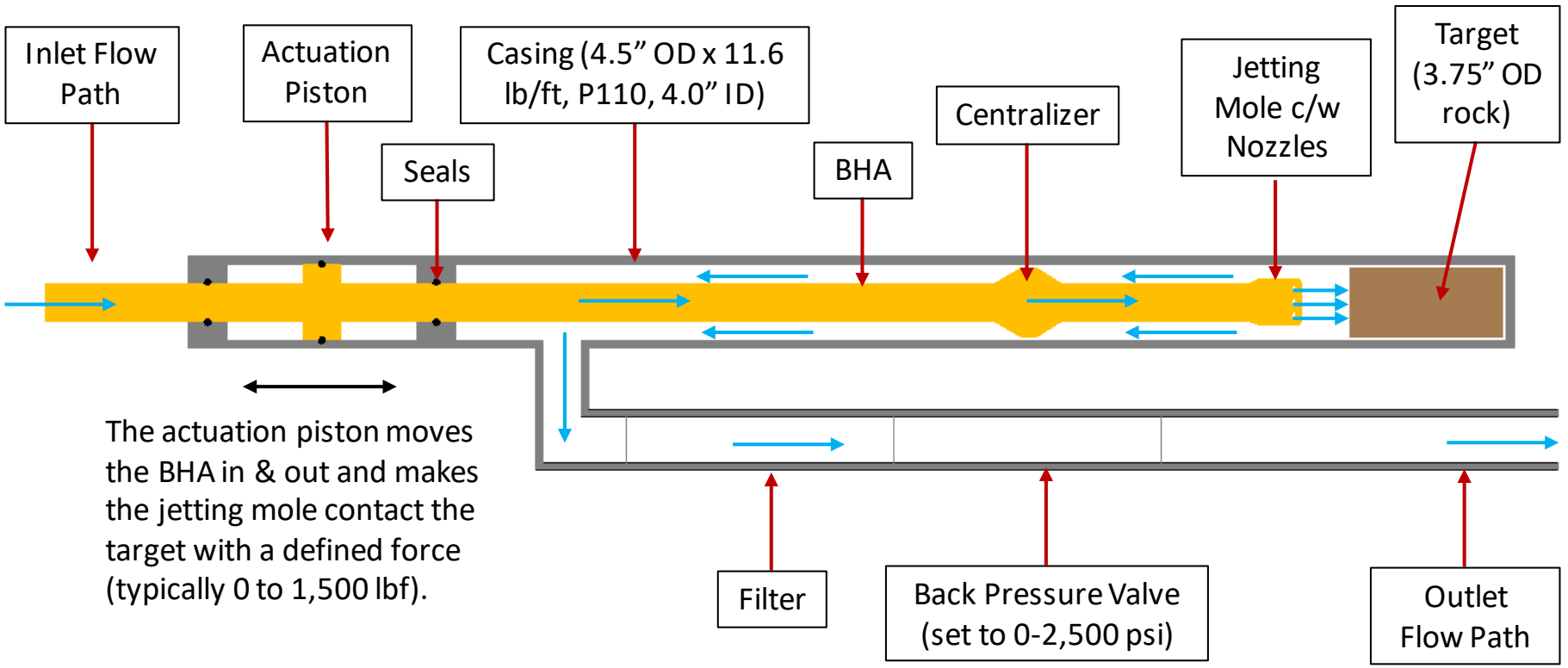
Wormholes and tunnels exiting main wellbore following acid tunneling treatment



Field Experience (SPE-135604, SPE-188294)

- More than 100 treatments globally with 10 and 15 wt% HCl acid
- More than 500 tunnels
- 2 to 120 ft actual tunnel length (24 ft average)
- 0.05 to 2.5 ft/bbl actual tunnelling efficiency (0.35 ft/bbl average)
- 20 to 40 ft/hr actual penetration rate
- Previous focus on creating a pre-determined number of tunnels for a pre-determined volume of acid
- No real-time or post-job downhole data available
- Very limited post-stimulation production data available

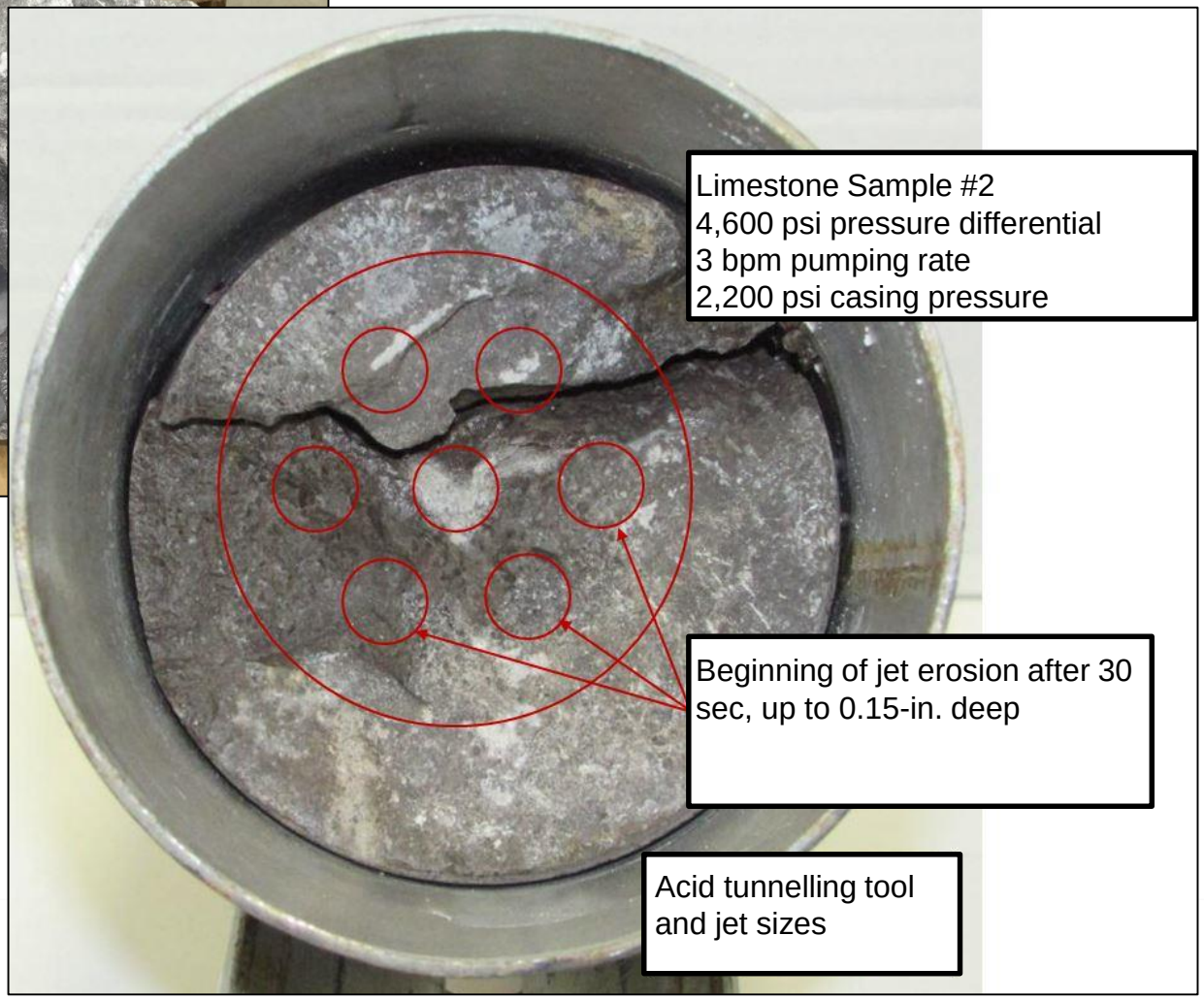
Laboratory Water Tests



Laboratory Water Tests (Continued)

- Input parameters: pump rate, nozzle pressure differential, nozzle design, casing pressure, weight on tool
- Many cores
  - Firebrick
  - Ice
  - Cement (firm, hard, very hard strength)
  - Sandstone from local supplier
  - Tight limestone from local supplier (0.1 mD permeability)
  - Indiana limestone (2-4 mD permeability and 12-14% porosity)

Water Testing – Tight Limestone Results

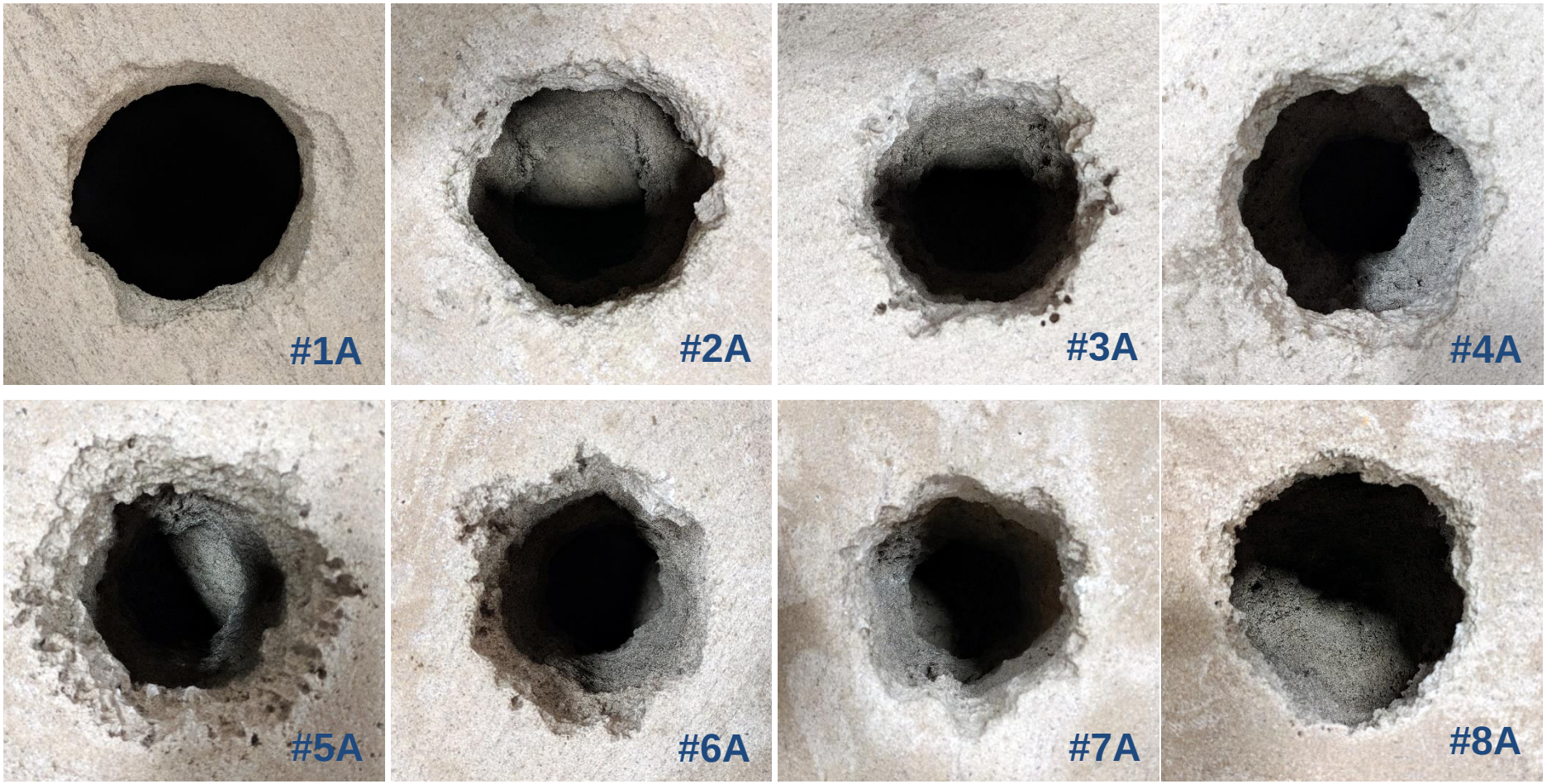


Water Testing – Indiana Limestone Results

Test No.	Pumping Rate	Water Volume	Tunnel	
			Diameter	Length
	bpm	bbl	in.	in.
10	1.15	12	1.50	1.75
11	0.50	5	0.00	0.10
12	1.90	19	0.00	0.50

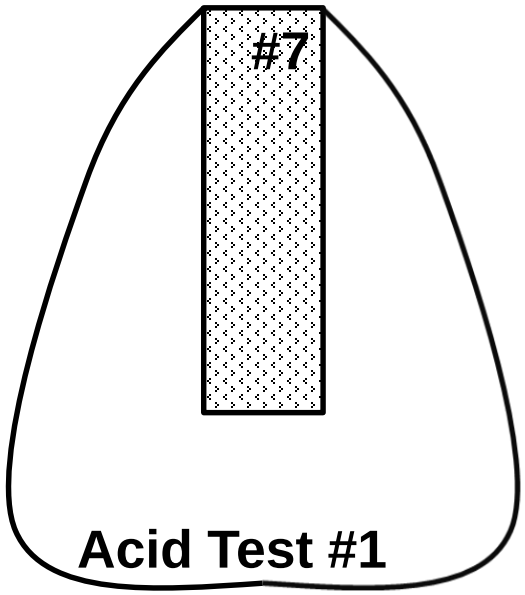
Full-Scale Acid Testing

Acid Testing – Indiana Limestone Tunnels

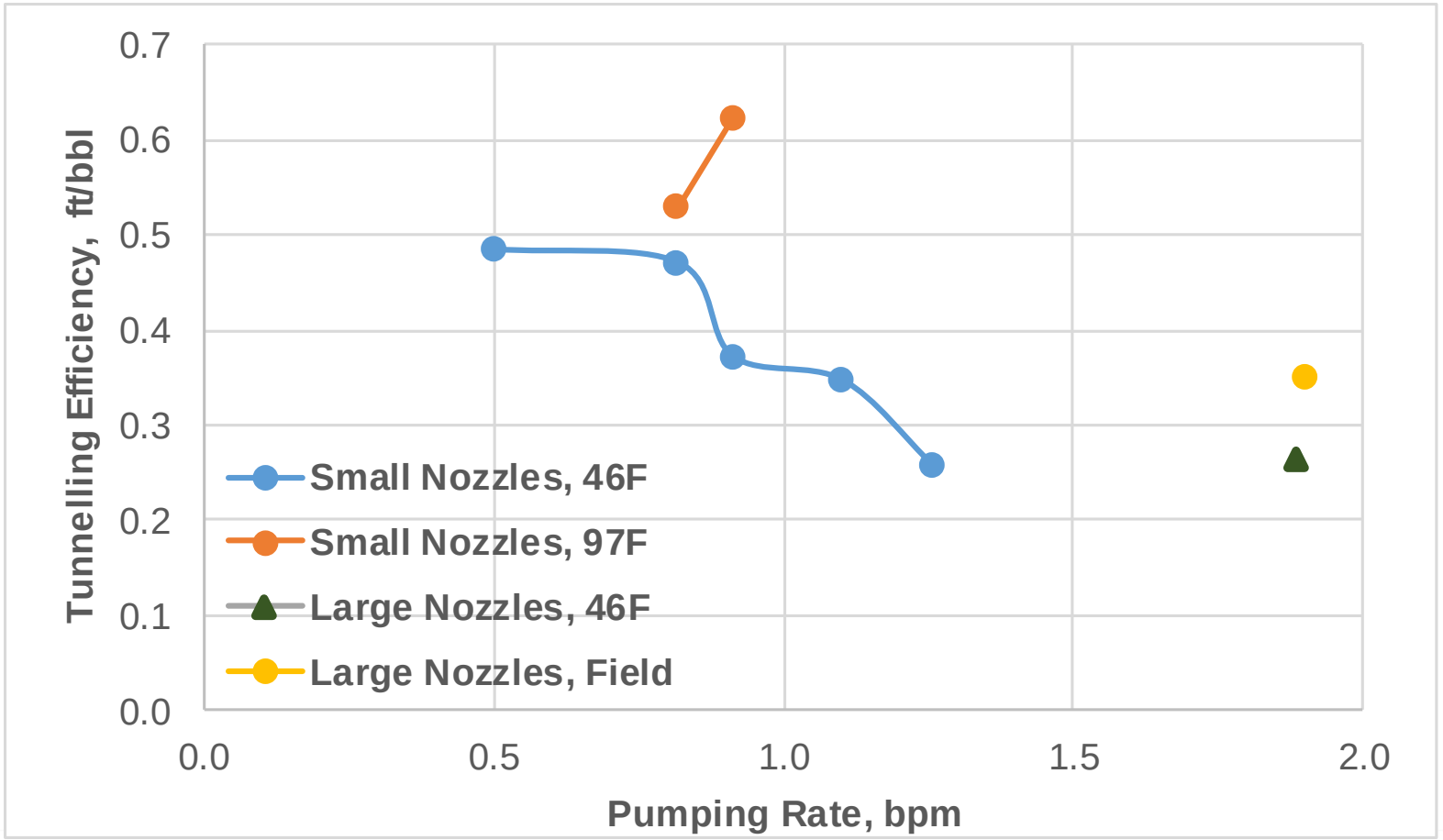


Acid Testing – Indiana Limestone Results

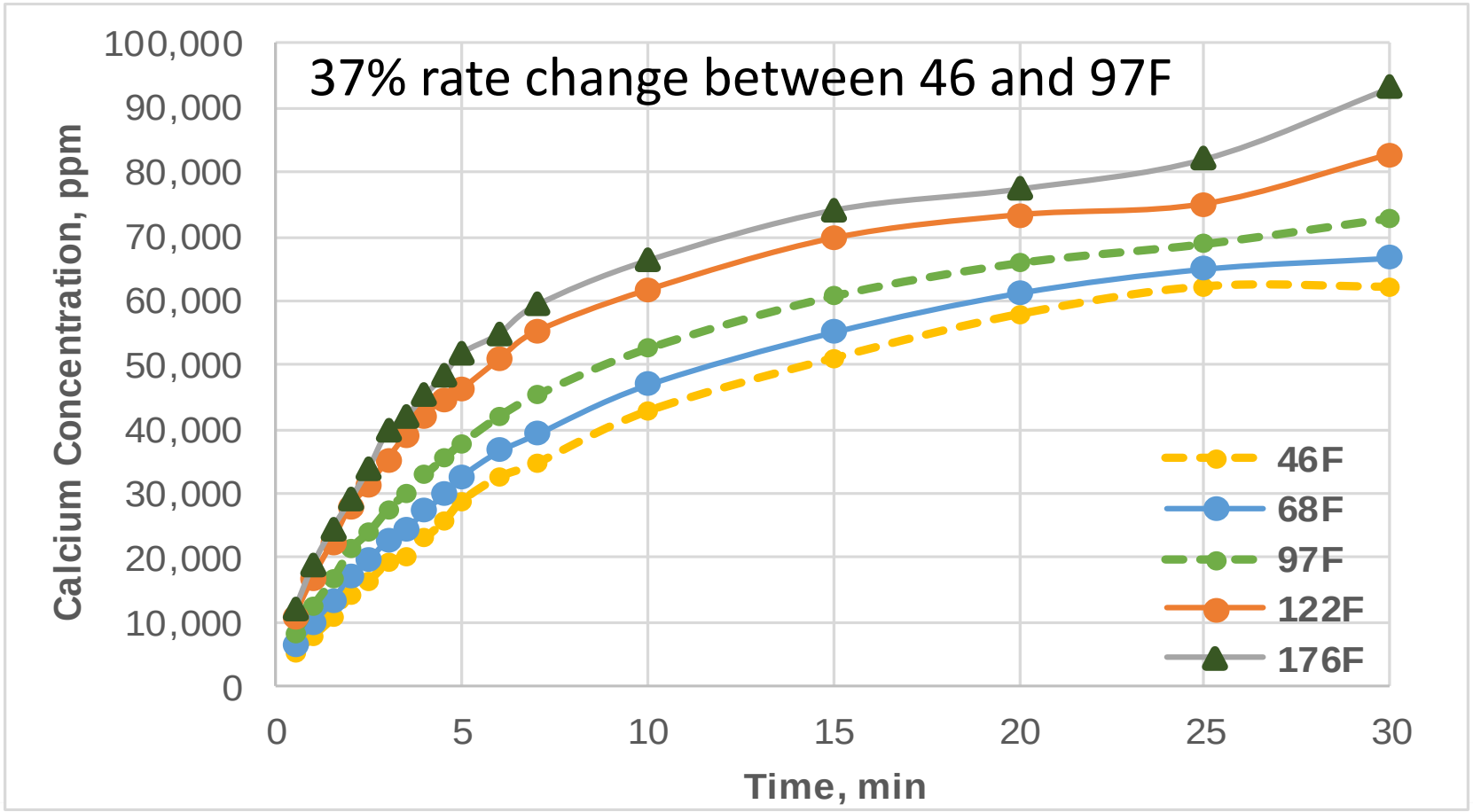
Test No.	Pumping Rate	Acid Volume	Tunnel			Tunneling Efficiency
			Diameter	Length	Volume	
	bpm	bbl	in.	in.	bbl	ft/bbl
1	1.26	5.0	3.50	15.50	0.049	0.26
2	1.10	2.5	3.50	10.50	0.013	0.35
3	0.91	2.5	3.50	11.25	0.011	0.37
4	0.82	2.1	3.70	11.75	0.014	0.47
7	0.50	1.9	3.00	11.00	0.011	0.49
5	0.82	1.9	3.75	12.00	0.013	0.53
6	0.91	1.6	3.25	11.75	0.012	0.62
8	1.89	2.5	3.75	8.00	0.011	0.26



Acid Testing – Tunnelling Efficiency



Indiana Limestone Acid Reaction Rate



Acid Testing – Temperature Results

Test No.	Pumping Rate	Acid Volume	Temperature	Tunnel			Tunneling Efficiency	Acid Volume Reduction
				Diameter	Length	Volume		
	bpm	bbl	F	in.	in.	bbl	ft/bbl	%
4	0.82	2.1	46	3.70	11.75	0.014	0.47	–
5	0.82	1.9	97	3.75	12.00	0.013	0.53	9
3	0.91	2.5	46	3.50	11.25	0.011	0.37	–
6	0.91	1.6	97	3.25	11.75	0.012	0.62	38

- More full-scale tests needed at higher temperature

Conclusions

- Acid tunneling in global use with positive production benefits
  - Limited post-job analysis for tunnel length variation
- Recent R&D efforts
  - Quantify erosional effect of jetting
  - Optimize tool design
  - Optimize acid usage
- Further work
  - More full-scale tests at higher temperature
  - Field validation
- Take-away: acid tunneling has more potential than before

Acknowledgements

- Trent Kursen, Andre Naumann, Nkem Ononye, Mitch Lambert (Baker Hughes)
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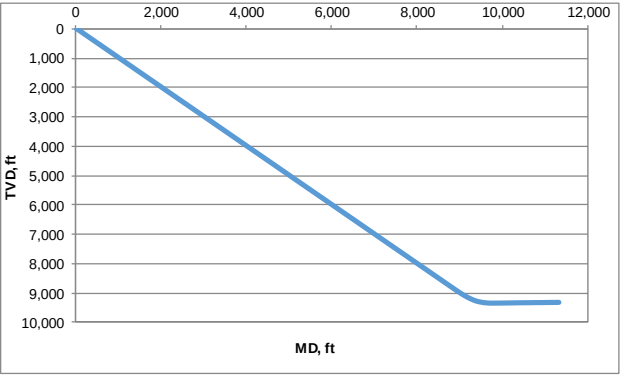
- Tom Watkins, Scott Sherman

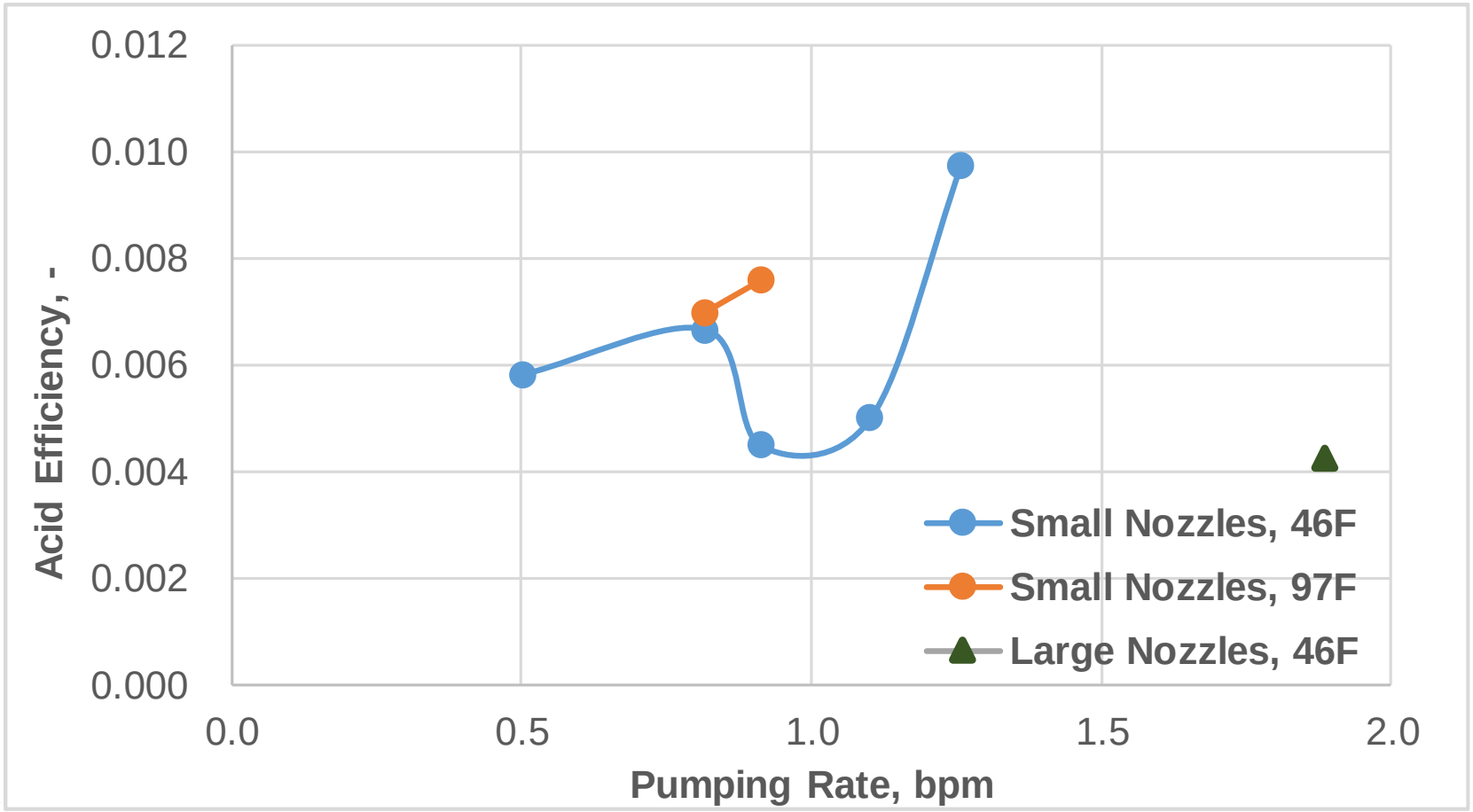
Actual vs. Predicted Tunnel Lengths (SPE-188294)



Tunnel No.	Tunnel Initiation MD	Actual Tunnel Length	Predicted Tunnel Length
	ft	ft	ft
1	11,101	12	19.67
2	11,000	13	20.33
3	10,900	10	16.67
4	10,800	13	18.67
5	10,700	11	13.33
6	10,600	9	17.67
7	10,500	10	16.33
8	10,400	10	17.67
9	10,300	9	17.33
10	10,200	17	27.33
11	10,100	18	29.67
12	10,000	17	27.67
13	9,900	16	24.33
14	9,800	19	32.67
15	9,700	13	19.33

- No model yet for tunnel creation and CT TFA

Acid Testing – Tunnel/Acid Volume



Acid Testing – Indiana Limestone Results (Imperial)

Test No.	Pressure Differential	Pumping Rate	Acid Volume	Temperature
	psi	bpm	bbl	F
1	4,496	1.26	5.0	46
2	3,481	1.10	2.5	46
3	2,466	0.91	2.5	46
4	2,031	0.82	2.1	46
7	870	0.50	1.9	46
5	2,031	0.82	1.9	97
6	2,466	0.91	1.6	97
8	3,481	1.89	2.5	46
Test No.	Tunnel Diameter	Tunnel Length	Tunnel Volume	Tunnelling Efficiency
	in.	in.	bbl	ft/bbl
1	3.50	15.50	0.049	0.26
2	3.50	10.50	0.013	0.35
3	3.50	11.25	0.011	0.37
4	3.70	11.75	0.014	0.47
7	3.00	11.00	0.011	0.49
5	3.75	12.00	0.013	0.53
6	3.25	11.75	0.012	0.62
8	3.75	8.00	0.011	0.26

Acid Testing – Indiana Limestone Results (Metric)

Test No.	Pressure Differential	Pumping Rate	Acid Volume	Temperature
	Mpa	ipm	l	C
1	31	200	800	8
2	24	175	400	8
3	17	145	400	8
4	14	130	330	8
7	6	80	300	8
5	14	130	300	36
6	17	145	250	36
8	24	300	400	8
Test No.	Tunnel Diameter	Tunnel Length	Tunnel Volume	Tunnelling Efficiency
	cm	cm	l	m/l
1	8.9	39.4	7.80	0.0005
2	8.9	26.7	2.00	0.0007
3	8.9	28.6	1.80	0.0007
4	9.4	29.8	2.20	0.0009
7	7.6	27.9	1.75	0.0009
5	9.5	30.5	2.10	0.0010
6	8.3	29.8	1.90	0.0012
8	9.5	20.3	1.70	0.0005