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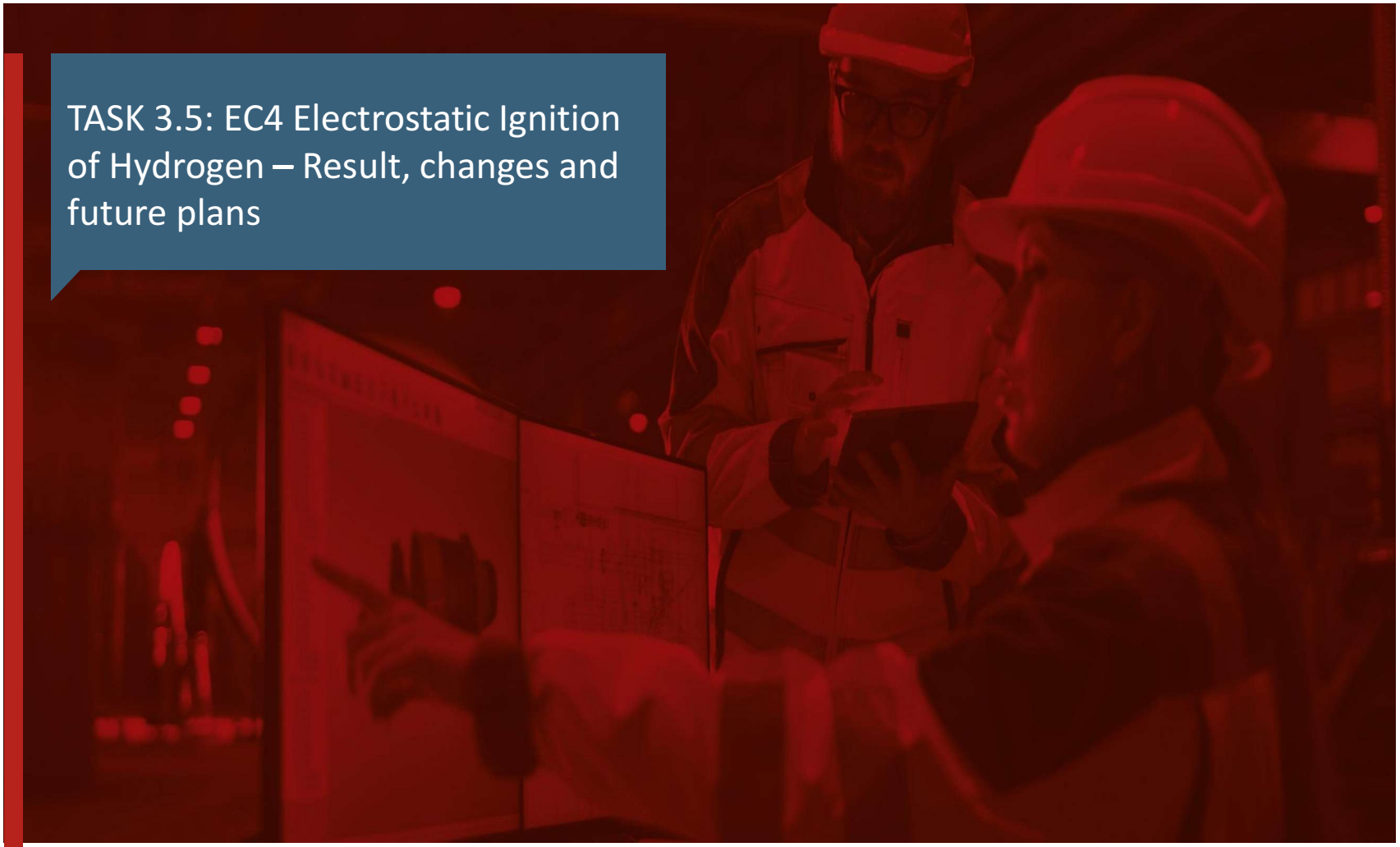

TASK 3.5: EC4 Electrostatic Ignition of Hydrogen – Result, changes and future plans

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Stages of testing work

Initial design (2024/2025):

- Design/risk assessment and FMEA
- Initial rigging and equipment verification
- Calibration of temperature and pressure
- Calibration of logging system

Commissioning with air (2025):

- Compressed air used
- To determine if charge is able to be built up
- Allows for system verification and robustness without explosive atmosphere
- 11 tests
- Single spark discharge

Tests with hydrogen (2025):

- 30+ tests
- To determine if ignition of gas is possible/likely
- To be compared with commissioning data (i.e. ignition source probability)
- 2 mm and 3 mm nozzles
- 0.1 – 0.2 m release height
- 1.5 m – 3 m "throw" distance (nozzle to plate)
- Sand and gravel

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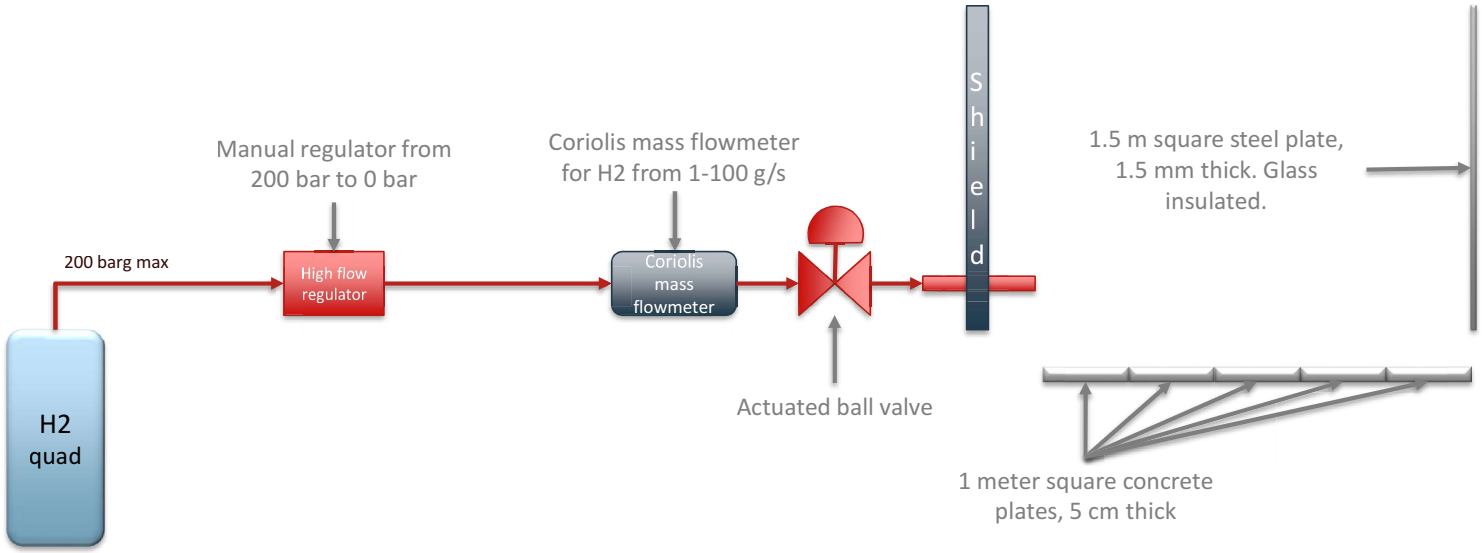
Testing rig



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Pre-commissioning rig testing

Conditions/deviations:

- High humidity during these tests (typically above 60 %RH)
- Not run as full value tests (no logging)
- Not run at fully stable pressures
- Not utilizing final rig
- Using compressed air

Trends found:

- Gravel pick-up at 5 bar essentially non-existent
- Gravel pick-up at 15 bar and 10 cm height limited, but not negligible
- 30 cm height gives poor pick-up for sand, and essentially nothing for gravel
- 5 meter throw distance is unlikely to be useful
- 1 mm nozzle provides almost no pick-up

Changes made:

- 1 mm nozzle dropped
- 5 bar tests planned to be dropped pending commissioning tests
- 30 cm height planned to be reduced to 20 cm pending commissioning tests
- 5 meter throw distance planned to be reduced pending commissioning tests

Presented at FABIG Technical Meeting 111 "From Research to Practice: Insights From Recent Projects on Hydrogen & Ammonia Safety", 24 March 2026.
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Commissioning test matrix changes

Original plan:

- Only large nozzle
- Only low height
- No low pressure for gravel

Test number	Drive gas	Nozzle diameter (mm)	Nozzle height (m)	Throw distance (m)	Particle type	Pressure (barg)
1	Air	2	0.1	2	Sand	5
2	Air	2	0.1	2	Sand	15
3	Air	2	0.1	2	Sand	30
4	Air	2	0.1	2	Gravel	15
5	Air	2	0.1	2	Gravel	30
6	Air	2	0.1	5	Sand	5
7	Air	2	0.1	5	Sand	15
8	Air	2	0.1	5	Sand	30
9	Air	2	0.1	5	Gravel	15
10	Air	2	0.1	5	Gravel	30

Actual matrix:

- Only 2 mm nozzle
- Selected high height
- No 5 or 15 bar tests for Gravel

Test number	Drive gas	Nozzle diameter (mm)	Nozzle height (m)	Throw distance (m)	Particle type	Pressure (barg)
100	Air	2	0.3	5	Sand and gravel	30
101	Air	2	0.3	3	Gravel	30
102	Air	2	0.3	3	Sand	30
103	Air	2	0.1	3	Sand	30
104	Air	2	0.1	3	Gravel	30
105	Air	2	0.1	2	Sand	30
106	Air	2	0.1	2	Gravel	30
107	Air	2	0.1	2	Sand	15
108	Air	2	0.1	3	Sand	15
109	Air	2	0.1	3	Sand	5
110	Air	2	0.1	2	Sand	5

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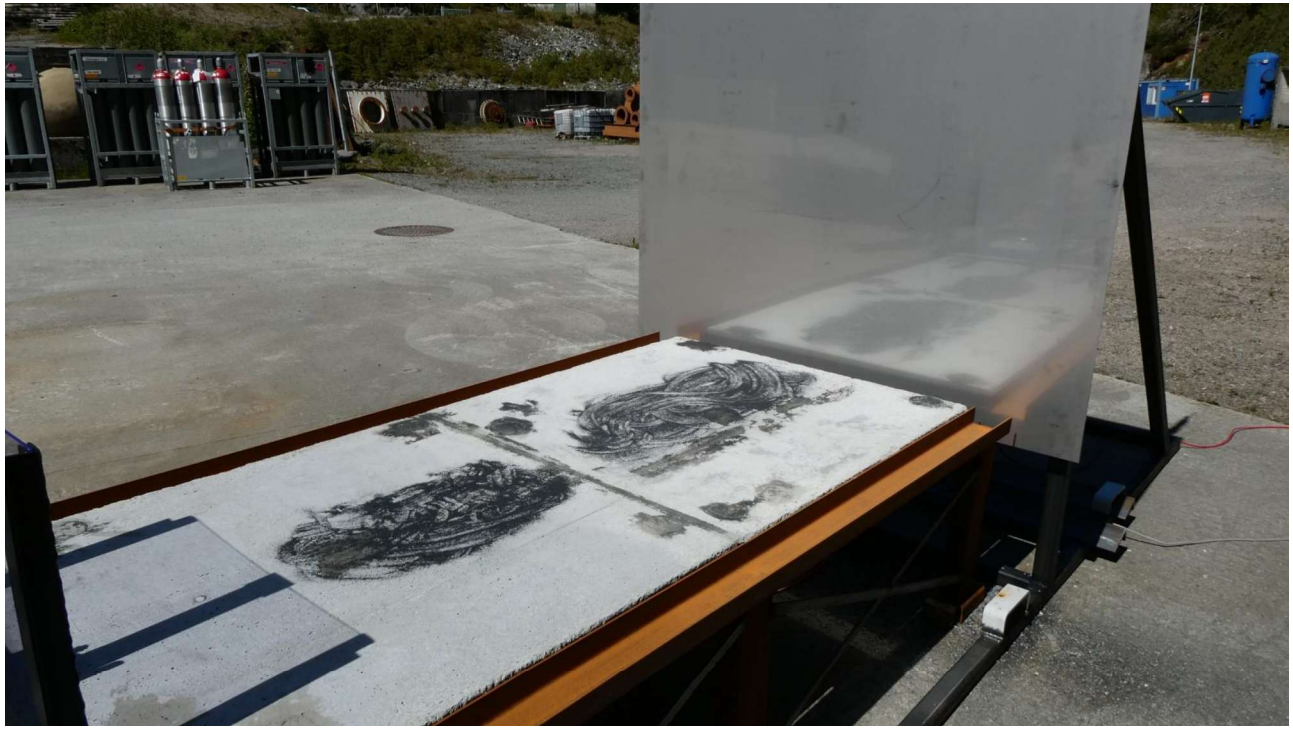
Media distribution and pickup (before test, 2 mm nozzle, 15 barg, 10 cm height)



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Media distribution and pickup (after test, 2 mm nozzle, 15 barg, 10 cm height)

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Preliminary findings

Electrostatic charging potential:

- Sand provides a significant charge (highest measured level: 21.2 nC)
- Sand provides low, but measurable, charge with 5 bar
- No discharge with 30 cm height
- No discharge with gravel

Hydrogen matrix changes:

- All 5 bar tests removed from matrix
- 30 cm height replaced with 20 cm
- 3 mm nozzle to be added as "large" nozzle, with 2 mm "downgraded" to small
- Gravel testing to be of reduced focus

Plans for "provoking" tests:

- Higher pressures, 50 bar or more?
- Larger nozzle, 5 mm?
- Downward angle for nozzle?

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Initial exploratory tests with hydrogen

Initial tests:

- To compare with air
- All tests with 30 bar
- All tests with sand
- All tests with 10 cm nozzle height
- 6 tests unrelated to original matrix

Test number	Drive gas	Nozzle diameter (mm)	Throw distance (m)	Particle mass (g/m)	Nozzle gradient (degrees)
200	H2	2	2	100	0
201	H2	2	2	100	0
203	H2	2	1	200	0
204	H2	3	1	200	0
205	H2	3	1.5	200	15
206	H2	3	1.5	200	15

Takeaways from initial testing:

- 1 meter throw distance is too close, giving only a 50 cm effective pickup
- 200 g/m with concentrated distribution along jet axis best
- 15 degree downward gradient gives increased pickup, but no change in results

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Sand entrainment at 30 barg, 10 cm height, 3 mm nozzle

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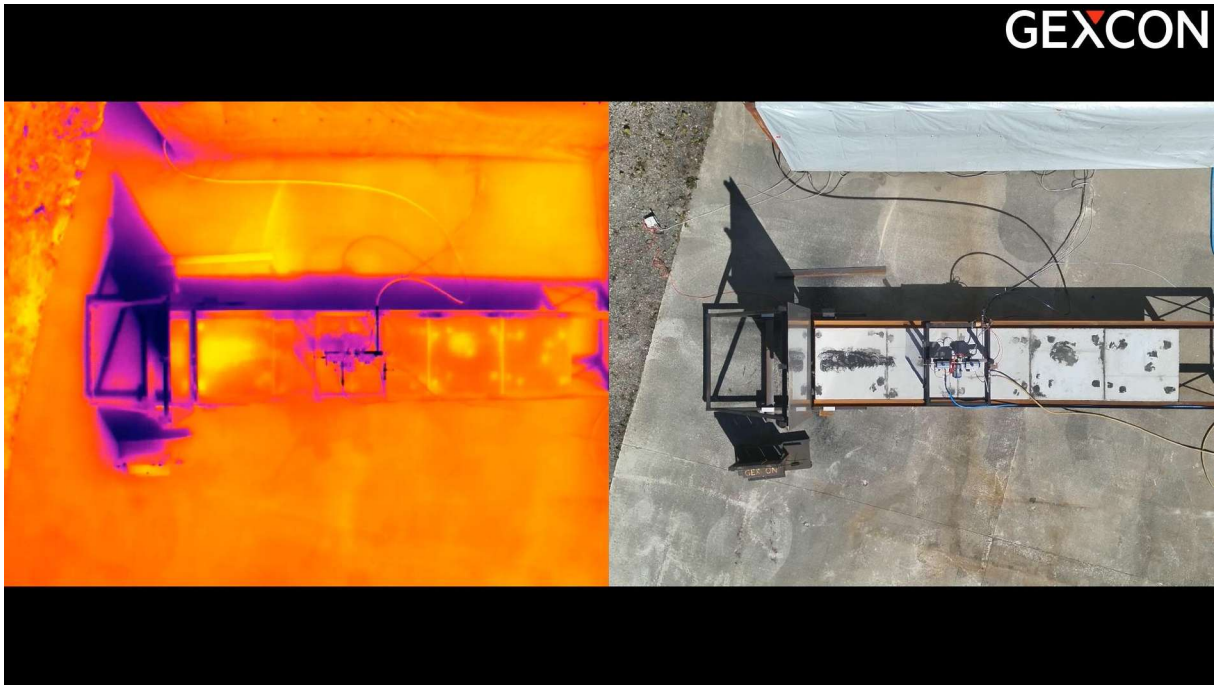
Sand entrainment at 30 barg, 10 cm height, 3 mm nozzle



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Core test matrix

Hydrogen tests:

- Throw distances modified to 1.5 m and 3 m
- 200 g/m of media used for all tests
- 0 degree gradient on nozzle for all tests
- 23 tests related to original matrix

Test number	Drive gas	Nozzle diameter (mm)	Nozzle height (cm)	Throw distance (m)	Particle type	Pressure (barg)
202	H2	2	10	1.5	Sand	30
207	H2	3	10	1.5	Gravel	30
208	H2	3	10	1.5	Sand	30
209	H2	3	10	3	Gravel	30
210	H2	3	10	3	Sand	30
211	H2	2	10	3	Sand	30
212	H2	2	10	3	Gravel	30
213	H2	2	10	1.5	Sand	30
214	H2	2	10	1.5	Gravel	30
217	H2	2	10	1.5	Sand	15
218	H2	2	10	1.5	Gravel	15
219	H2	2	10	3	Sand	15
220	H2	2	10	3	Gravel	15
221	H2	3	10	3	Sand	15
222	H2	3	10	3	Gravel	15
223	H2	3	10	1.5	Sand	15
224	H2	3	10	1.5	Gravel	15
225	H2	3	20	1.5	Sand	15
226	H2	3	20	3	Sand	15
227	H2	3	20	3	Sand	30
228	H2	3	20	3	Gravel	30
229	H2	3	20	1.5	Sand	30
230	H2	3	20	1.5	Gravel	30

Overall results:

- No hydrogen ignition for any tests
- Voltage field build-up noted, but no discharge

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Gravel entrainment at 30 barg, 10 cm height, 3 mm nozzle

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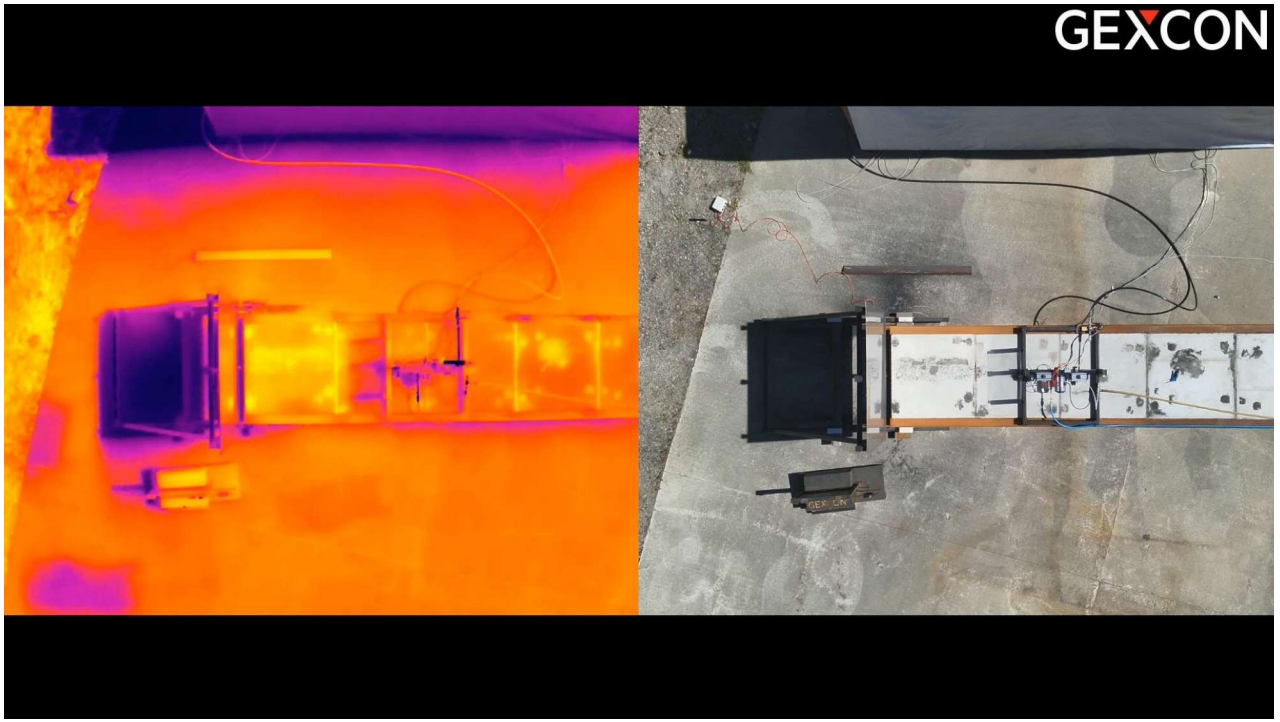
Gravel entrainment at 30 barg, 10 cm height, 3 mm nozzle



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"Provoking" tests with hydrogen

Goal:

- To increase likelihood of ignition
- To increase charge buildup
- To probe for boundary conditions

Test number	Drive gas	Nozzle diameter (mm)	Throw distance (m)	Nozzle height (cm)	Particle type	Pressure (barg)
215	H2	1	1.5	10	Sand	50
216	H2	3	1.5	10	Sand	50
231	H2	3	3	20	Sand and gravel	83 to 77

Takeaways from initial provoking testing:

- Higher pressures add to the voltage buildup measured, but did not lead to ignition nor discharge.
- Sand and gravel combo seems to have a dampening effect. Clear trend in polarity of voltage build-up between sand and gravel in other tests as well.

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Sand and gravel entrainment at 83 to 77 barg, 20 cm height, 3 mm nozzle

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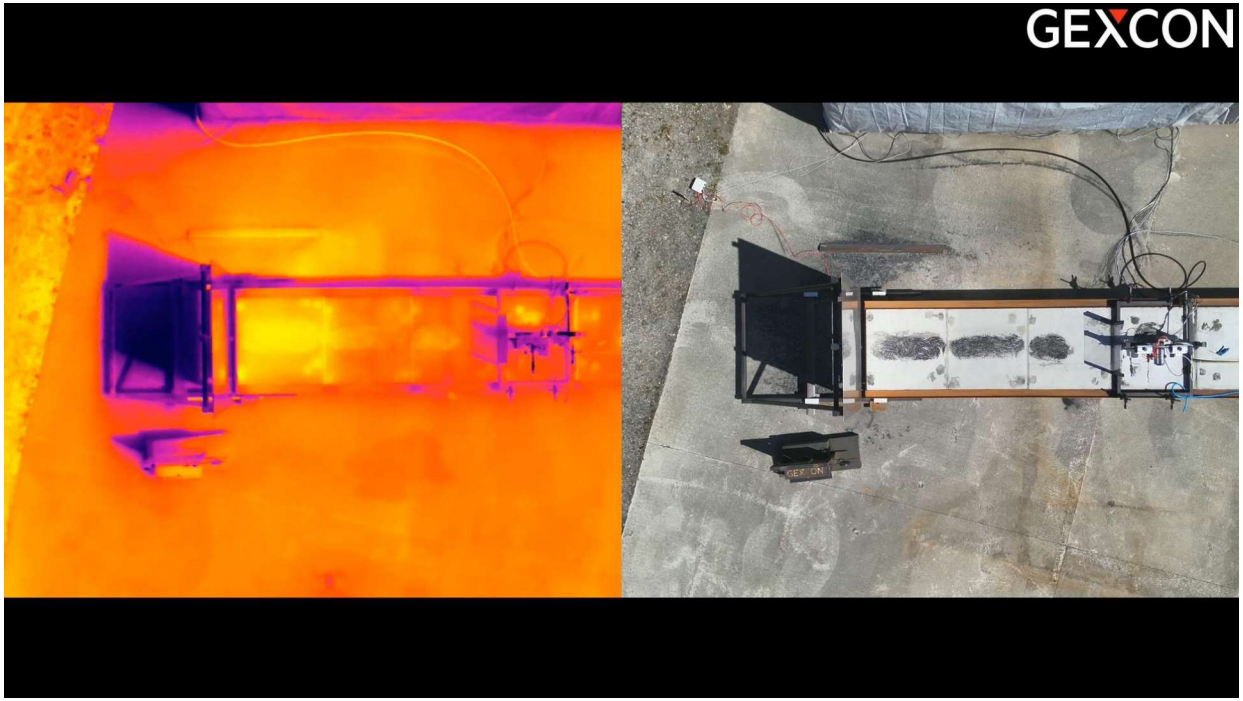
Sand and gravel entrainment at 83 to 77 barg, 20 cm height, 3 mm nozzle



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Plans for final day of provoking tests

Striker plate reduction:

- 1.5 x 1.5 m reduced to 0.75 x 1.5 m to reduce capacitance
- Hopefully will increase voltage enough to provoke spark jump
- Top 75% of plate is essentially unused for particle impingement

Forced discharge:

- Similar to air tests, but the actuated electrode will now be placed in the spark gap
- Will at the very least allow measurement of charge, if not cause ignition

Larger nozzle:

- Plans to increase nozzle size to approximately 5 mm
- Heavily increased mass flow
- Should increase velocity of entrained particles
- Planned with blow-down conditions from ~95 barg

Expected number of additional tests to be carried out: 6 tests on the next weather appropriate day