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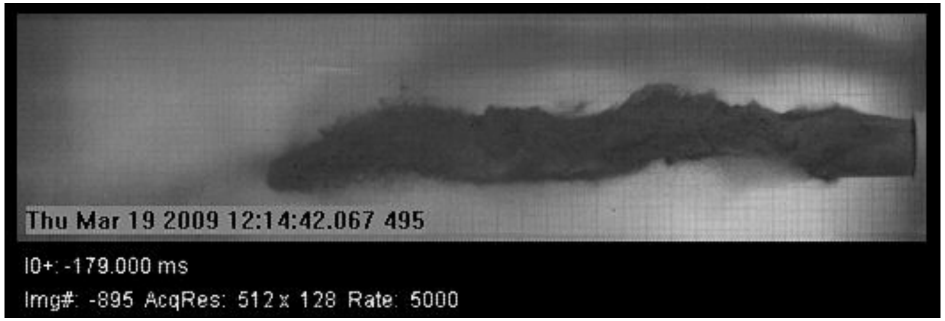


Fluidised Powder Targets

The Flying Couscous Concept

Work by:
Ottone Caretta, Peter Loveridge, Tristan Davenne and Chris Denham
@
Rutherford Appleton Laboratory

Presented by Ottone Caretta

4th High Power Targetry Workshop

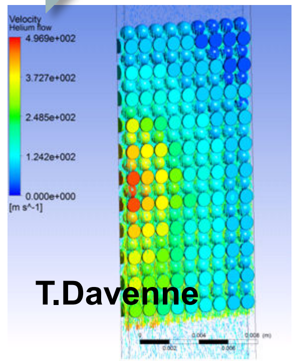
Malmo, May 4, 2011

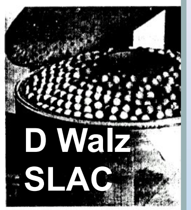
High Power Targets

The least of all evils

beam power

Energy deposition
Radiation damage
Steady s. thermal stresses
Dynamic/inertial stresses
Cavitation
Erosion
H&S
Disposal





target problems

Stationary solids

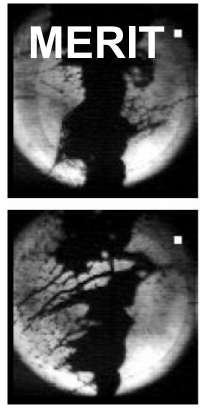
Moving solids

Packed beds

Liquid/molten

Fluidised powder

Cooling
Dimensional stability
Structural integrity
Distortion
Fatigue/failure
Erosion
Access/handling



High Power Targets

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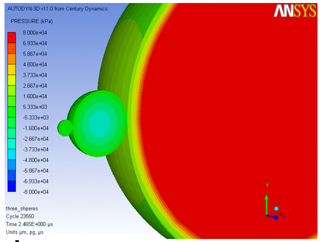
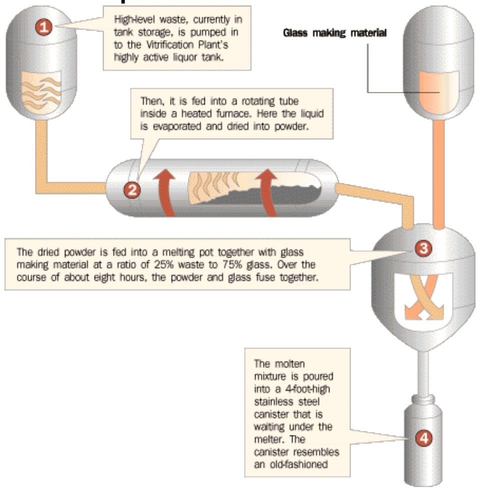
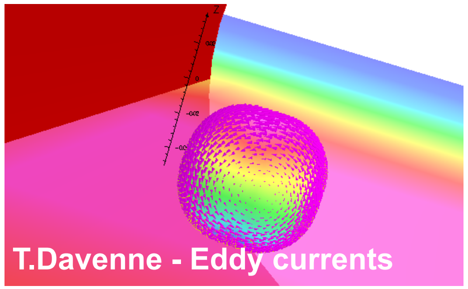
Advantages and issues



- **Solid**
  - Shock waves constrained within material – no splashing, or cavitation as for liquids
  - Material is already broken
  - Reduced chemistry problems compared with the liquid
- **Fragmented**
  - Small (roundish) grains can withstand higher stresses
  - Favourable disposal of the activated material through verification
- **Moving/flowing**
  - Replenishable
  - Favourable heat transfer (off-line cooling)
  - Metamorphic (can be shaped for convenience)
- **Engineering considerations:**
  - It is a mature technology with ready solutions for most issues
  - Few moving parts and away from the beam!
- **Issues & Questions:**
  - Its dusty
  - Erosion + powder break down. Can be tamed with careful design
  - Beam induced electrostatic charge? Unlikely to be a problem.
  - Eddy currents. Simulations suggest this is ok (T.Davenne)
  - Beam induced thermal expansion of the carrier gas (HiRadMat tests: N.Charitonides, I. Efthymiopoulos)
  - Grain to grain stress propagation: sand bags good for stopping bullets.





High Power Targets

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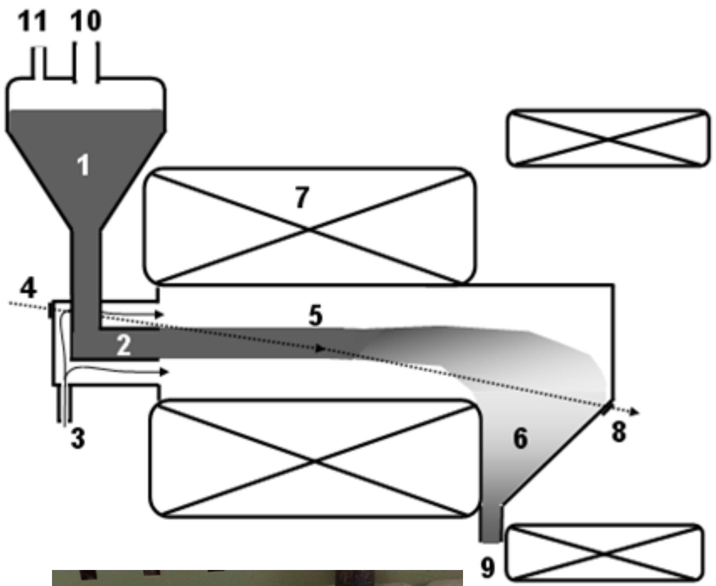
Schematic layouts of flowing powder targets for neutrino facilities

NF target

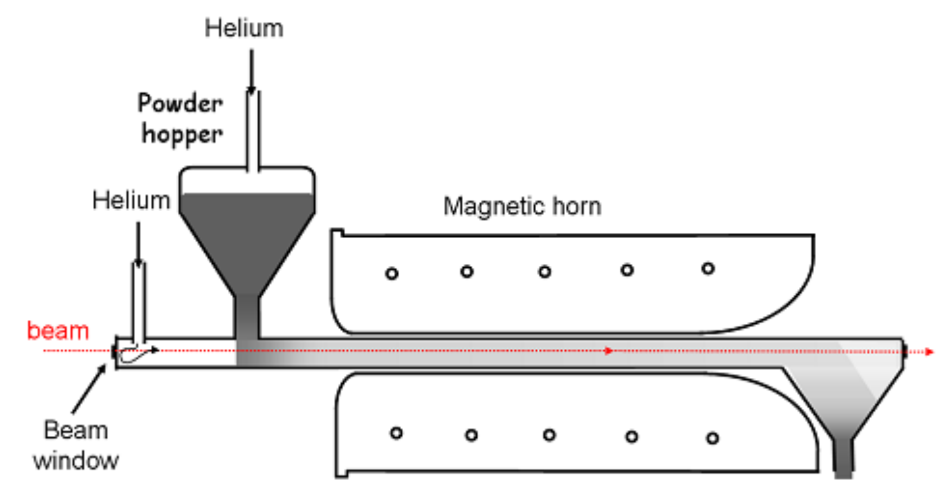
high Z material, open jet configuration (MERIT-type)



e.g. Tungsten powder

Superbeam target

low Z material, contained within pipe



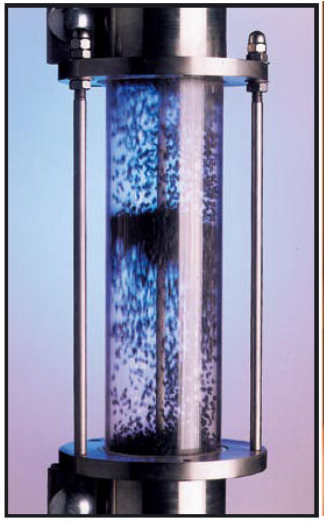
e.g. alumina powder

Applying powder technology to a MERIT-type NF scenario

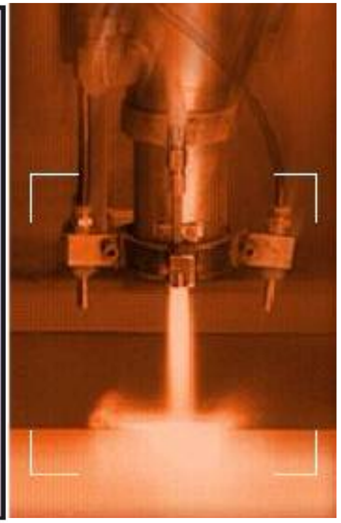
Tungsten powder: High Z, high density
(~10000 kg/m^3 @ 50% w/w)

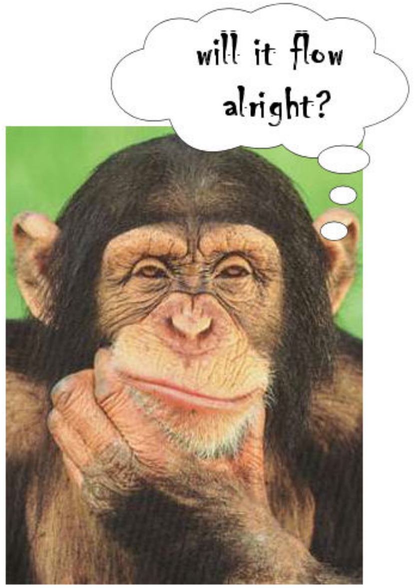
dense phase 4 conveying

lean phase 4 lifting

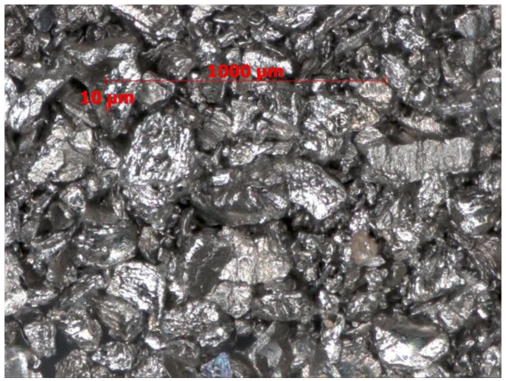


dense jet 4 beam interaction



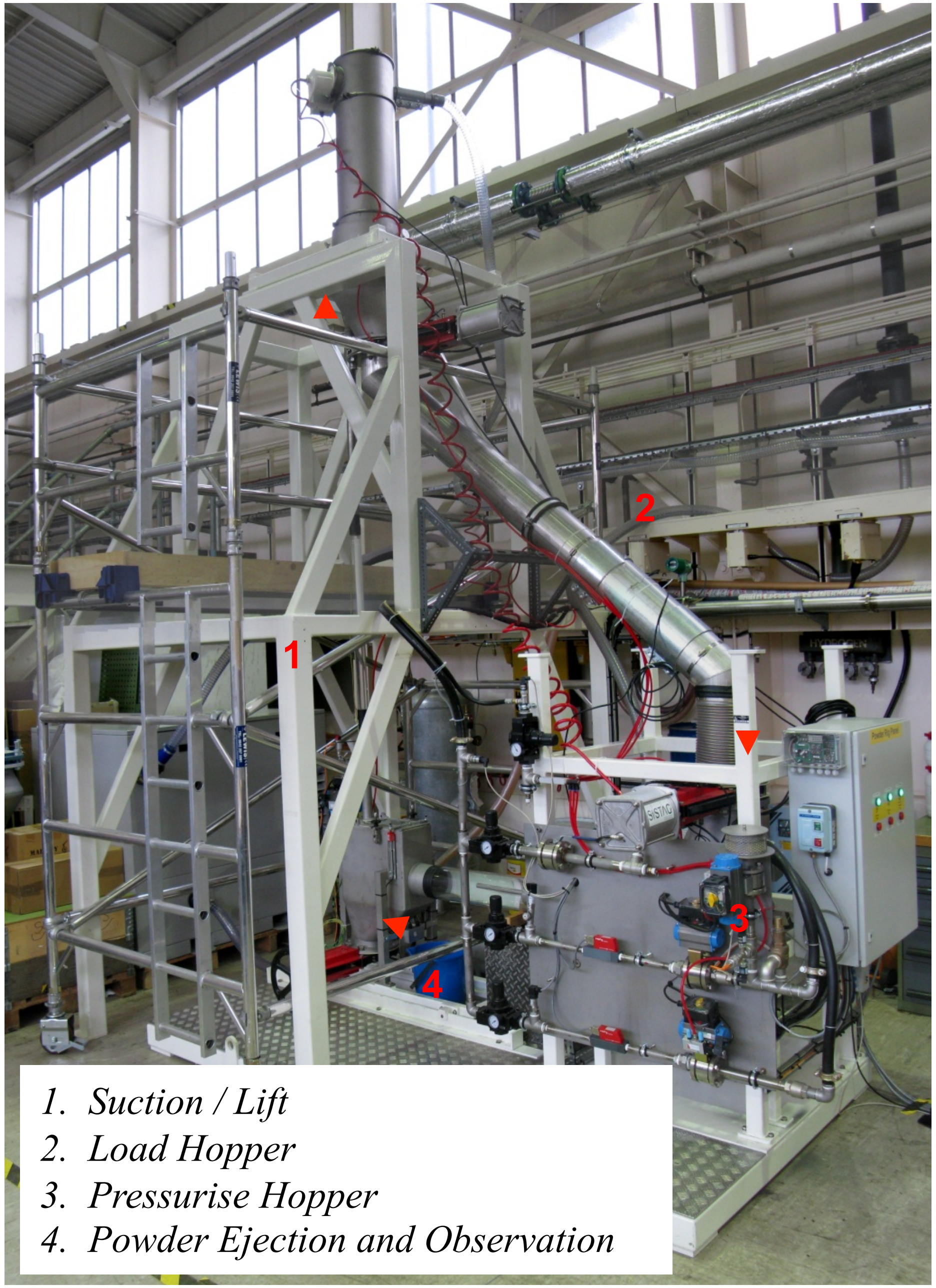


Tungsten powder



The rig: pneumatic conveying of tungsten

- Powder
  - Rig contains 100 kg Tungsten
  - Particle size < 250 microns
- Parameters
  - Stainless-steel or glass nozzle
  - Nozzle length: 0.5 – 1.2 m
  - Driver pressure: 1 – 4 bar
- Batch process:
  1. Suction / Lift
  2. Load Hopper
  3. Pressurise Hopper
  4. Ejection / observation



1. *Suction / Lift*
2. *Load Hopper*
3. *Pressurise Hopper*
4. *Powder Ejection and Observation*

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Control Interface

Fully automated control system

- Process control
- Data Logging @ 20 Hz
- Hard-wired safety interlocks

Warning messages

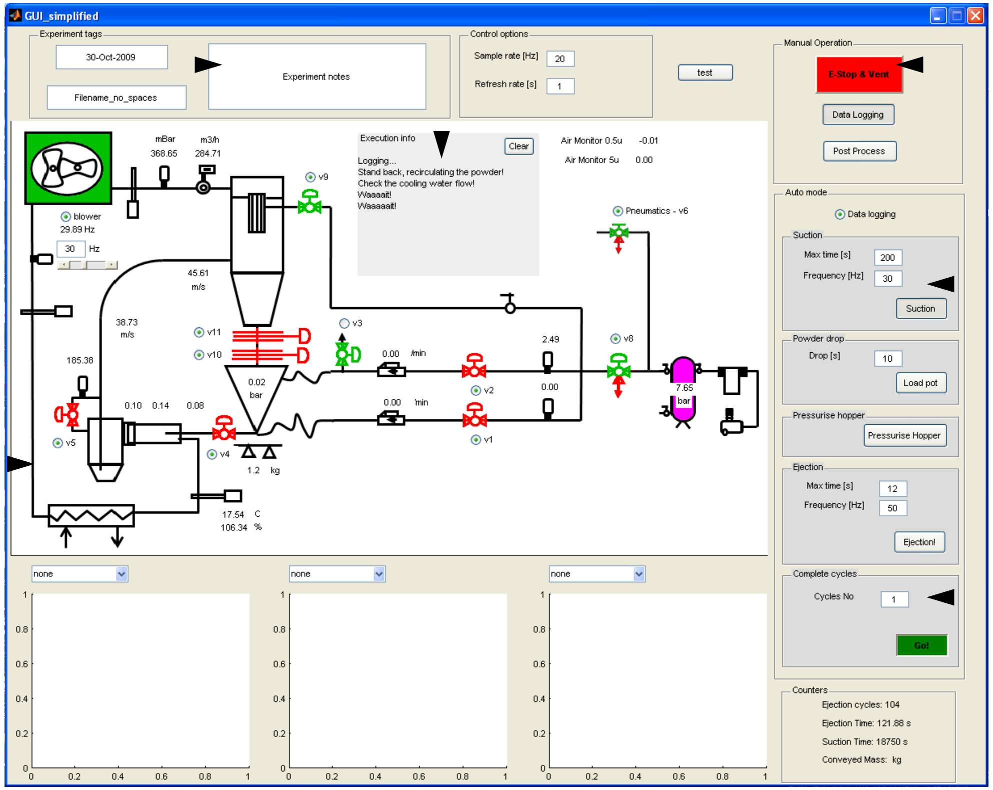
Experiment notes

System indicator window

Emergency stop

Suction settings

Ejection settings

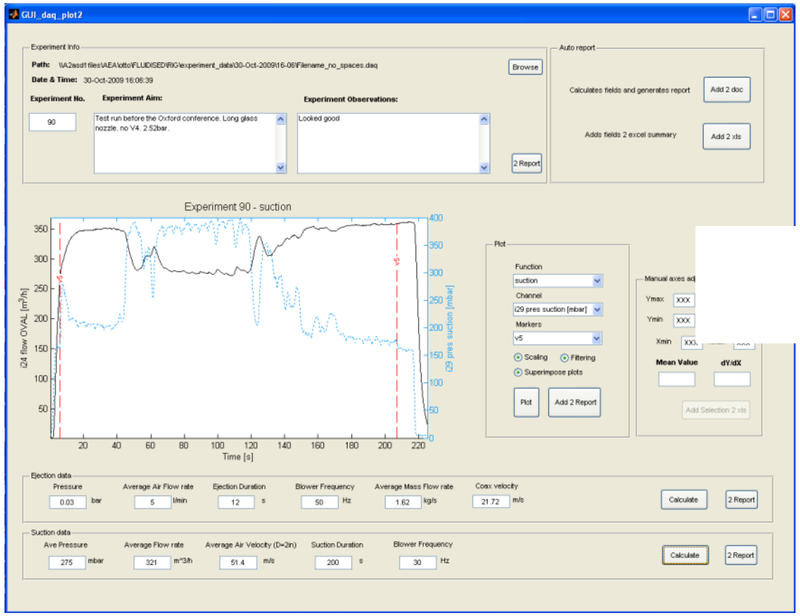


Control System Interface (MATLAB)

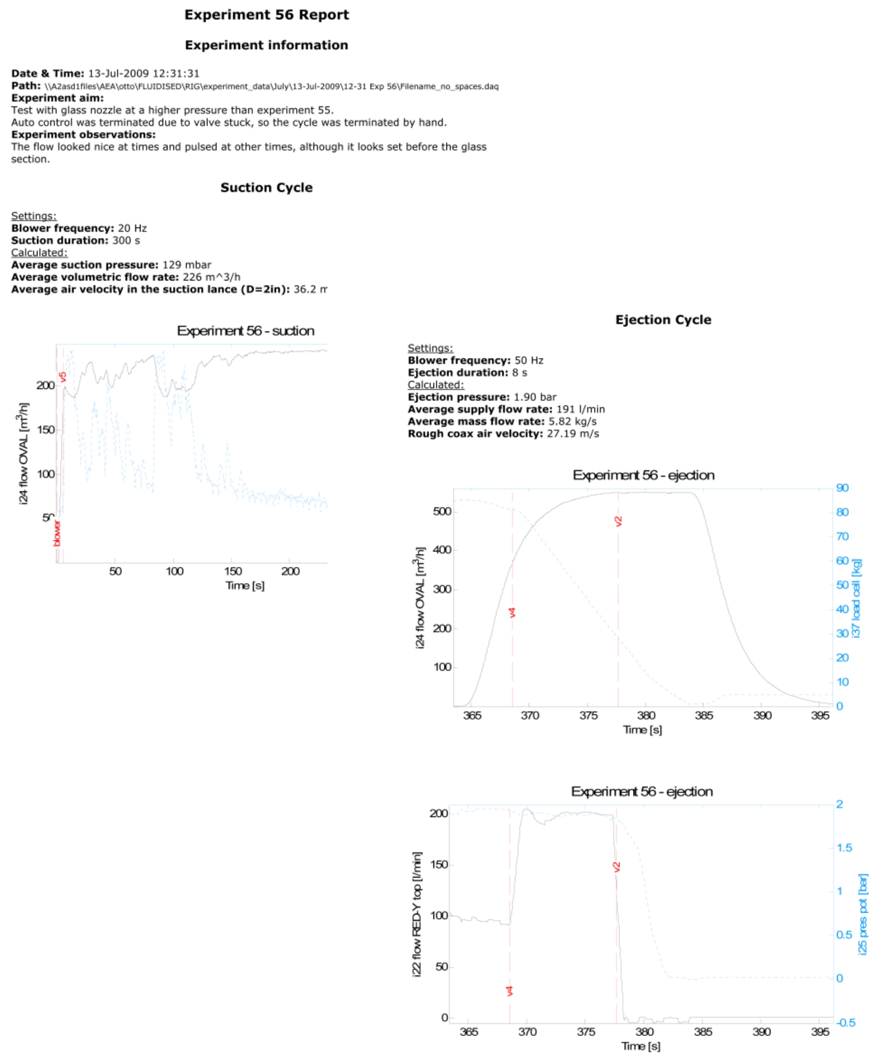
Post Processing

Automatic report generator

- Records experiment settings
- Graphs the data
- Generates a Microsoft word document for each cycle



Post-processing user interface - Matlab



Experiment 56 Report

Experiment information

Date & Time: 13-Jul-2009 12:31:31
Path: \\A2asd1files\AEA\otto\FLUIDISED\RIG\experiment_data\July\13-Jul-2009\12-31 Exp 56\Filename_no_spaces.daq
Experiment aim:
Test with glass nozzle at a higher pressure than experiment 55.
Auto control was terminated due to valve stuck, so the cycle was terminated by hand.
Experiment observations:
The flow looked nice at times and pulsed at other times, although it looks set before the glass section.

Suction Cycle

Settings:
Blower frequency: 20 Hz
Suction duration: 300 s
Calculated:
Average suction pressure: 129 mbar
Average volumetric flow rate: 226 m^3/h
Average air velocity in the suction lance (D=2in): 36.2 m

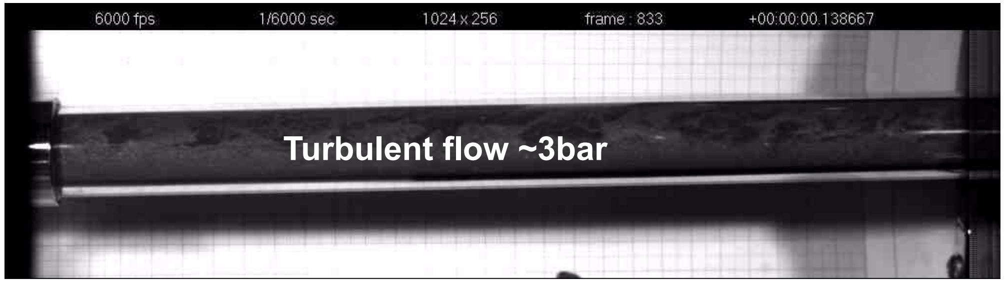
Ejection Cycle

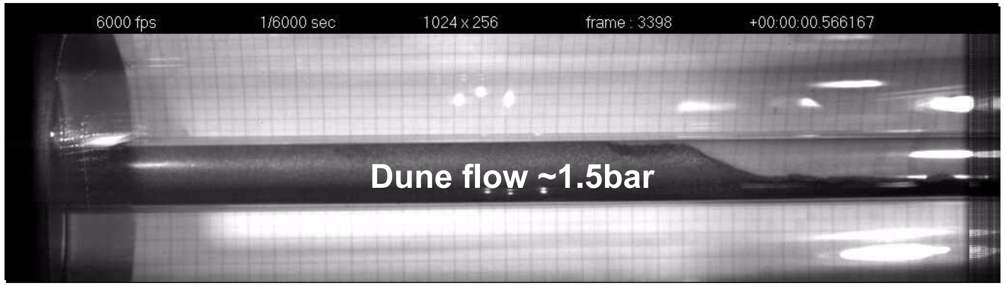
Settings:
Blower frequency: 50 Hz
Ejection duration: 8 s
Calculated:
Ejection pressure: 1.90 bar
Average supply flow rate: 191 l/min
Average mass flow rate: 5.82 kg/s
Rough coax air velocity: 27.19 m/s

Two-page Report - Microsoft Word

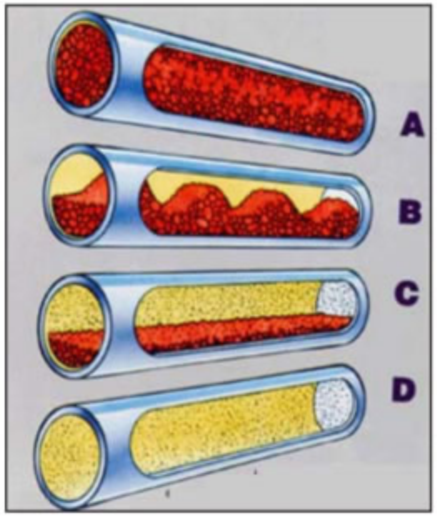
The results: good news!

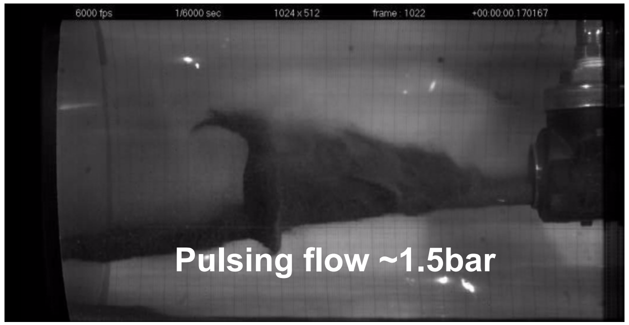
Tungsten **can** be conveyed in the dense phase, the lean phase and makes interesting dense/coherent jets

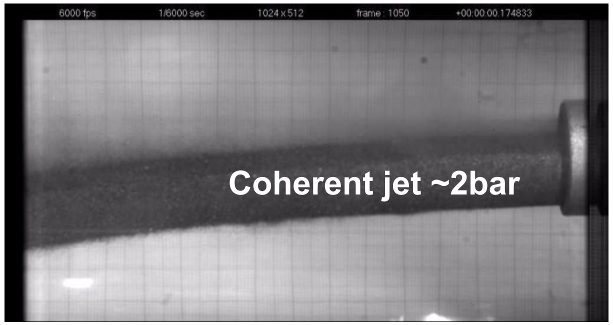




Theoretical powder conveying regimes







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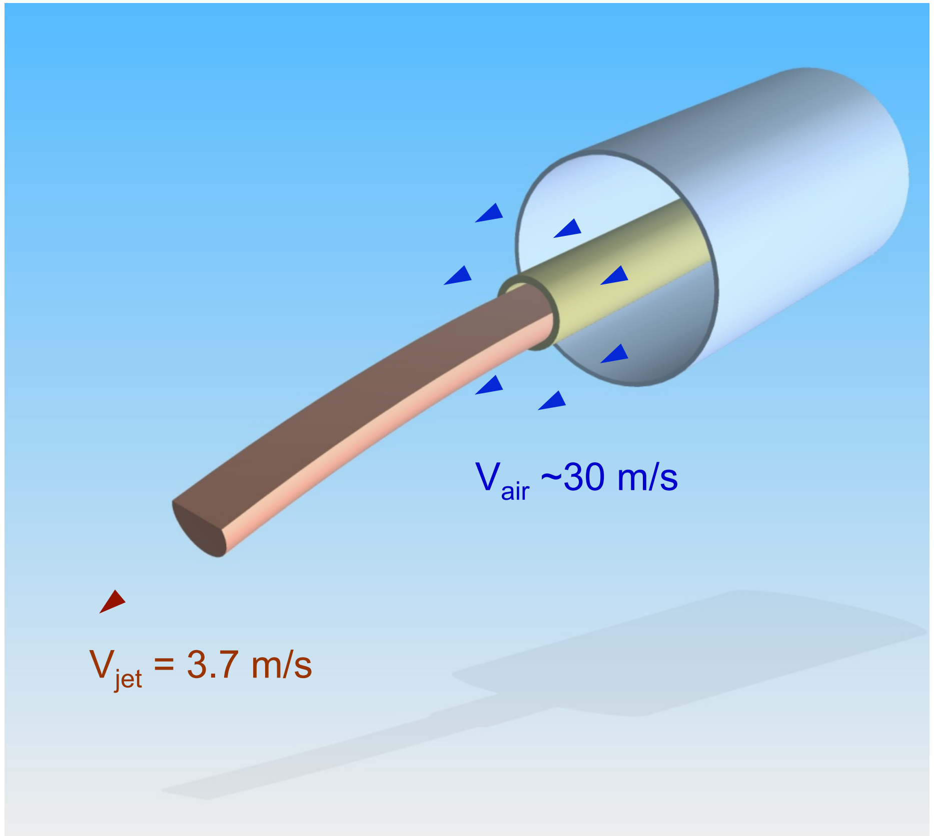
High Power Targets

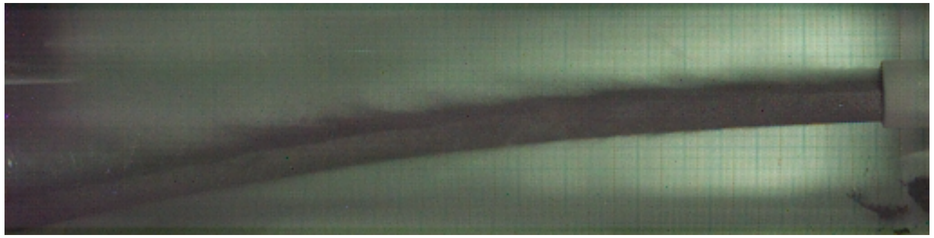
Coherent jet characterisation

Coherent Jet workout

- Tungsten powder <250 um
- 2.0 bar ejection hopper pressure
- Jet "droops" by ~30 mm over a 300 mm length
- Each particle takes ~0.1 sec to traverse viewport
- Coherent flow with separation between the 2 phases
- Constant pressure in hopper throughout ejection
- Small velocity gradient from top to bottom
- Velocity constant over time
- Cross section of the jet remains constant as the jet flows away from the nozzle
- Geometry of the jet remains reasonably constant with time



Low pressure ejection schematic



Still from video clip
(2 bar ejection hopper pressure)

Jet Density Calculation

- Recall: Solid Tungsten density = 19,300 kg/m3
- Powder density "at rest" ~ 50% solid

<u>Density Calculation for 2 bar ejection</u>

Jet area, A= <u>262 mm2</u>
(from nozzle dimensions and video still measurements)

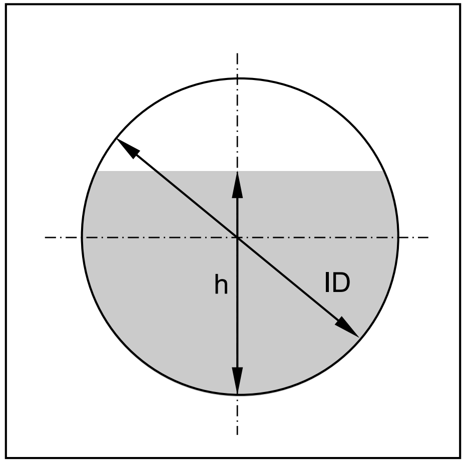
Powder bulk velocity, V = <u>3.7 m/s</u>
(from particle tracking)

Vol flowrate = A.V = <u>0.000968 m^3/s</u>

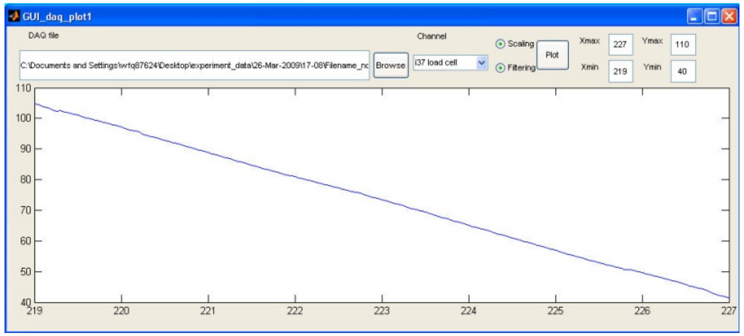
Mass flowrate = <u>7.875 kg/s</u>
(from loadcell)

Jet Density = Mass flowrate / Vol flowrate = <u>8139 kg/m^3</u>
Jet Density = 42% Solid tungsten density

Uncertainty is of the order ± 5% density



Nozzle ID = 21.45 mm
Jet height = 14.6 mm
Jet Area = 262 mm^2



From hopper load-cell data log:
63 kg in 8 sec = 7.875 kg/sec

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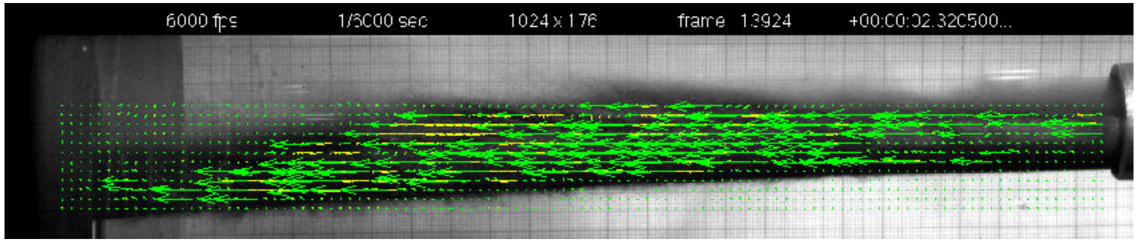
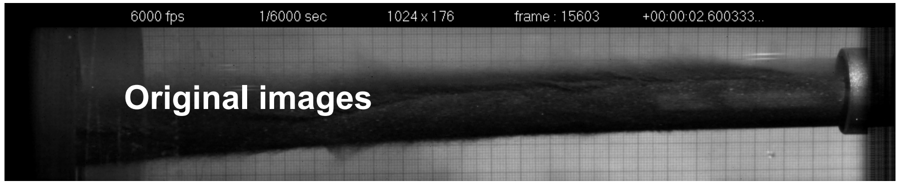
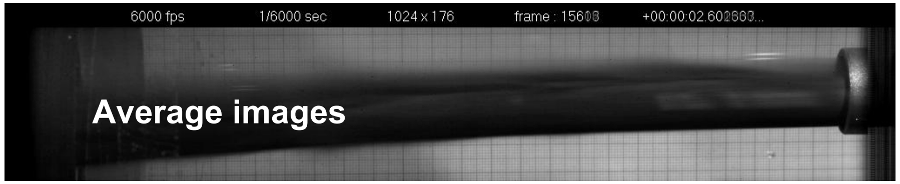
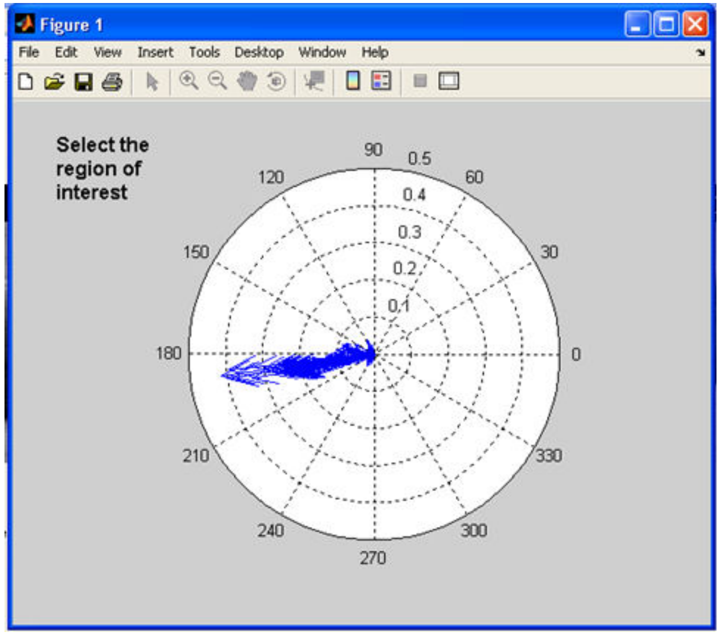
PIV (Particle Image Velocimetry)
“data massage”: highlighting the odd grains









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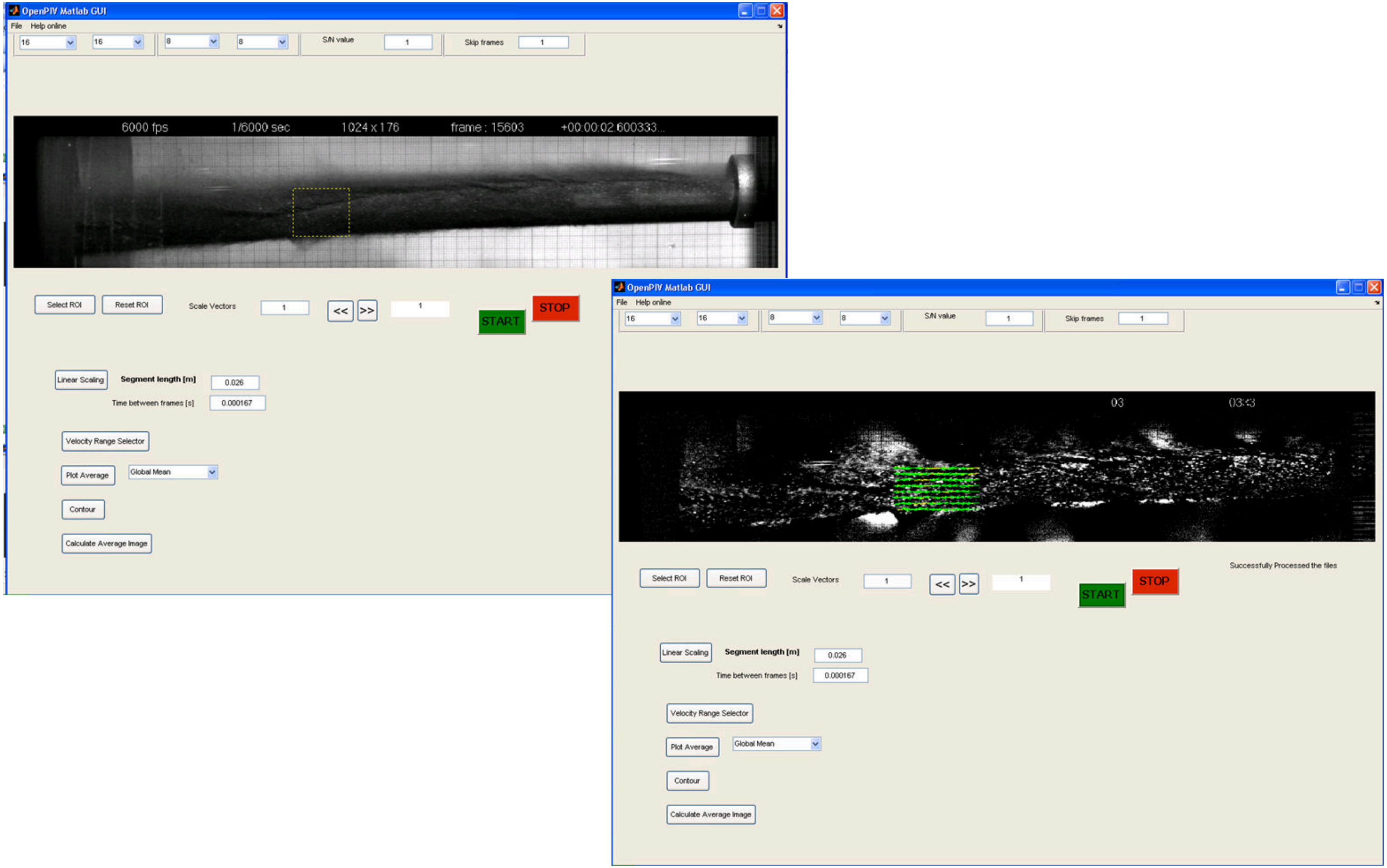
PIV - example



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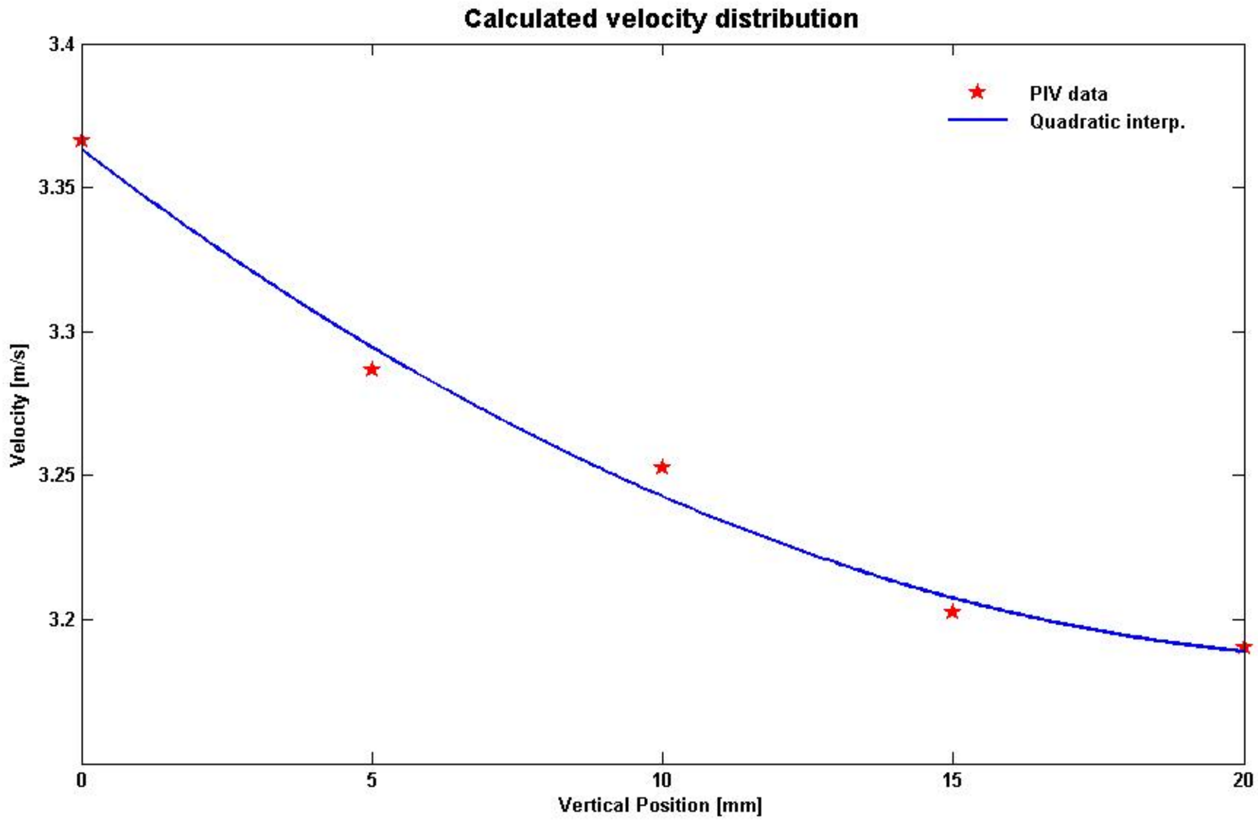
PIV – vertical velocity profile in the jet



Erosion Monitoring

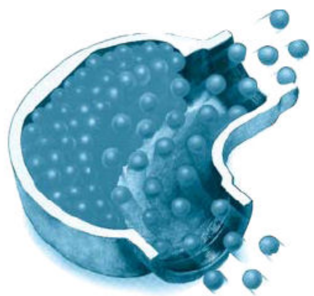
Expect rig lifetime to be limited by wear

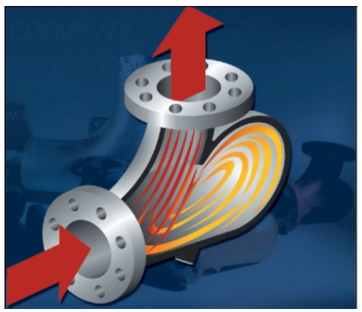
Wall thickness monitoring:

- Dense-phase hopper / nozzle
  - No damage
- Lean-phase suction pipework
  - Straight vertical lift to avoid erosion
- Temporary deflector plates
  - Grit polished!

Design to avoid erosion problems is critical

- Lean phase optimisation (↓u, ↑ρ)
- Avoid lean-phase bends ✓
- Operate without discharge valve ✓
- Replace deflector plate with powder/powder impact



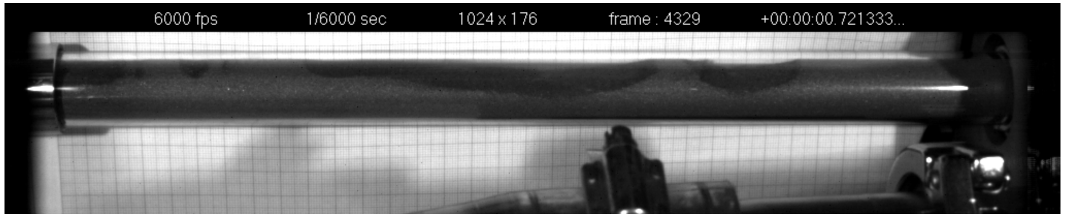


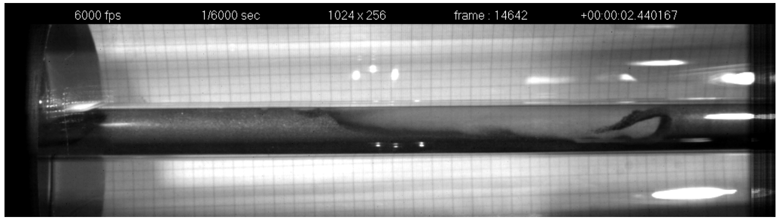
Ultrasonic Thickness Gauge

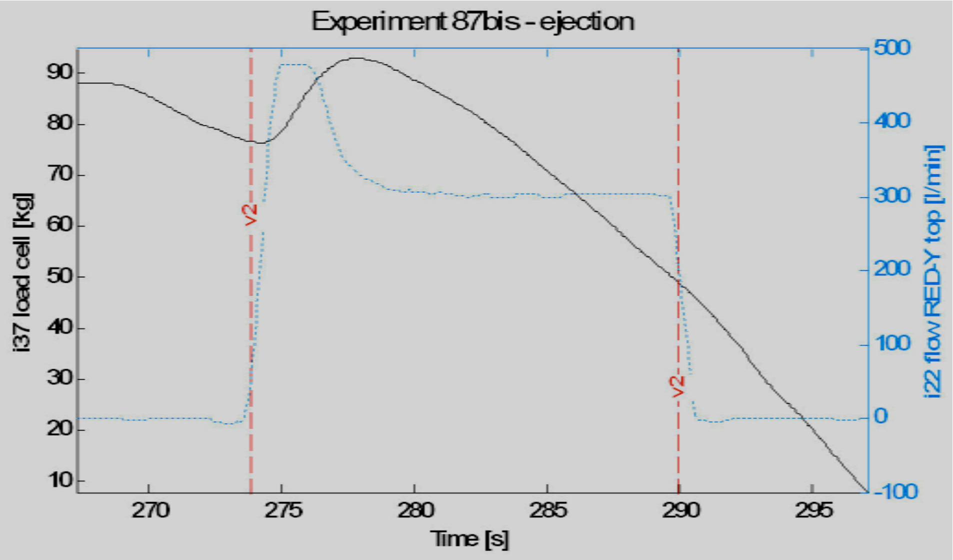
Material	Vickers Hardness
Stainless-steel 316L	140
Tungsten	360
Alumina (Al_2O_3)	1500
Boron Carbide (B_4C)	3200

Selected Material Hardness Values

Variations in the flow rate – typical 2bar ejection



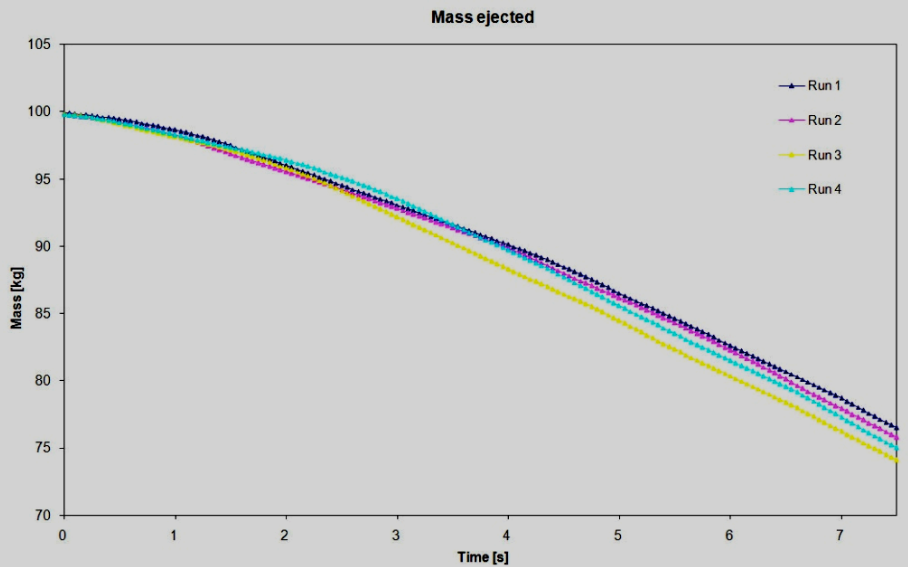




How much material does the beam meets?

Density?

Is the amount of material in the nozzle (or jet) constant?



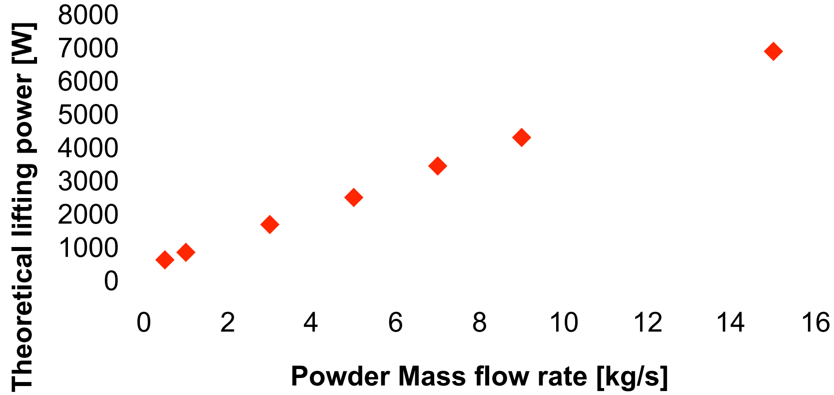
Suction: study on lifting power requirements

Initial mismatch between suction rate (~1kg/s) and ejection rate (~10kg/s)

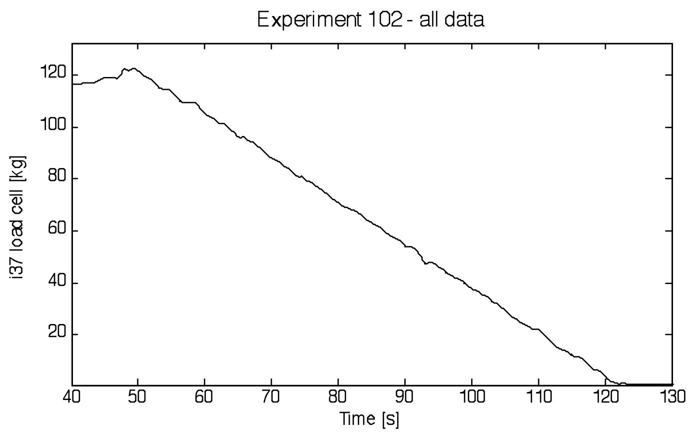
Powder lifting flow rate depends on a few variables:

- Powder entrainment in the air stream
- Powder size distribution
- Sphericity of the grains
- Diameter of the suction line
- Air to powder ratio
- Density of the powder
- Density of the gas
- Temperature of the gas
- Etc.!

Theoretical lifting work VS suction capacity



Matched the ejection rate by reducing nozzle diameter (ejection rate) and improving the suction pick up arrangement



18kW blower

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Powder Size Distribution

- Theory – bulk properties vary with particle size
- We expect powder grains to break down over time
- Tried sieve analysis to monitor particle size distribution
- Obtained reliable measurements with laser interferometer

300 μm
212 μm
150 μm
106 μm
75 μm
50 μm

Sieve shaker: Retsch AS 200

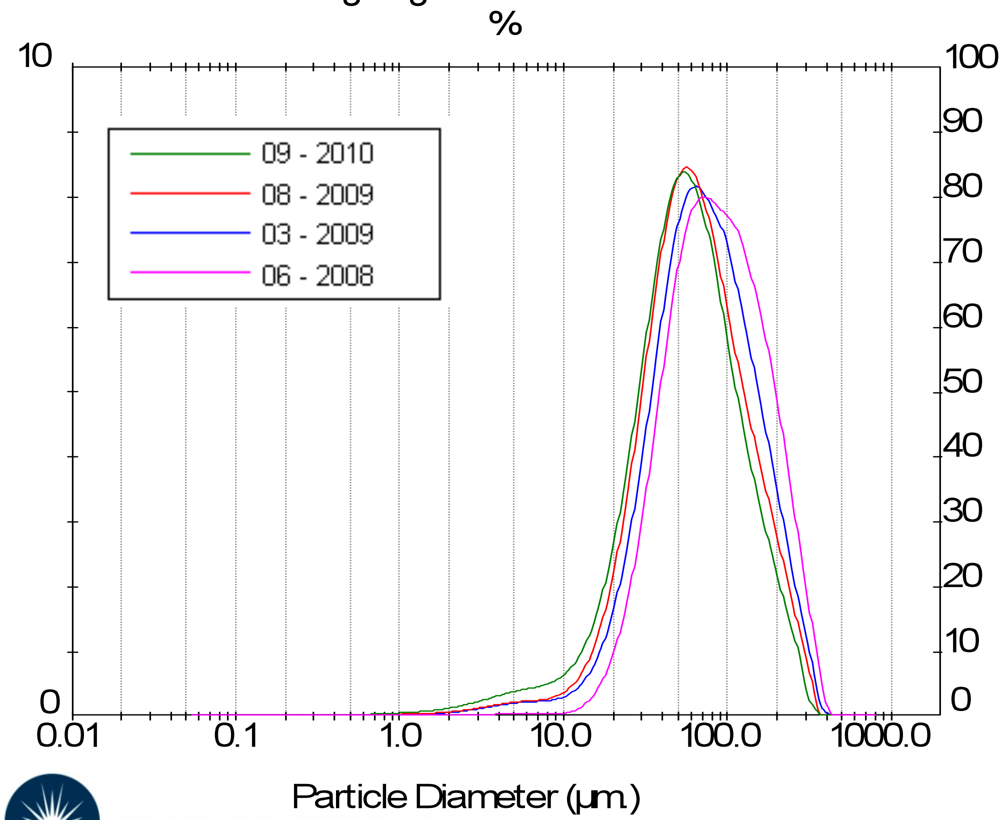
Sample size: 100g

Balance: ± 0.5 g

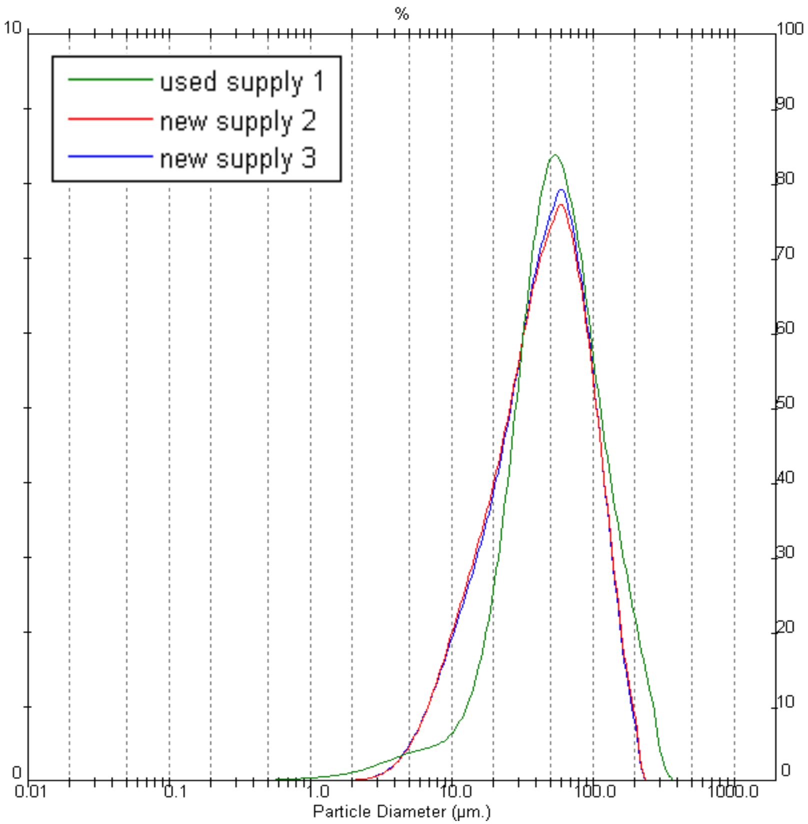
Powder breakdown?

Measurements show some powder breakdown.
However it is likely that initial powder sampling was not sufficiently "scientific":
you always eat larger corn flakes first and the smaller crumbles at the end..

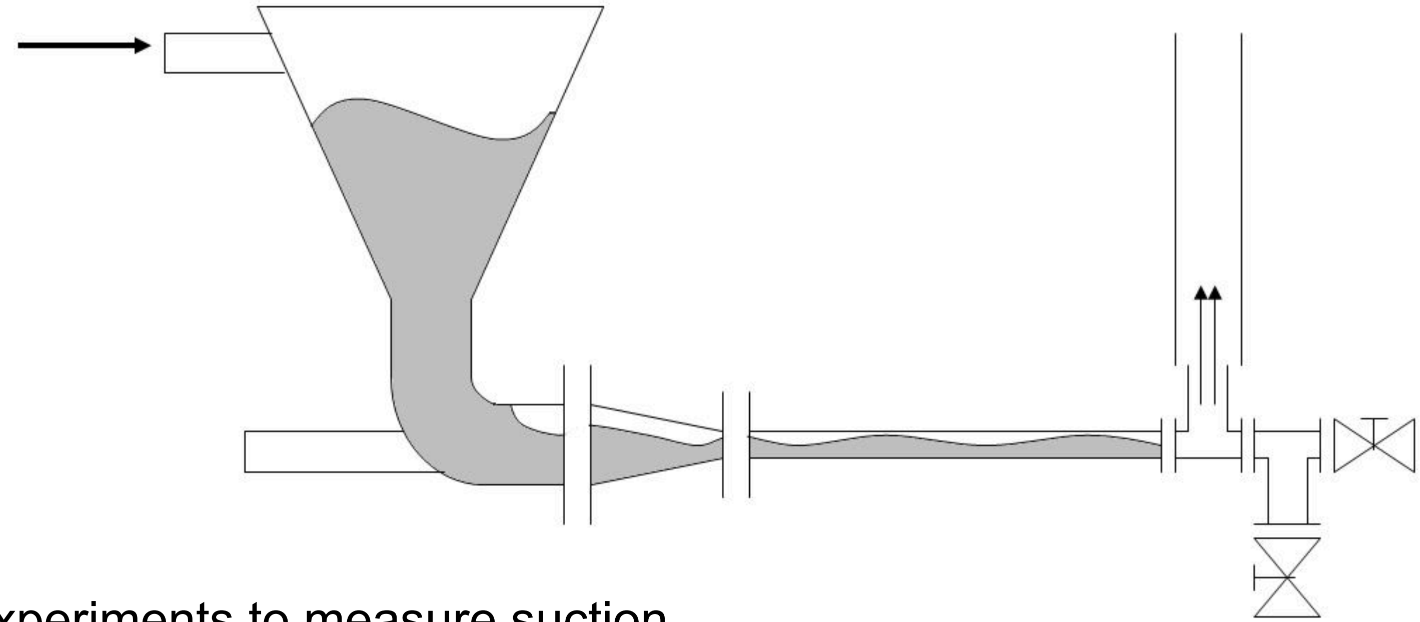
Mind flotation of larger grains!



Different supplies of tungsten show rather different in size distribution

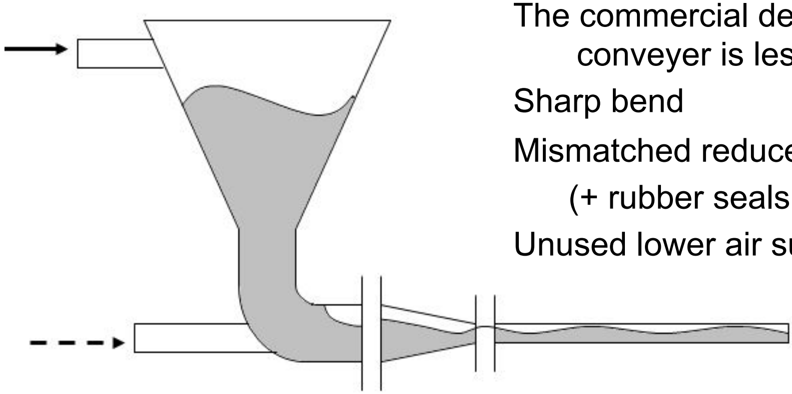


Future experiments – continuous recirculation (contained target)



Experiments to measure suction pressure drop, and powder terminal velocity as a function of the powder loading (ejection rate)

Future experiments – prevent phase separation

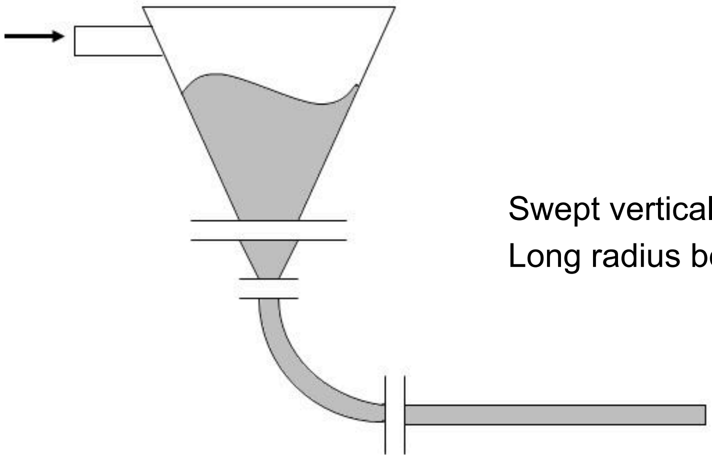


The commercial dense phase
conveyer is less than ideal!

Sharp bend

Mismatched reducers
(+ rubber seals)

Unused lower air supply



Swept vertical reducer

Long radius bend (perhaps glass?)

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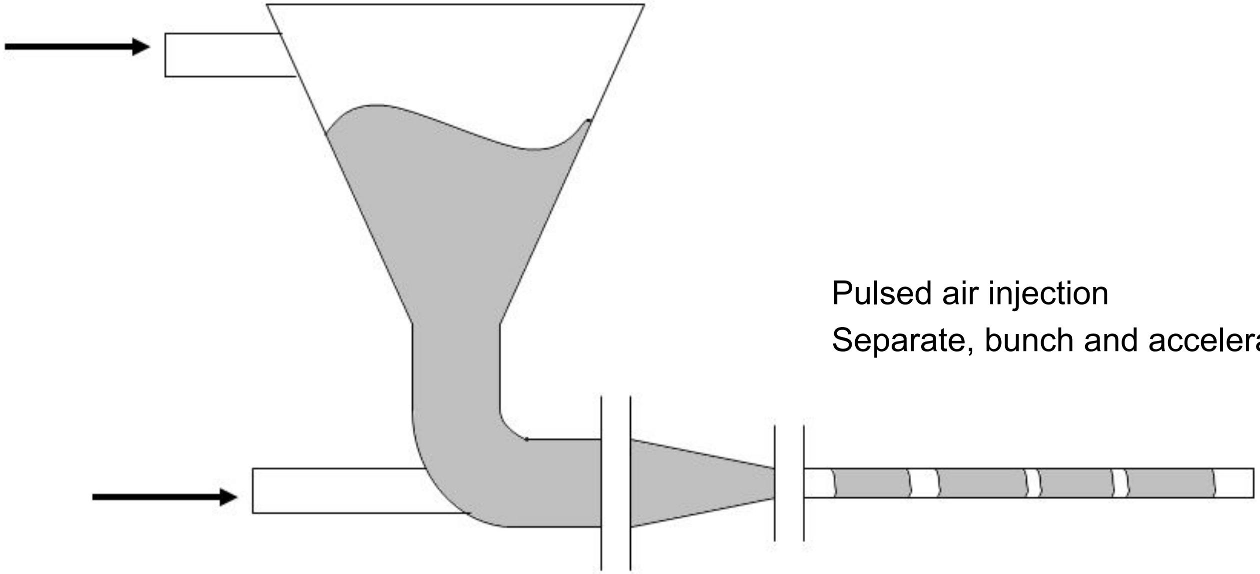
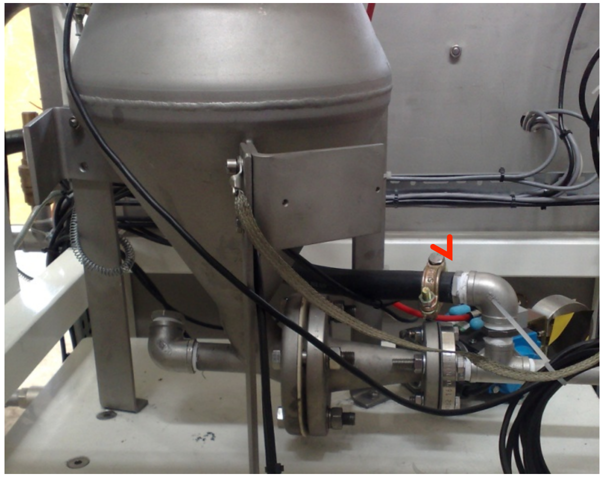
Future experiments – artificial/regular slug formation



Pulsed air injection

Separate, bunch and accelerate slugs



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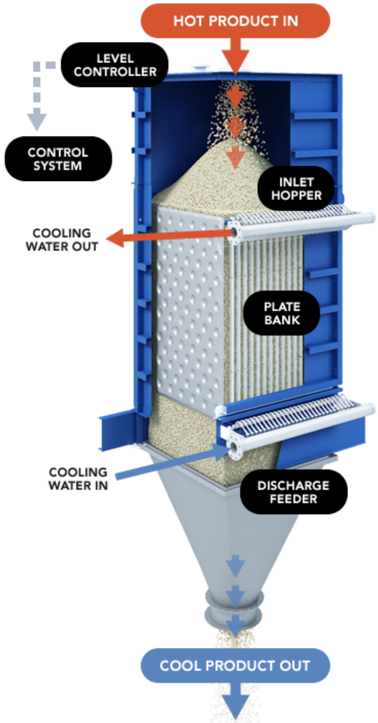
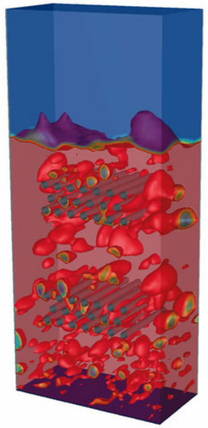
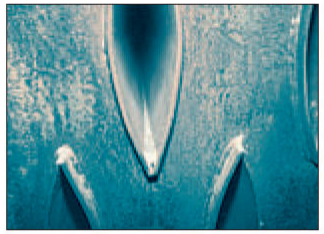
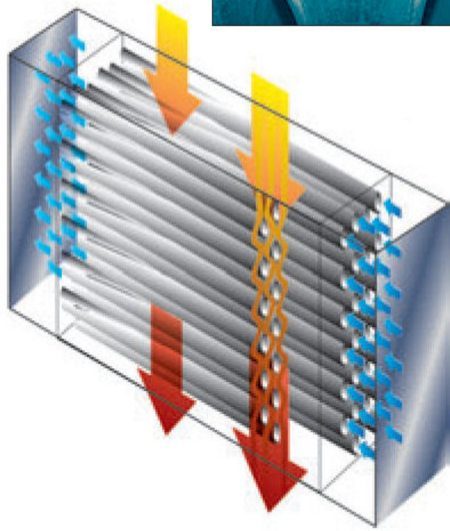
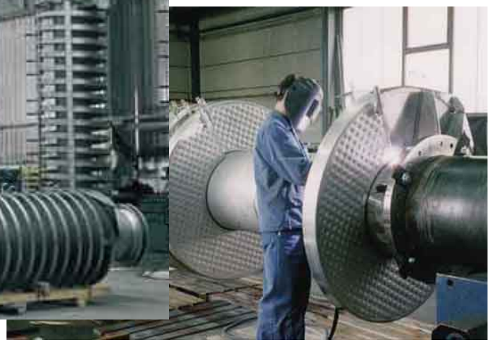
Future work – heat transfer





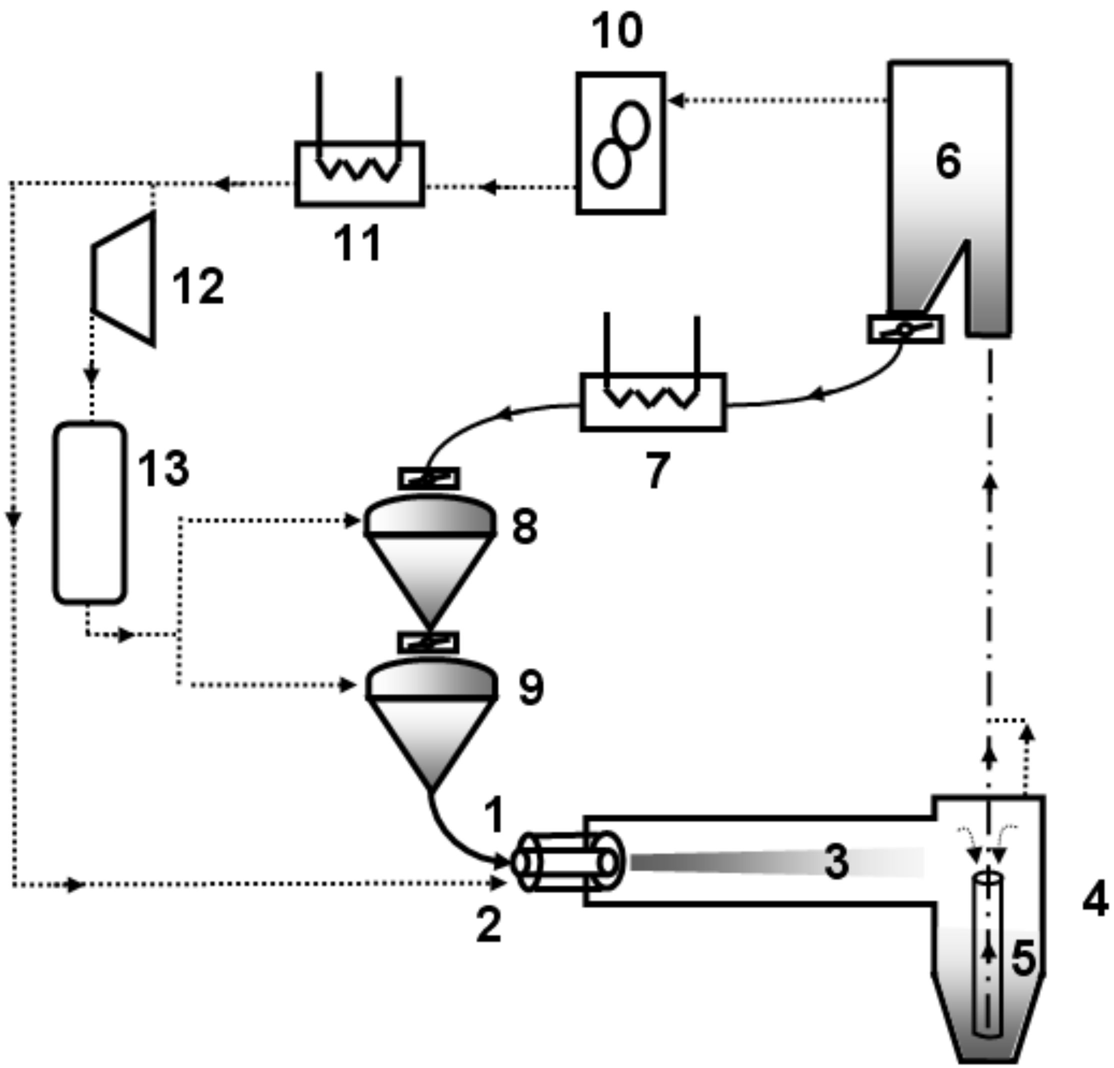






Future work – CW upgrade

(1) powder discharge nozzle
(2) gas return line forming coaxial flow
(3) target jet,
(4) receiver hopper
(5) suction nozzle for gas lift
(6) gas lift receiver vessel with filter
(7) powder heat exchanger
(8) and (9) pressurised powder hoppers
(10) Roots blower
(11) gas heat exchanger
(12) compressor
(13) gas reservoir



Powder target work conclusions:

So far lots of fun and plenty still to come!

Questions or suggestions?