Brief Background on Volcanic Ash Oxford

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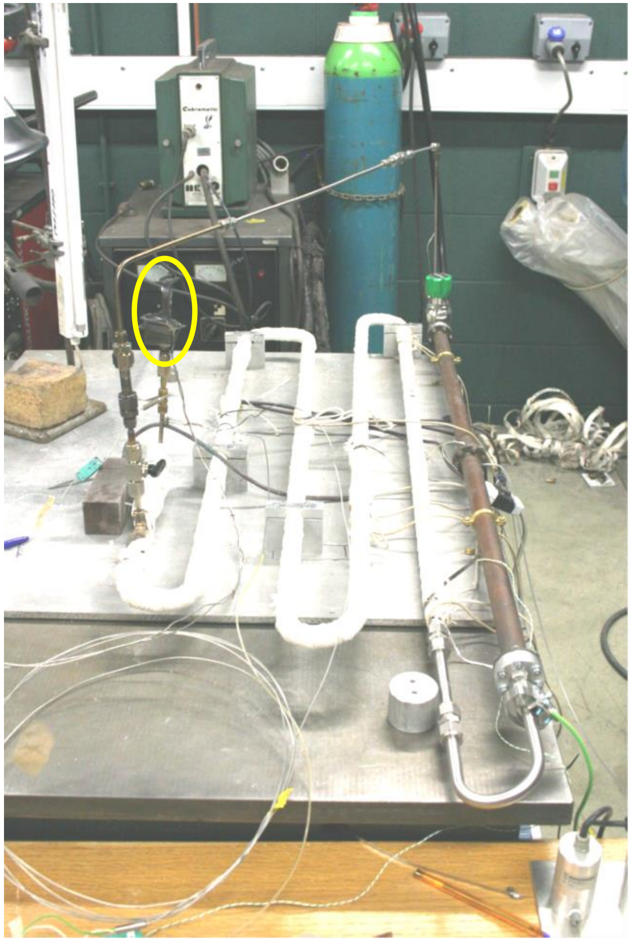
Rolls-Royce

Starting Point NEWAC

- Build a simple test rig to heat coolant to 650^{o}C
- Use cutaway of turbine blade to provide sample for testing
- Use blowtorch to obtain reasonable external boundary conditions
- Showed that internal deposition is possible in cooling holes
- Icelandic ash reground from Cranfield sample used.

- Match velocities but not pressures



General Set-Up

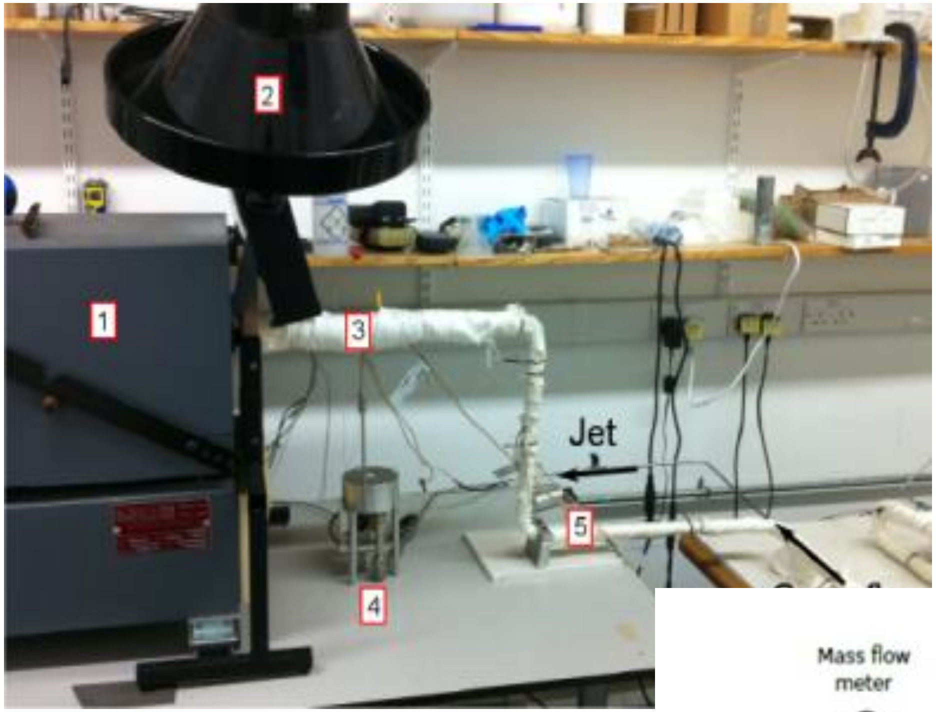


Fig 3.4 – rig in operation [11].
Key:
1 = Electric furnace
2 = Extractor
3 = Mixing chamber
4 = Continuous Delivery System (CDS)
5 = Heater tape

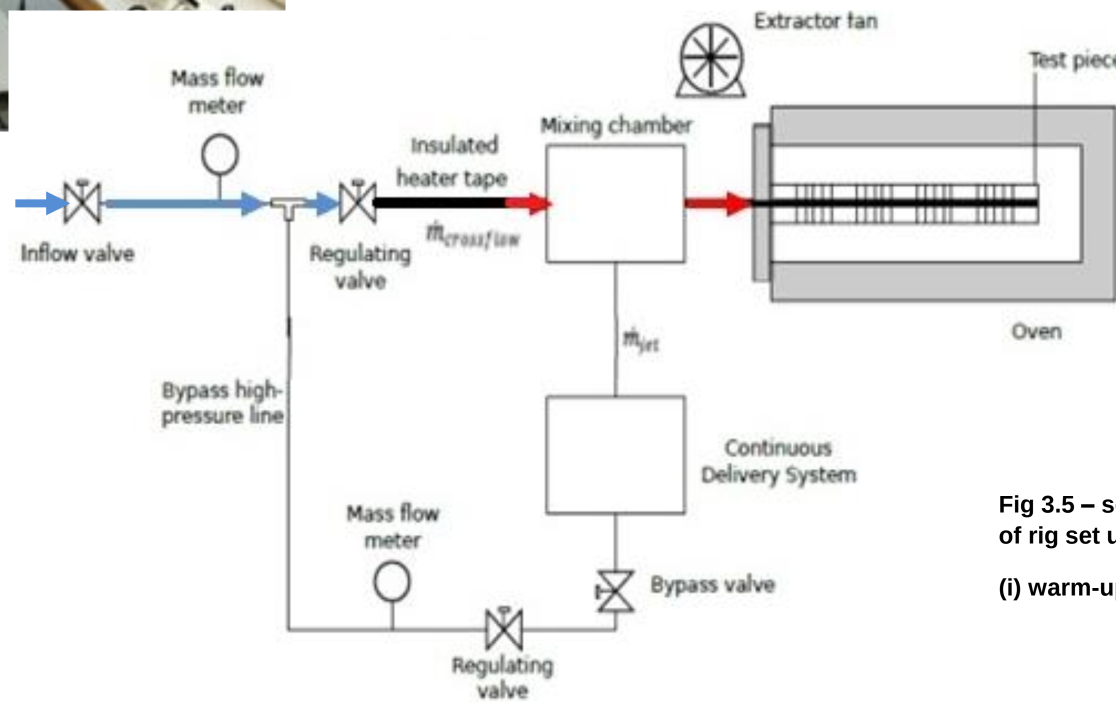
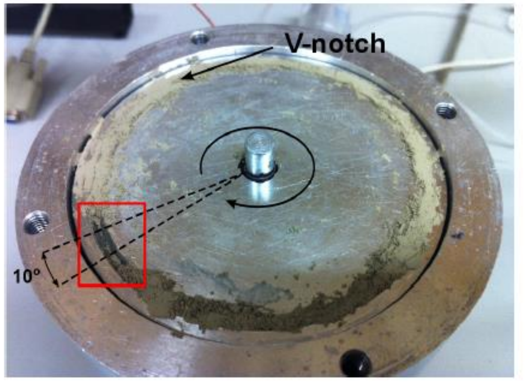


Fig 3.5 – schematic of rig set up for:

(i) warm-up

Experimental Improvements



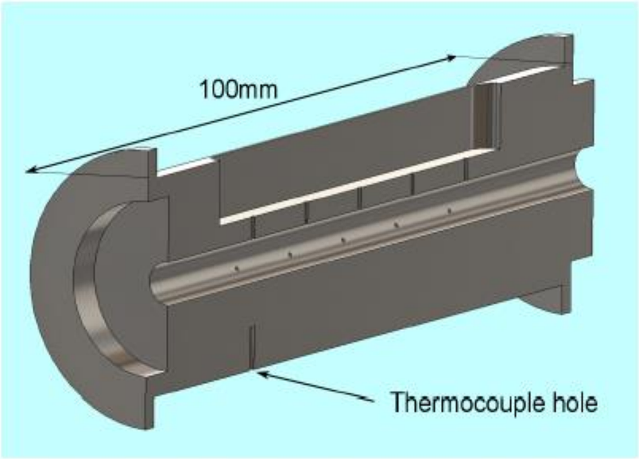
- Improved particle delivery system
  - Rotating ash snorter with
  mixing chamber

- Preheat of sample in oven up to 900 - 1200°C

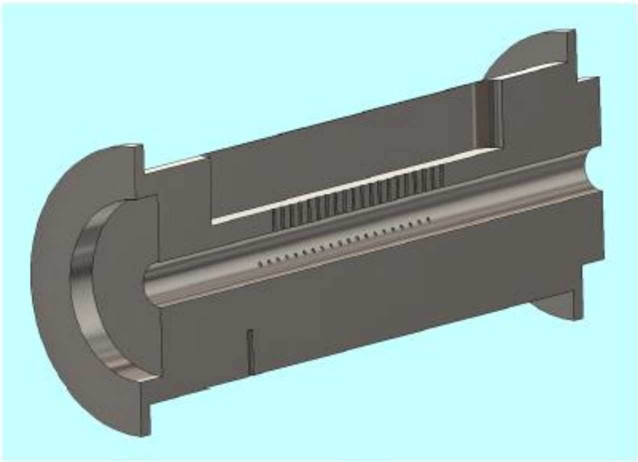
- Currently no funded programme

- 4 x 4YP students, Sam Hussain, James Parry-Crooke, Alex Bucknell and Seb Wylie

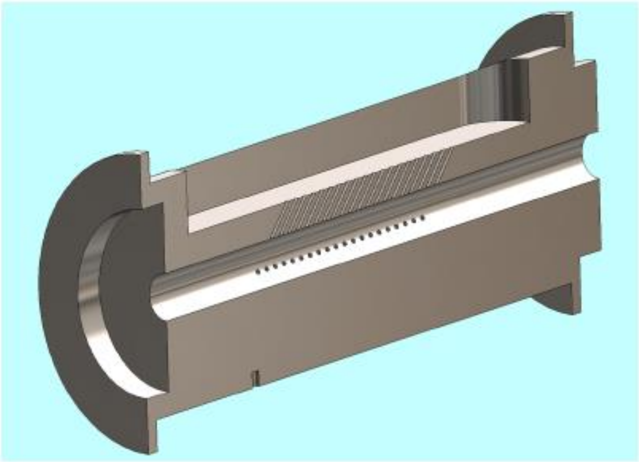
Improved Trial Test Pieces



(a) Low hole-density, 90° to flow (LD90, 1 of 4 pieces)



(b) High hole-density, 90° to flow (HD90)



(c) High hole-density, 45° or 135° to flow (HD45 or HD135)

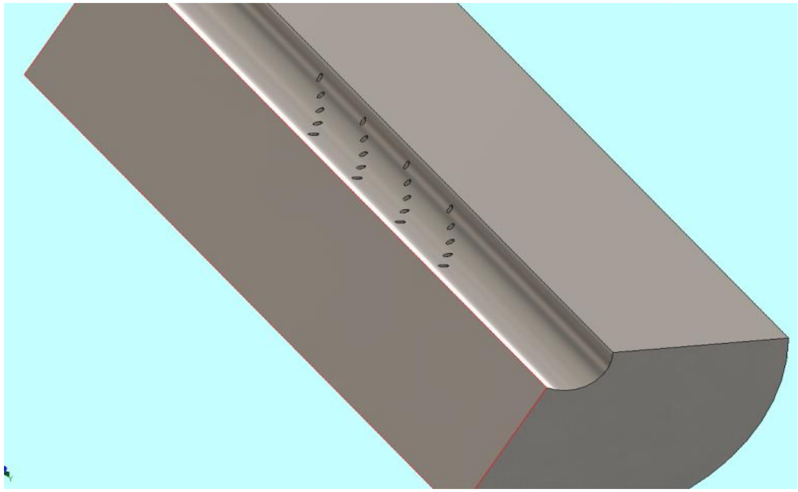


Fig 3.2 – Isometric view of a 120° section of HD90-S, showing the central channel interior. Used in meshing and analysis

Flow parameter measurements

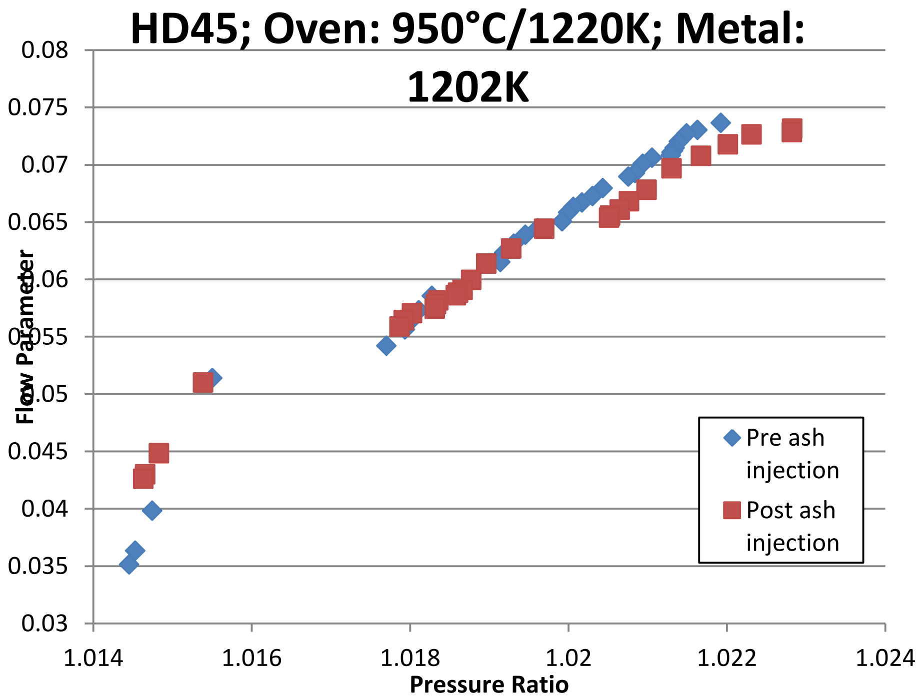


Fig. 6.2 – FP plotted against test section pressure ratio at 950°C, HD45

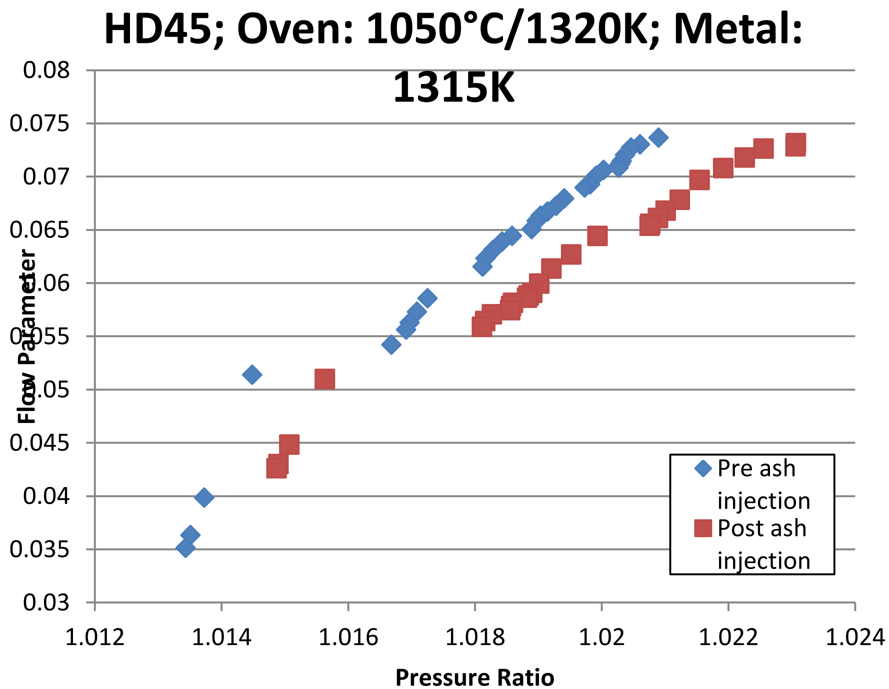


Fig. 6.3 – FP plotted against test section pressure ratio at 1050°C, HD45

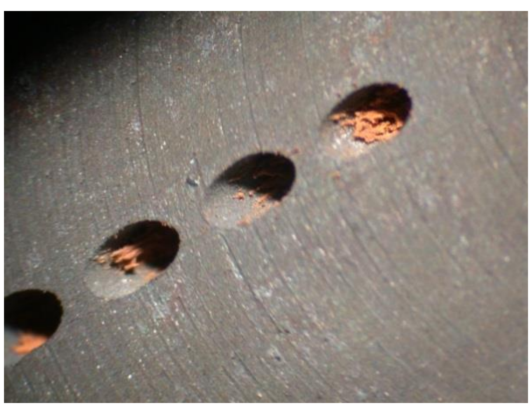


Fig. 6.6 – Deposition in first four cooling holes of HD45, 1050°C

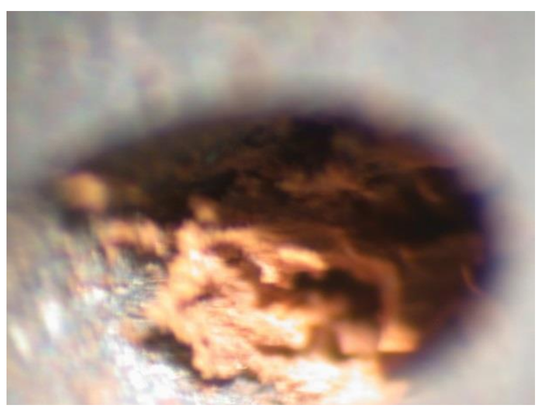


Fig. 6.7 – Blocked cooling hole in HD45, 1050°C

$$FP = \frac{\dot{m}_{coolant}\sqrt{T_{coolant}R}}{P_{coolant}d^2}$$

Comparison of reduction in Flow parameter

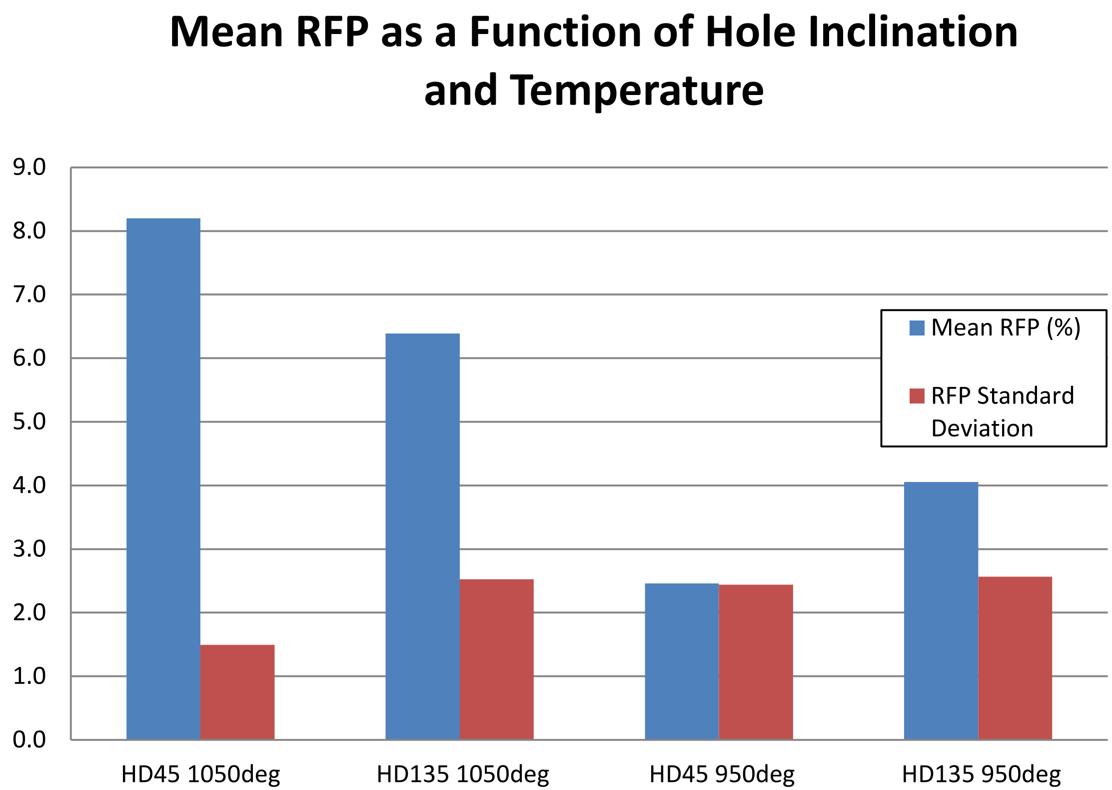
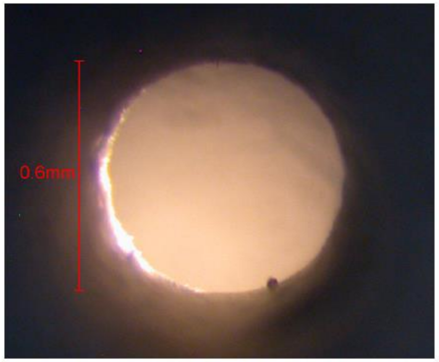
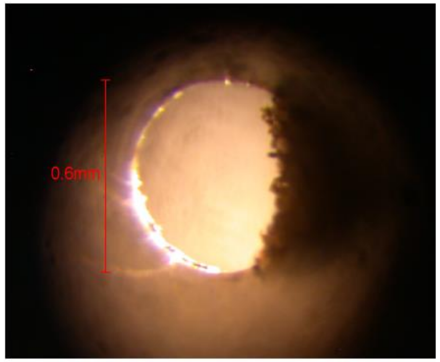


Figure 6.11 – Mean RFP for HD45 and HD135 at 950 and 1050°C

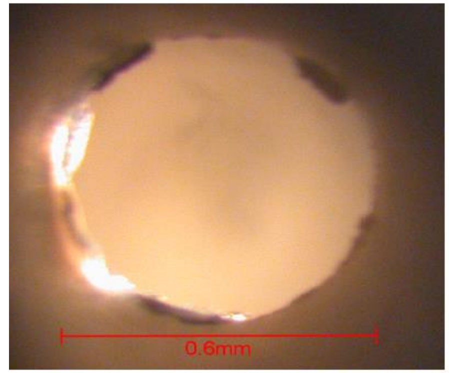
Qualitative Data on deposition



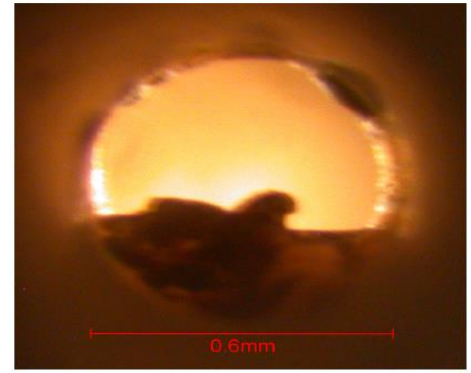
(a) Blockage-free cooling hole in LD90, T_{metal} = 1100K



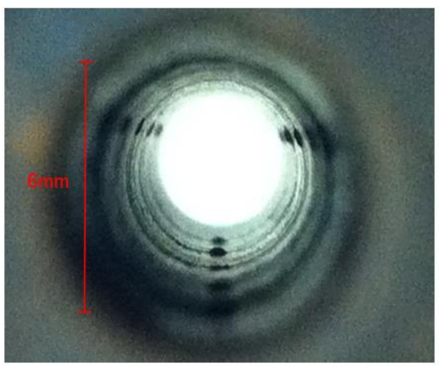
(b) Partially-blocked cooling hole in LD90, T_{metal} = 1100K



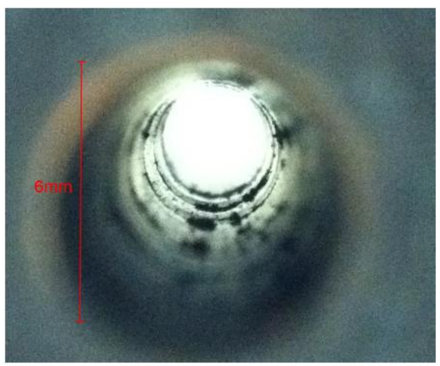
(a) Blockage-free cooling hole, T_{metal} = 1100K



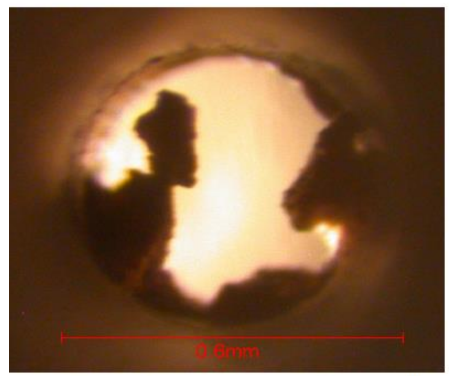
(b) Partially-blocked cooling hole, T_{metal} = 1200K



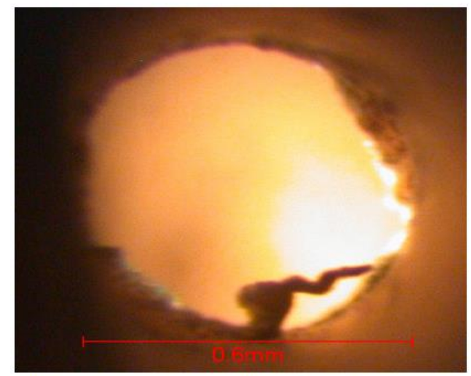
(c) Bulb-like deposits, LD90 main passage, T_{metal} = 1200K



(d) Pronounced deposits, LD90 main passage, T_{metal} = 1300K



c) Intricate deposition in a cooling hole, T_{metal} = 1200K



(d) Typical cooling hole deposition pattern, T_{metal} = 1300K

Cooling Passage

Cooling Hole

CFD Modelling in Fluent

- Conjugate CFD for walls and flow with particle size injection from a uniform entrance plane.

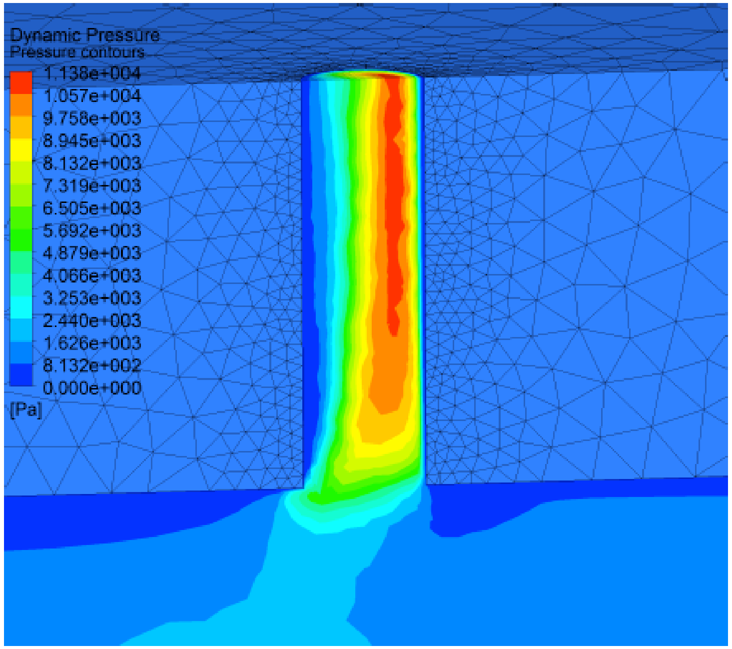


Figure 4.11: Dynamic pressure contours inside a cooling hole in LD90. Flow direction is left to right.

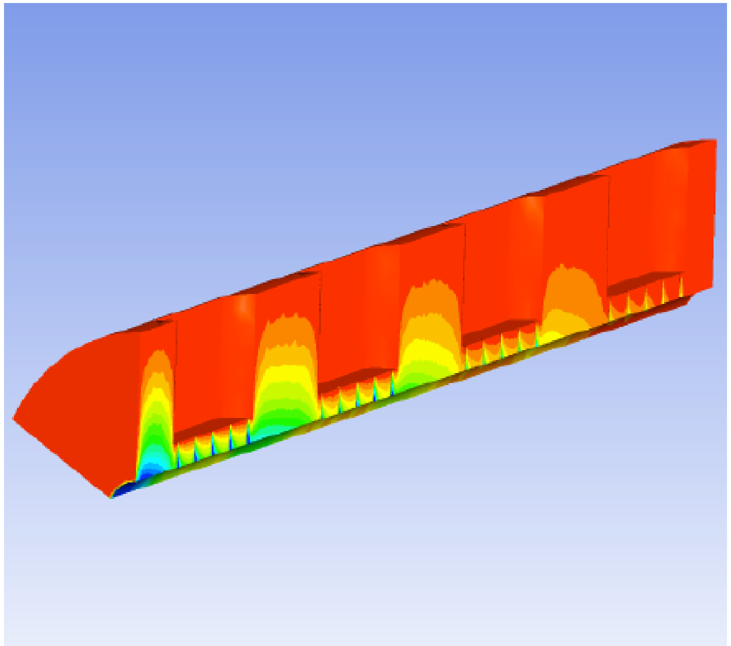
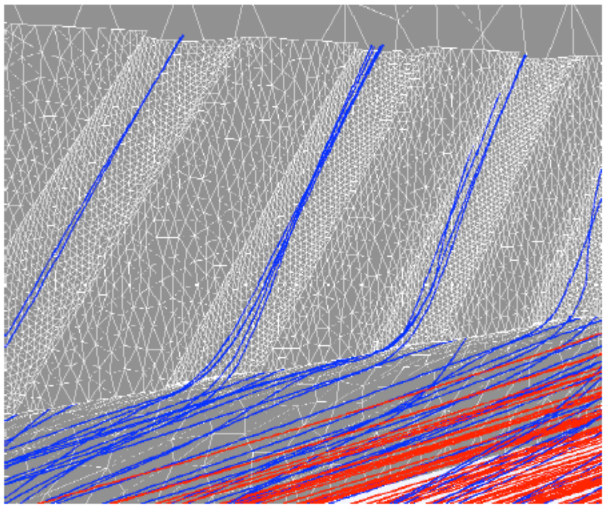
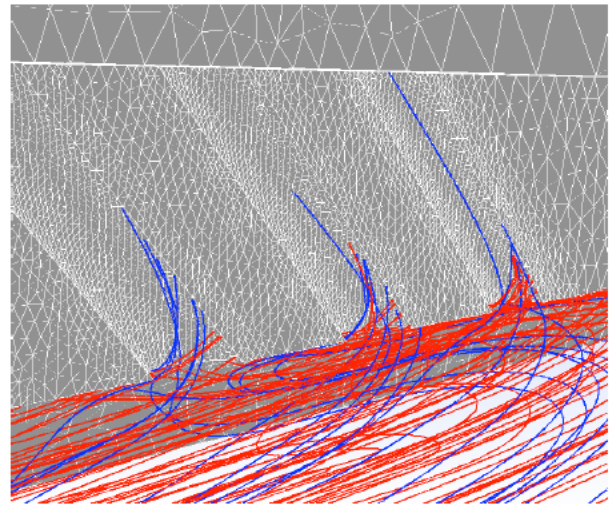


Figure 4.12: LD90 wall temperatures. Outer wall maintained at 1200K, inner wall cooling up to 15K. Flow direction is left to right.

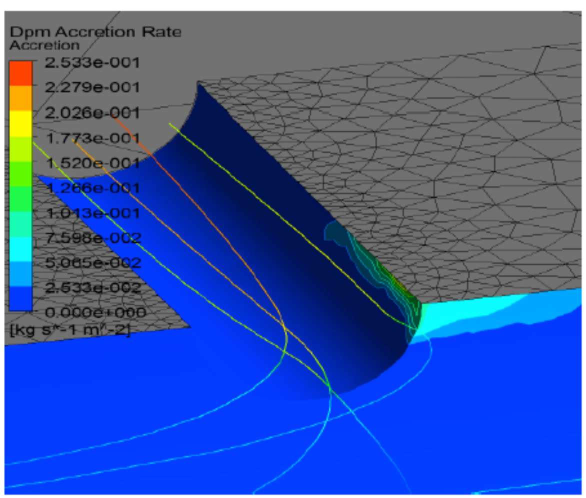
Particle ‘capture’ using Fluent in-built models & Lagranian tracking



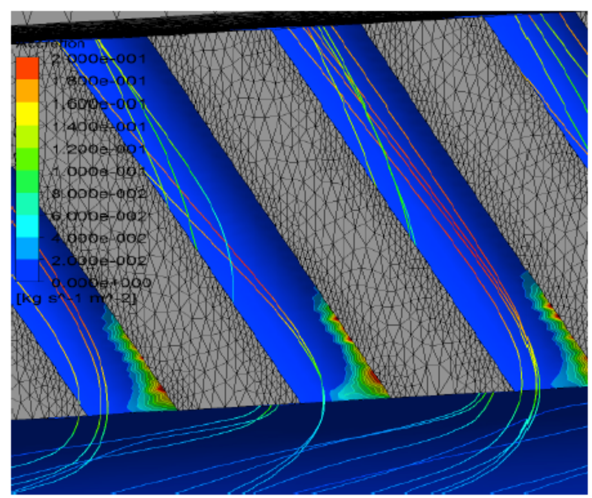
(a) 3μm (blue) and 15 μm (red) particles in HD45, holes 9-12



(b) 3μm (blue) and 15 μm (red) particles in HD135, holes 18-20



(a) Accretion pattern around LD90 cooling hole 10



(b) Accretive effects deep inside HD135 cooling holes 9-11

Current Work – Seb Wylie

- Rebuild test rig to allow better operating conditions
- Better control on mass flow rate with no variation when dust delivery employed
- Focus on high density cooling holes
- Better definition of volcanic ash particle sizes and distribution
- Better control of temperature of solid test pieces
- Rerun baseline CFD
- Collaborating with Loughboro on particle stick slip model
- Working with different ash sources to determine similarities and differences.

Experimental Setup

I = In-line heater

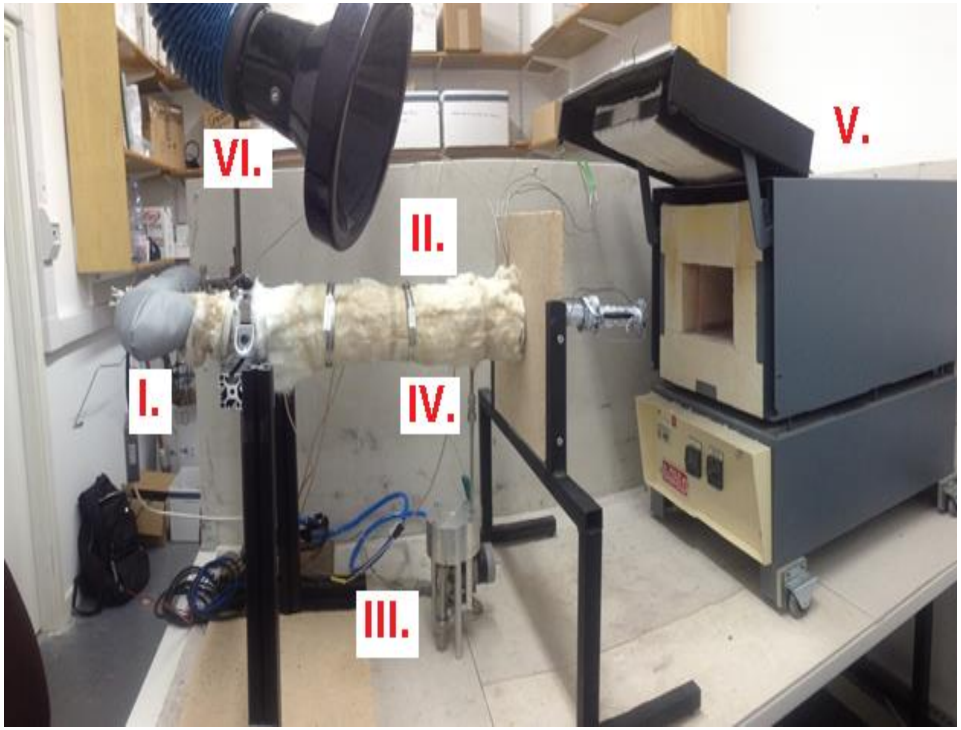
II = Electric heater tape and insulation

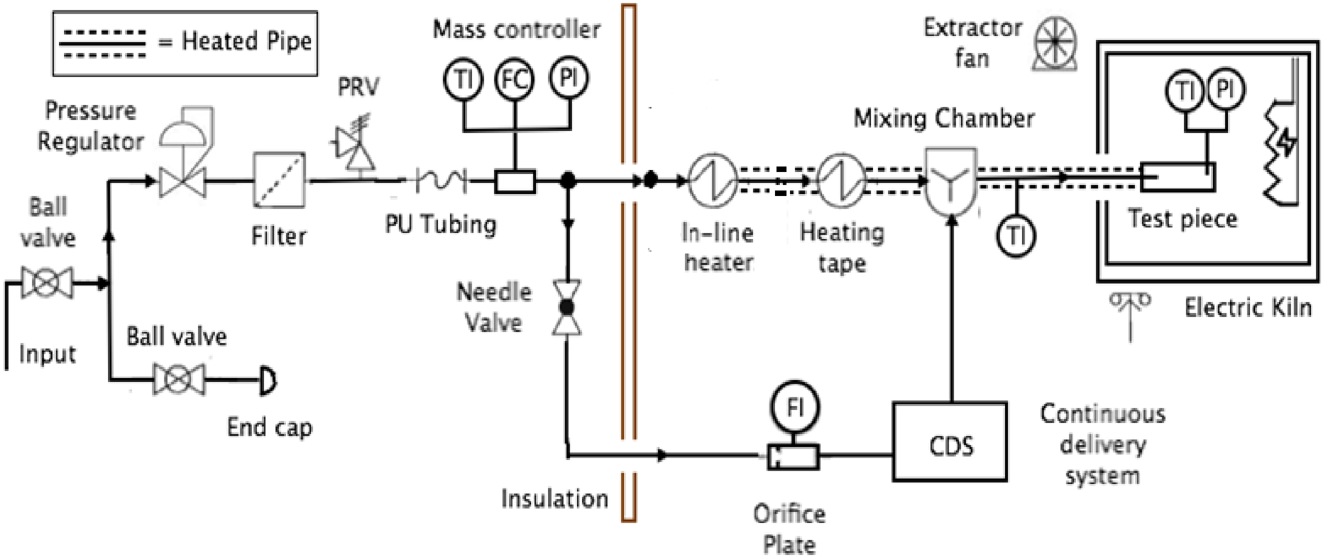
III = CDS

IV = Mixing chamber

V = Furnace

VI = Extractor fan.

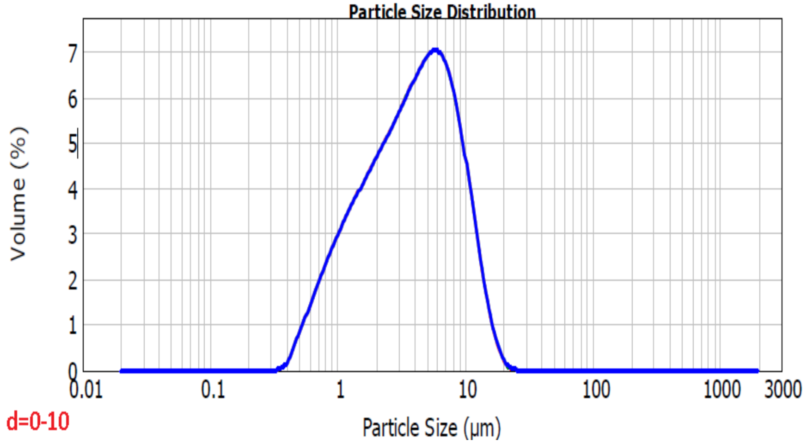


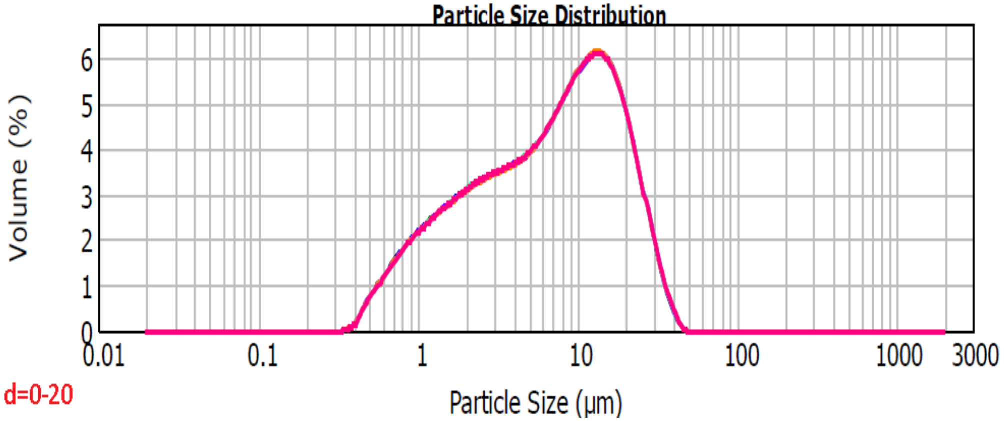


Particle Characterization – Size distribution

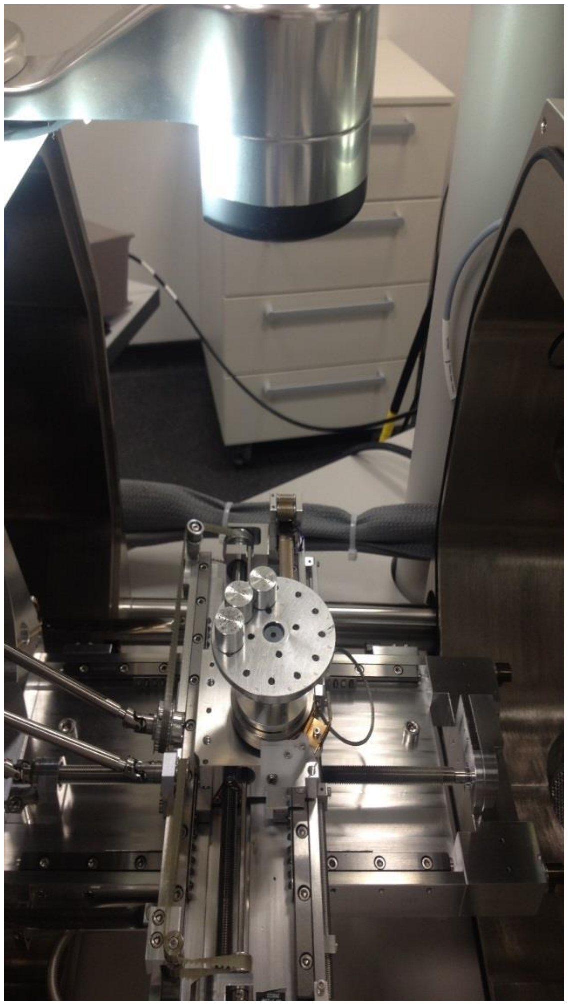
Particle Diameter Bands:

1. 0-10μm
2. 10-20μm
3. 0-20μm
4. 20-38μm
5. 38-100μm

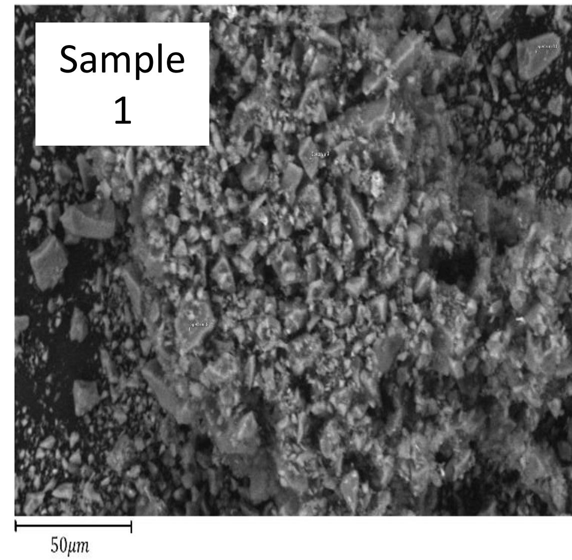




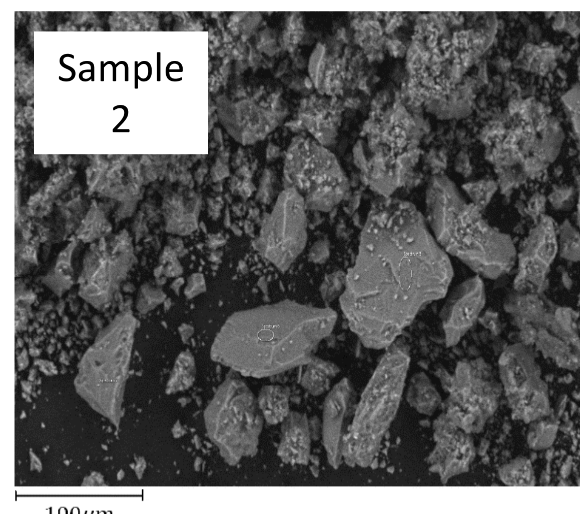
Particle Characterization - SEM



Sample 1: d = 0-20μm



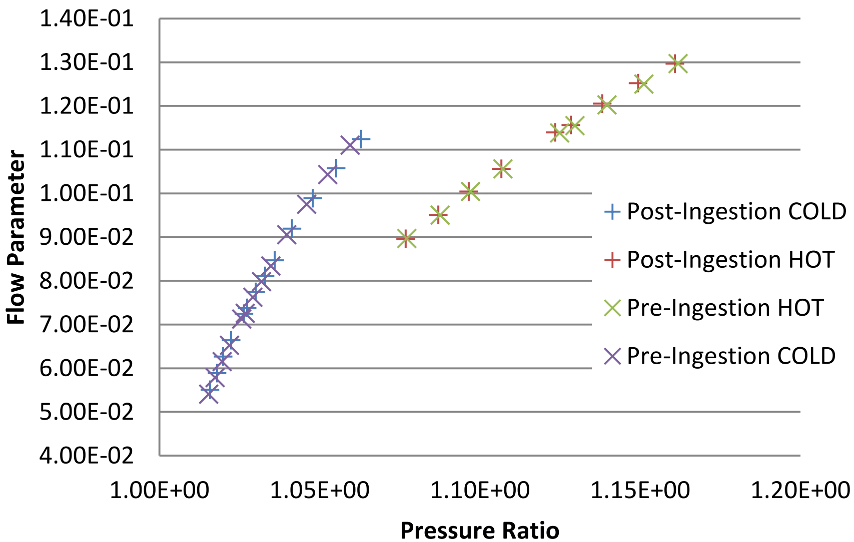
Sample 2: d = 38-100μm



Variation in Metal Temperature
Tc = 627ºC

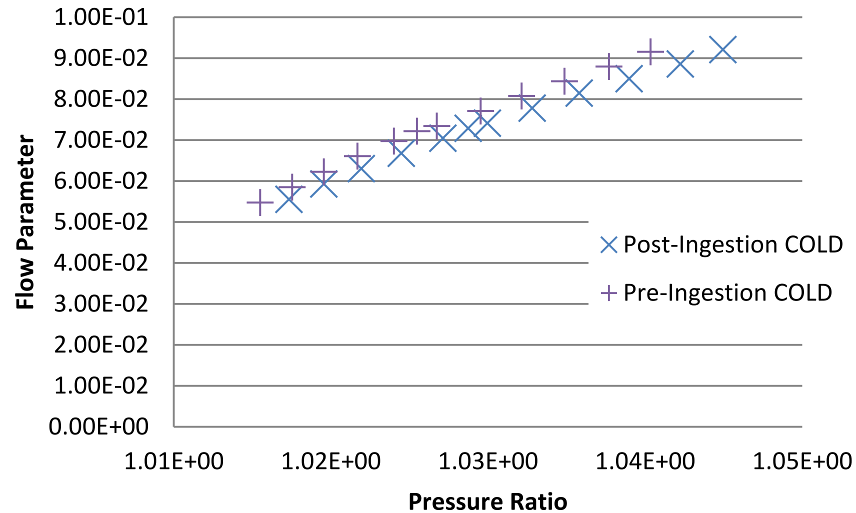
Below ATT

Volcanic Ash Injestion Conditions: Tm = 936ºC, 0<d<20



Above ATT

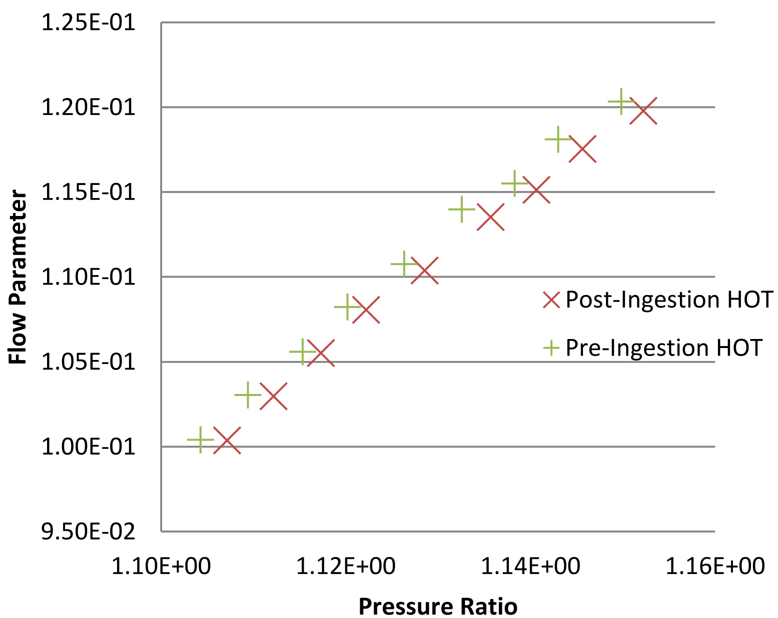
Volcanic Ash Ingestion: Tm=1000ºC, 0<d<20 Flow Parameter Cold



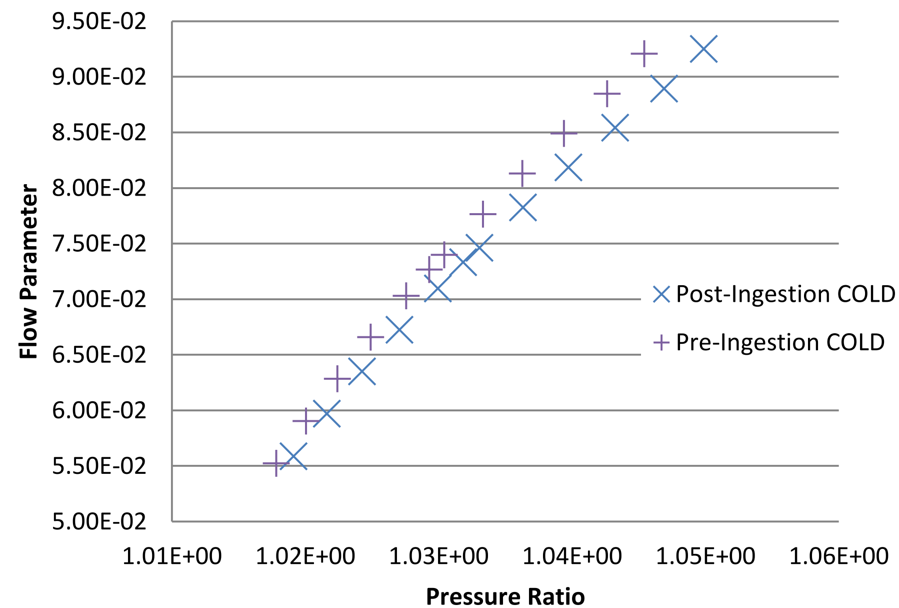
Variation in Metal Temperature

Approx ATT: Tm=980C

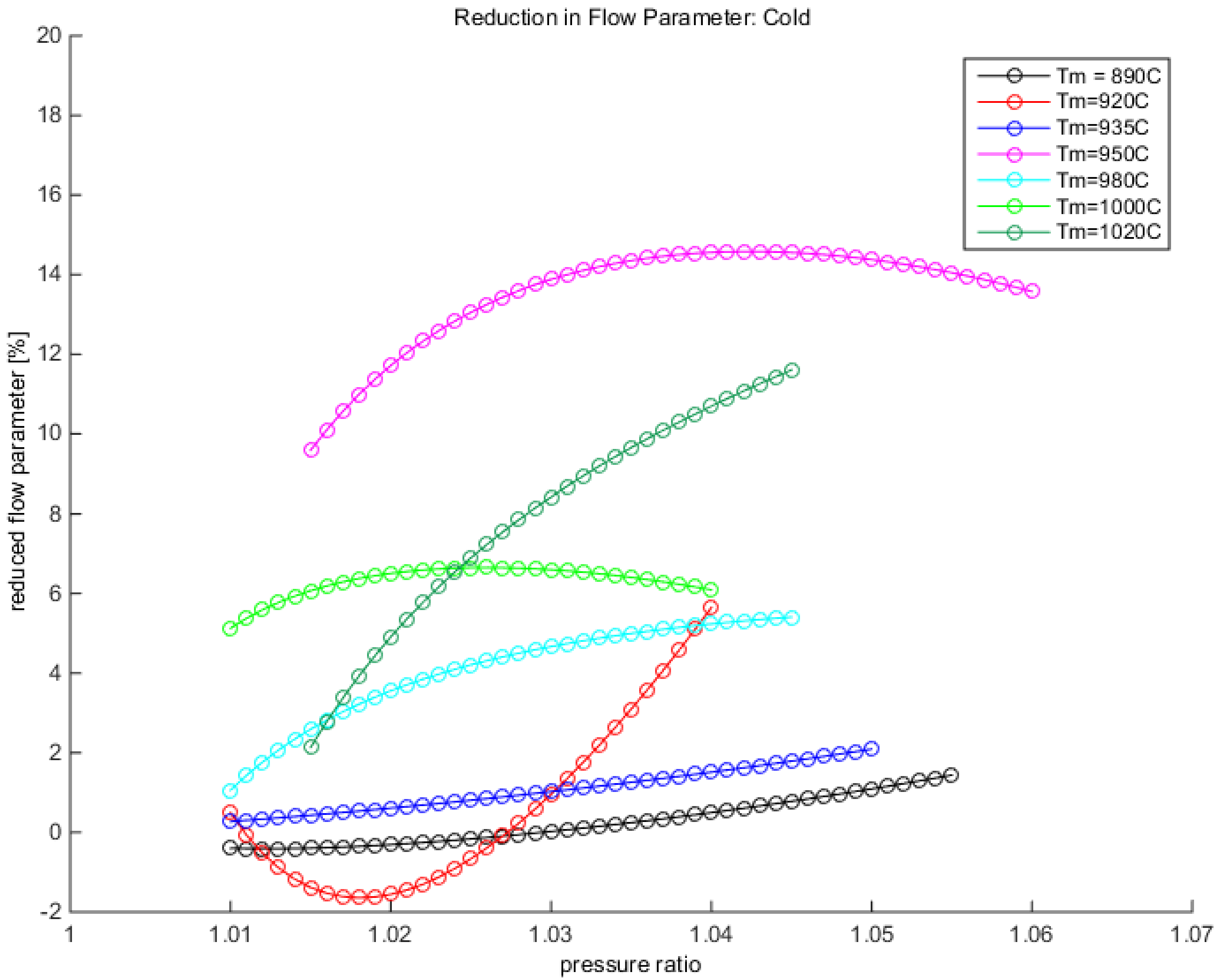
Volcanic Ash Ingestion: Tm=980C, 0<d<20
Flow Parameter Hot



Volcanic Ash Ingestion: Tm=980C, 0<d<20
Flow Parameter Cold



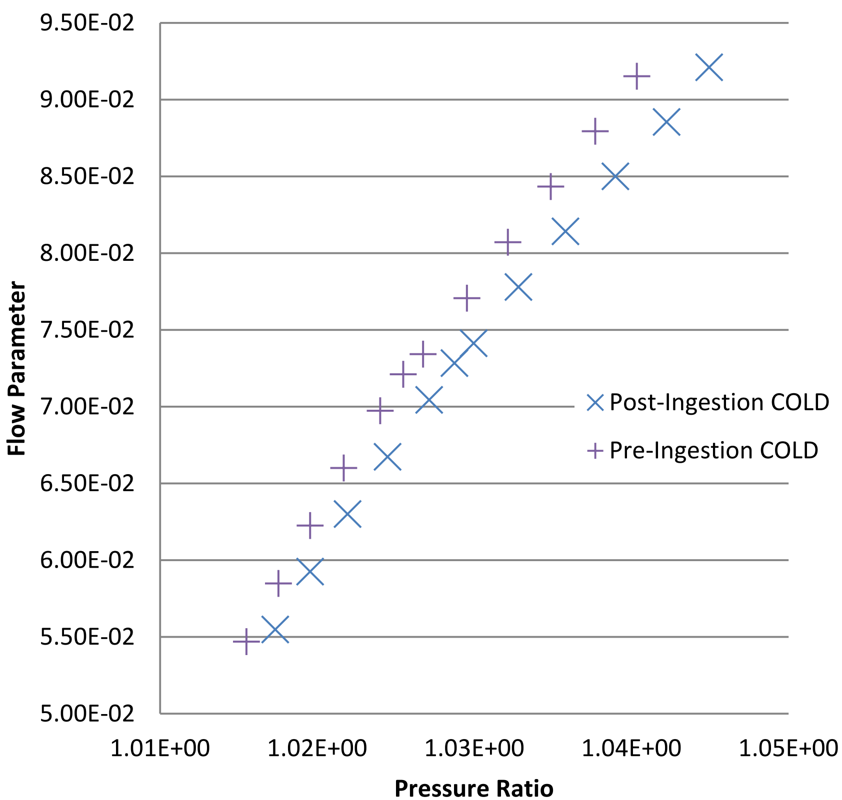
Metal Temperature EJYA2010 Ash
0<d<20 micron



Variation in Ash Diameter EJYA2010

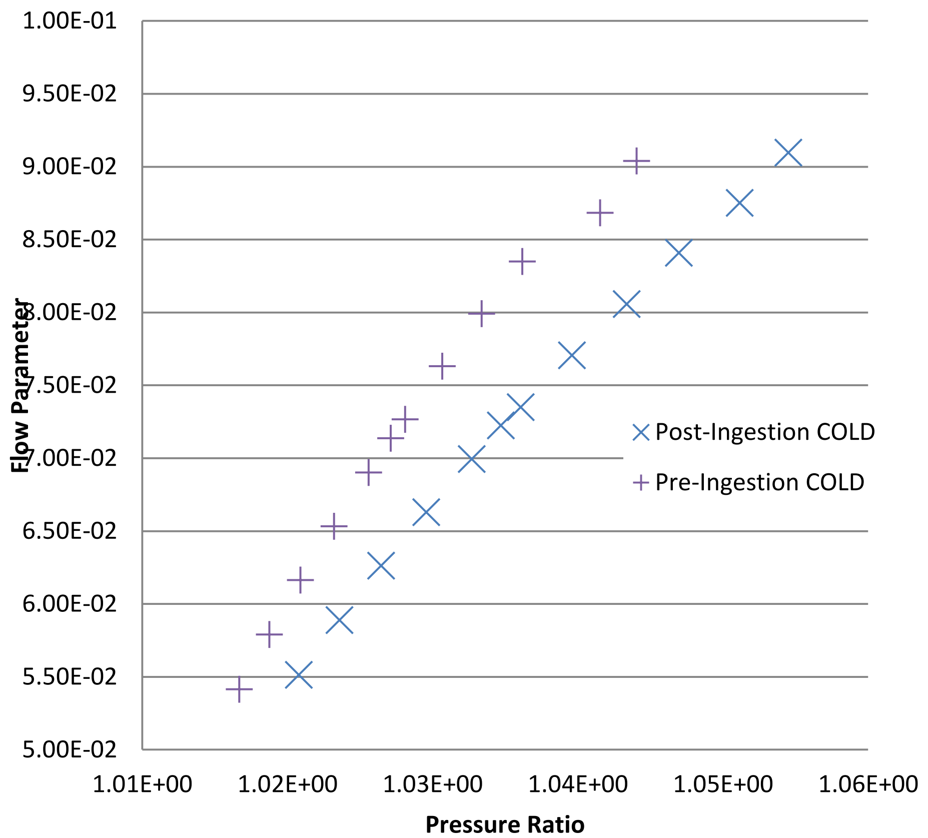
Tm=1000°C, 0<d<20

Flow Parameter Cold

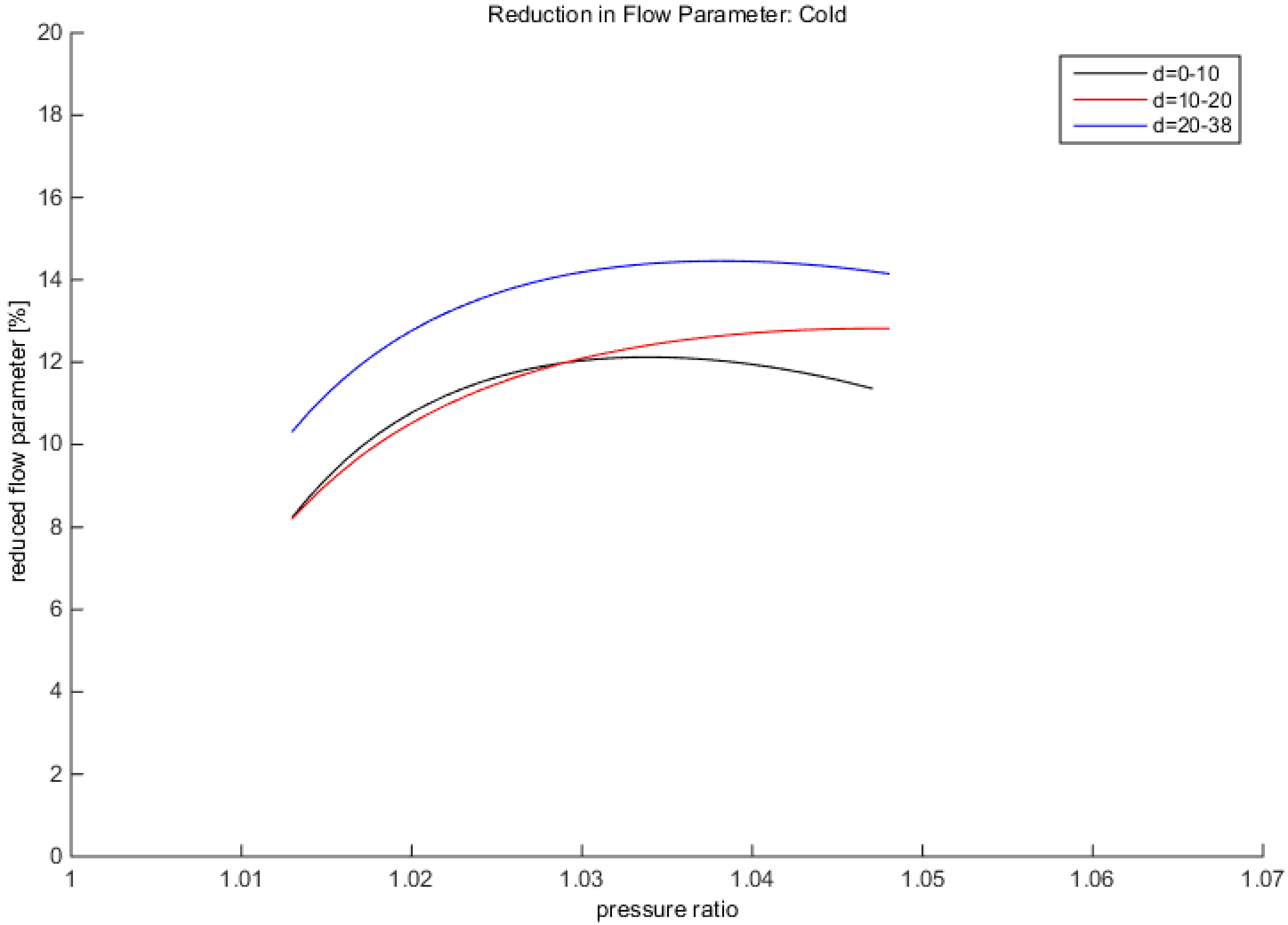


Tm=1020°C, 0<d<10

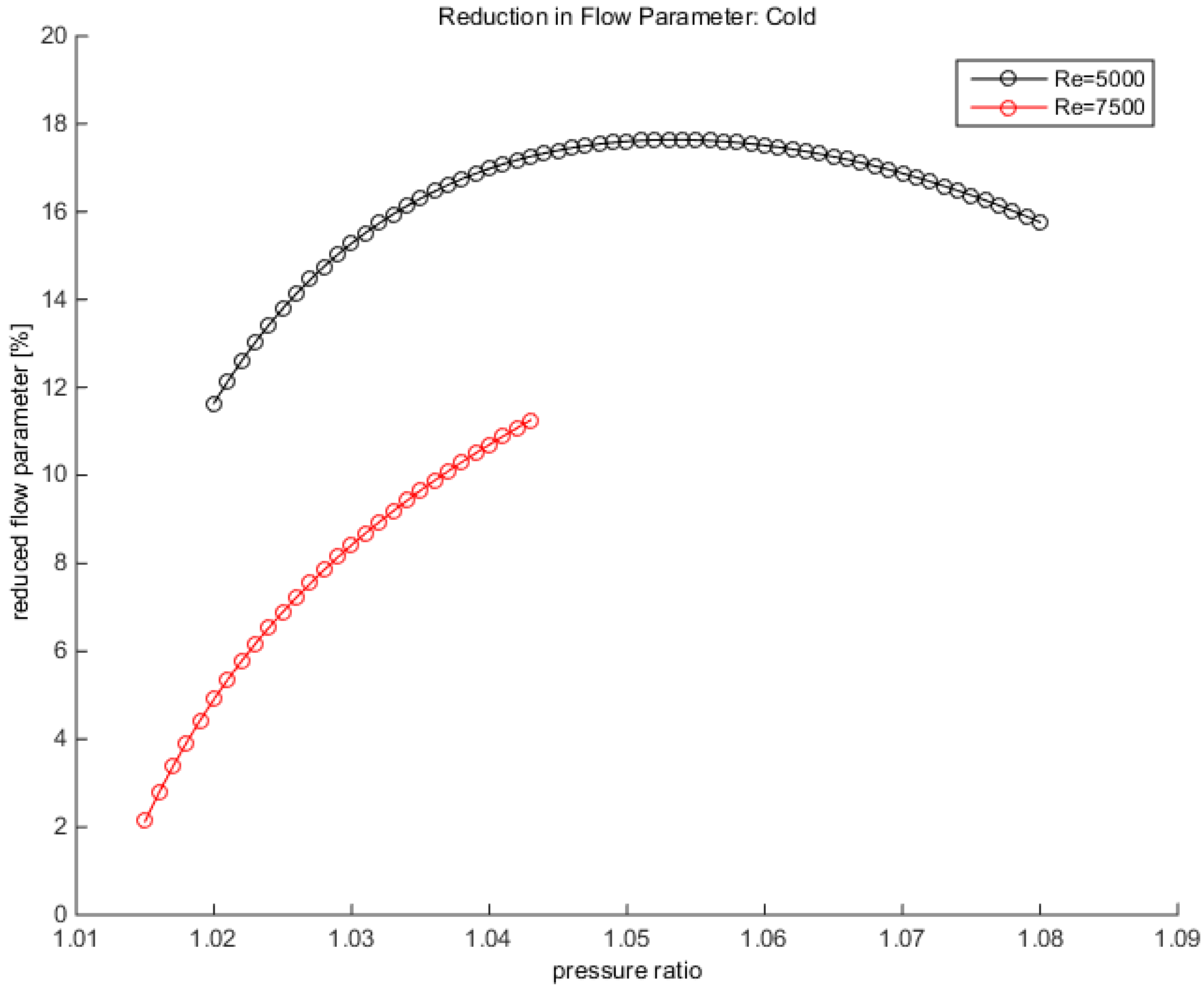
Flow Parameter Cold



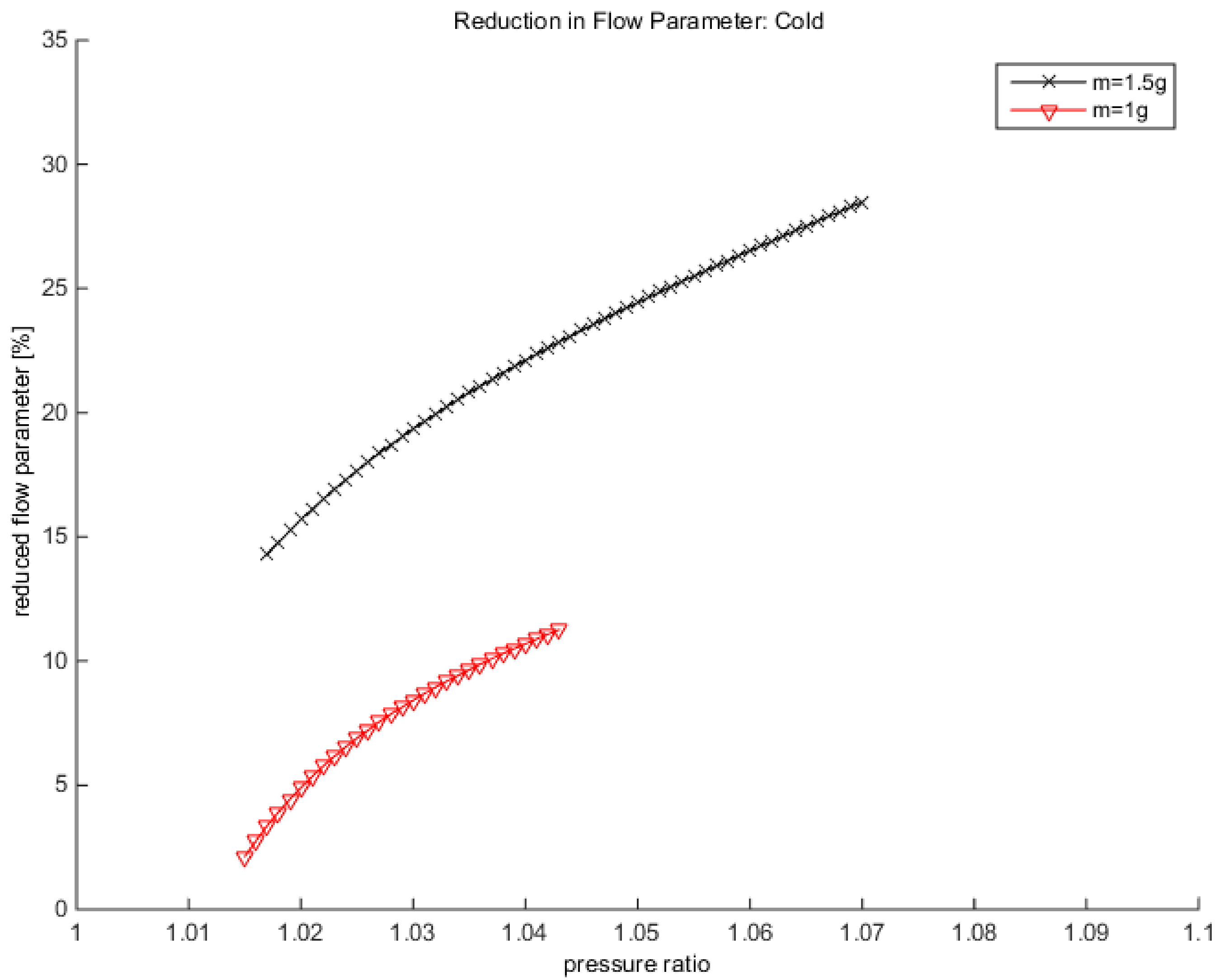
Particle diameter variation EJYA2010 Ash
Tm = 1020°C, Tc = 627°C



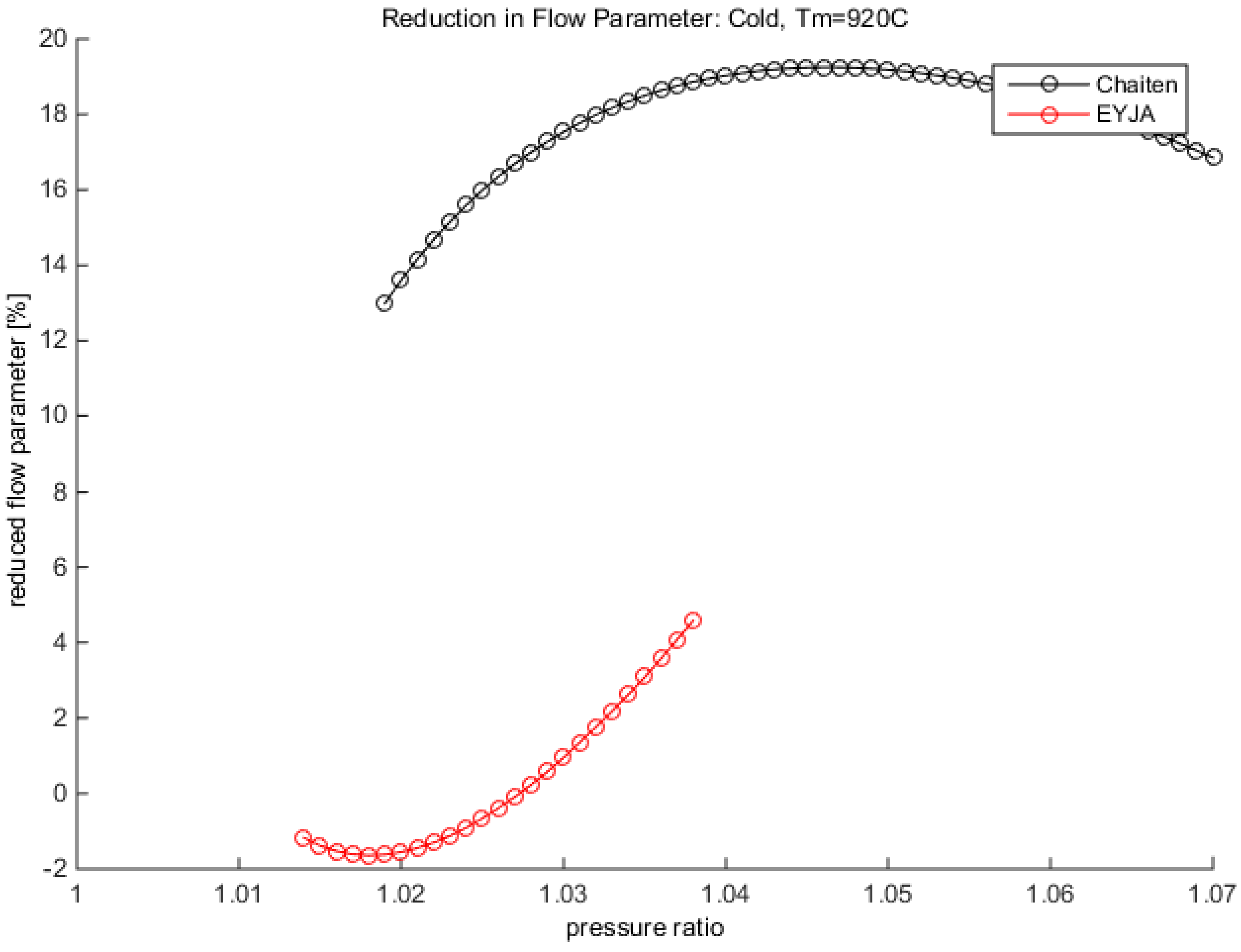
Effect of internal Reynolds number
Tm = 1020°C, Tc = 627°C EJYA2010 Ash
0<d<20 micron,



Effect of Dosing Density, EJYA2010 Ash
Tm = 1020^{o}C, Tc = 627^{o}C, Re = 5000



Effect of Ash Type
Tm = 920^{o}C, Tc = 627^{o}C



Effect of Ash Type
Tm = 1020^{o}C, Tc = 627^{o}C