Predicting and Improving the Performance of a Bagless Vacuum Cleaner using CFD

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3rd ANSA & μETA International Conference 2009

Acknowledgements

Mr. Jim Ferguson

Mr. John Kidd

Mr. John Semple

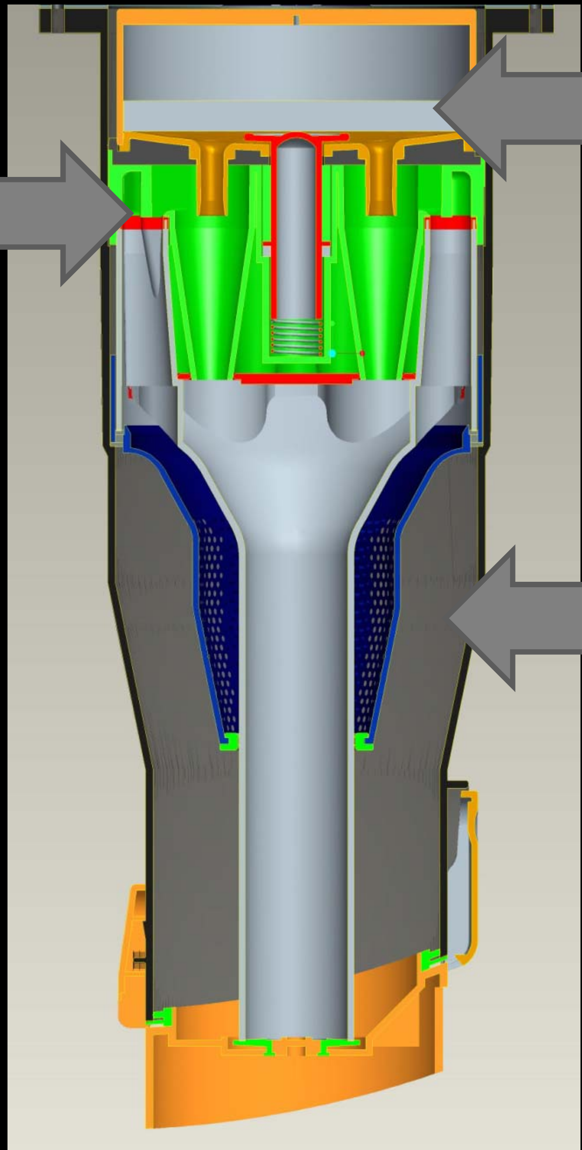
Dr. David Sykes

Contents

Bagless Vacuum Cleaner Technology

Technology • Process • Consulting

2nd Separation Stage
- 12 cyclones
- Small particles

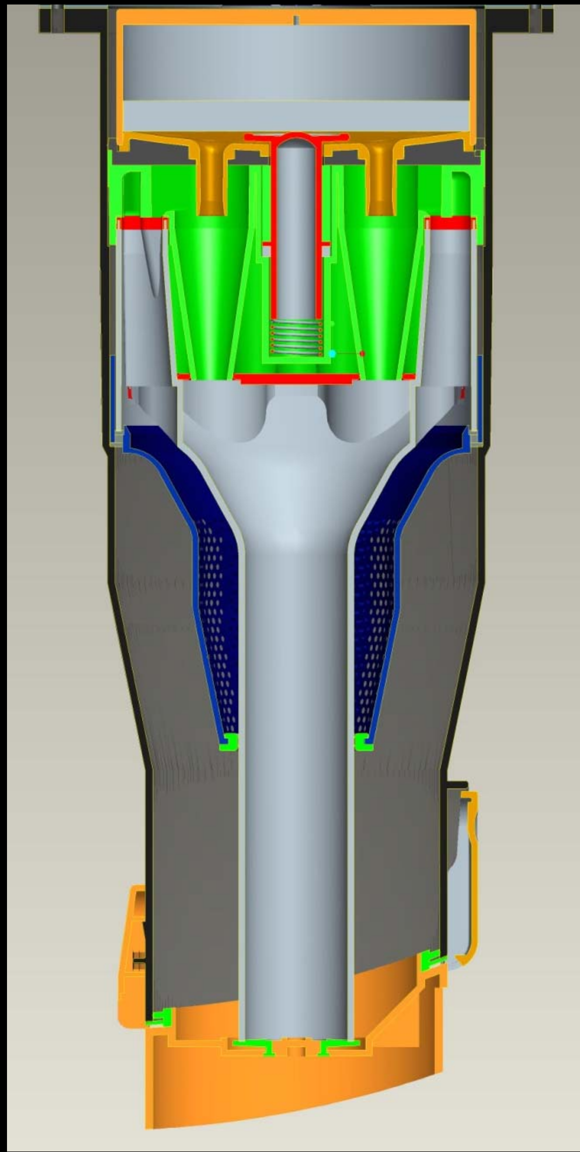


Filter
- Micro particles

1st Separation Stage
- Large solids

Project Motivations

- Separation efficiency tested using Kaolin
- Can separation efficiency be improved beyond current values?
- Modify 2nd separation stage design?
- What happens at different operating flow rates?

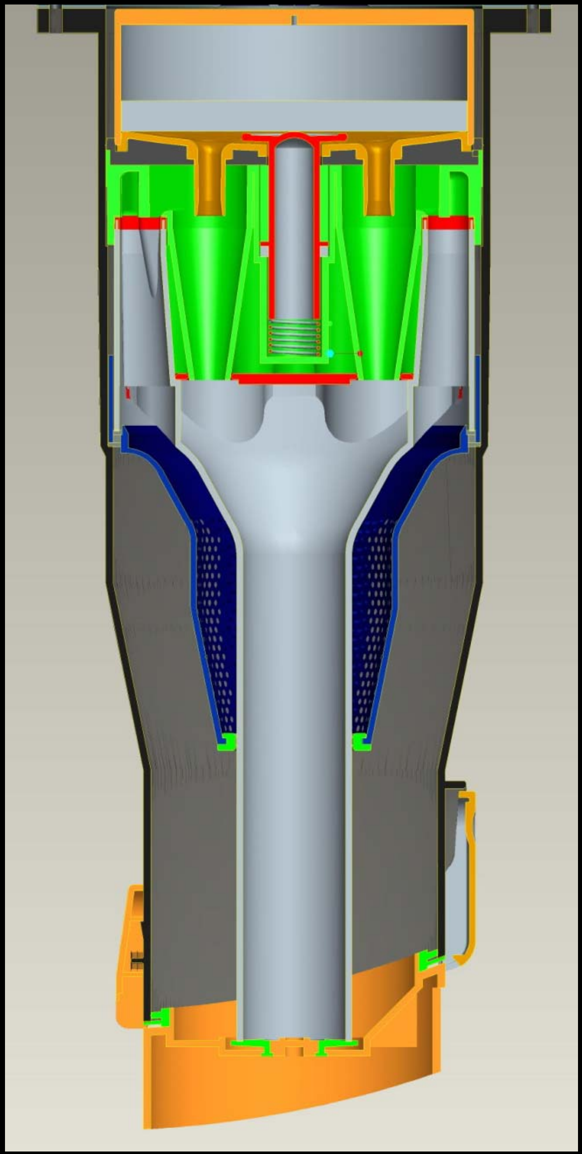


CFD Methodology

Optimisation 2nd Separation Cyclone

CFD Baseline Design

CFD Modified Design

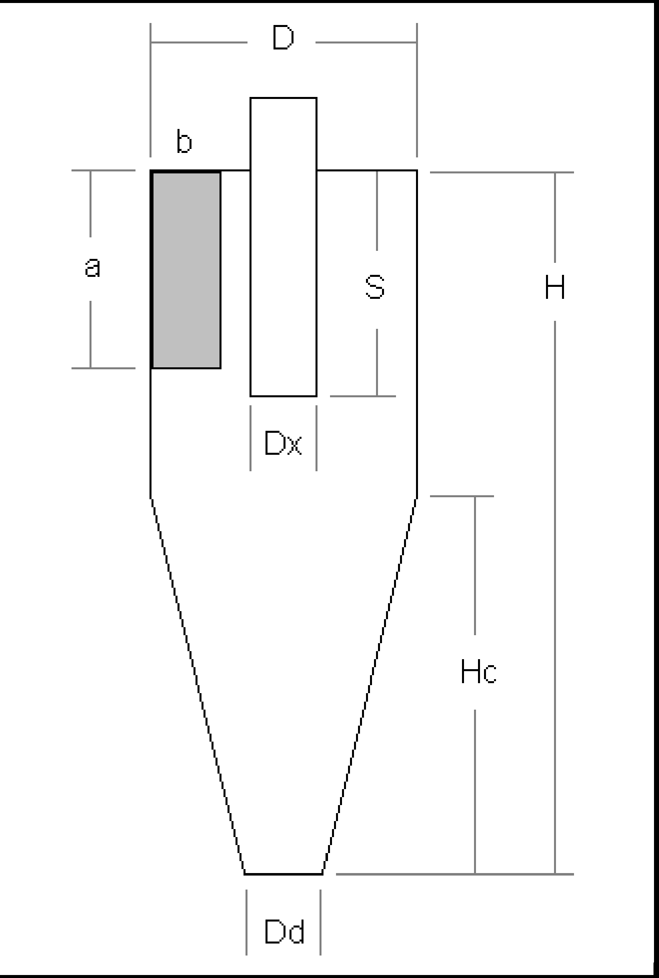


Summary

- Muschelknautz model (MM) implemented in Fortran
- modeFrontier → optimisation of individual 2nd stage separators cyclones using MM
  - Optimisation objectives:
    1. Minimise total pressure drop (Δp)
    2. Maximise separation efficiency (η_{max})
  - 5792 feasible designs variations evaluated in mF → 72 initial designs from Sobol DOE followed by 100 NSGAII generations
- CFD tests performed using single cyclone parametric model for validation purposes

Muschelknautz Model

- Semi-empirical model developed over 30 years to predict performance of cyclone separators across a wide range of sizes and applications.
- Model accounts for: wall roughness (due to material and collected solids); saltation or mass loading effects; particle size distribution.
- Model inputs → Geometric parameters
  Flow rates for air & solids
  Particle size distribution
- Outputs → Overall separation efficiency
  Total pressure loss
  x50 and Grade Efficiency Curve



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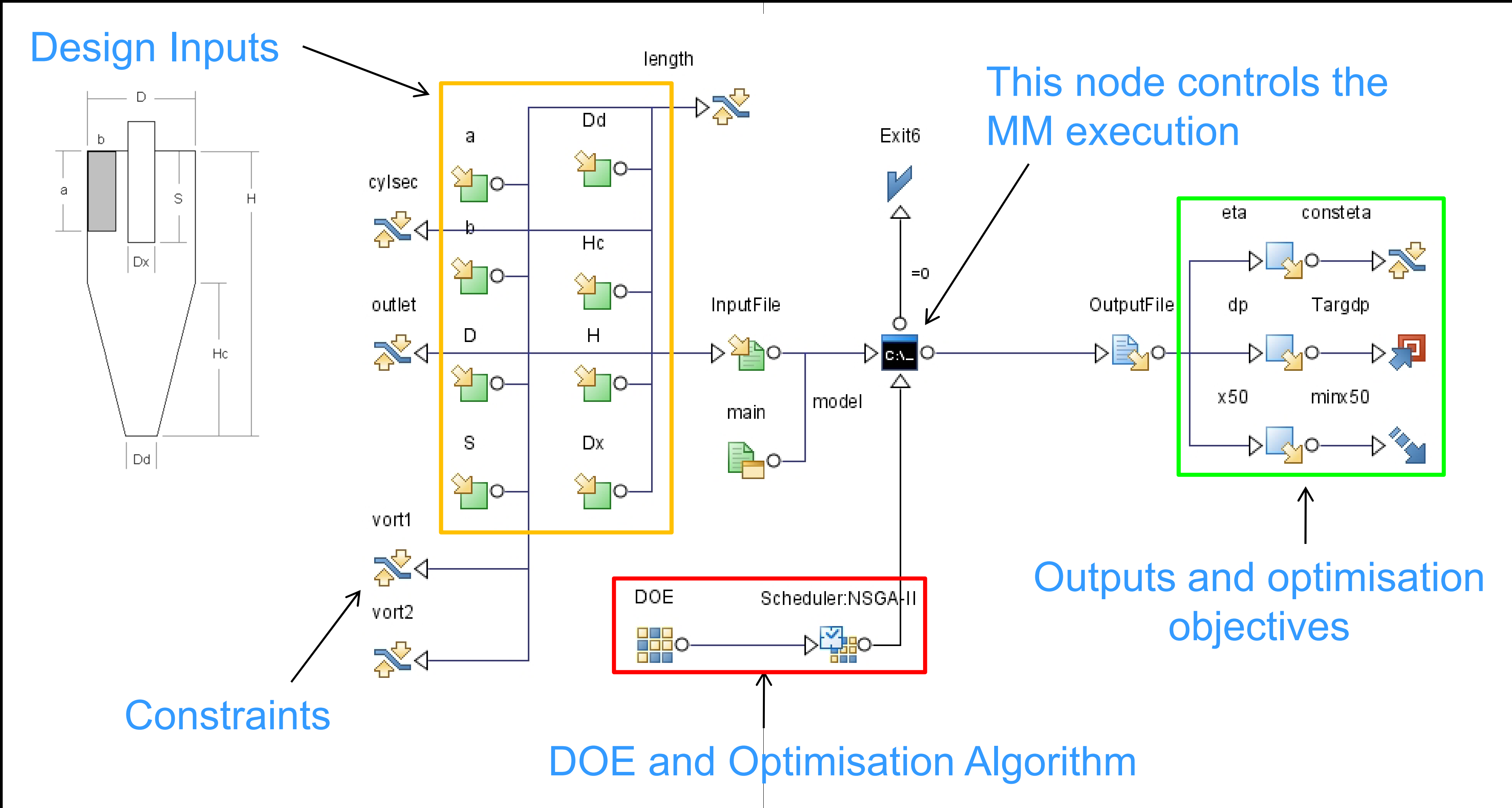
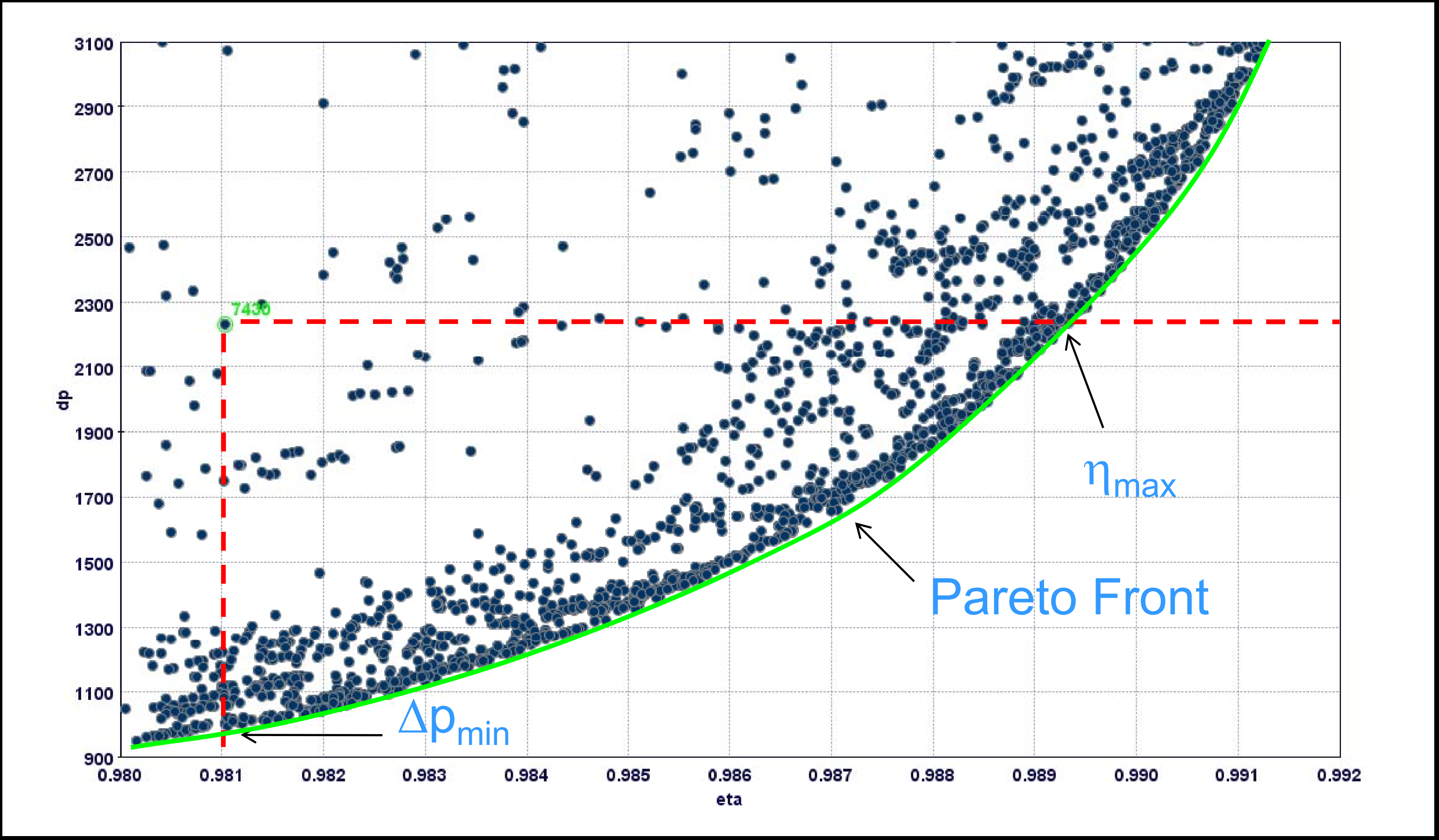
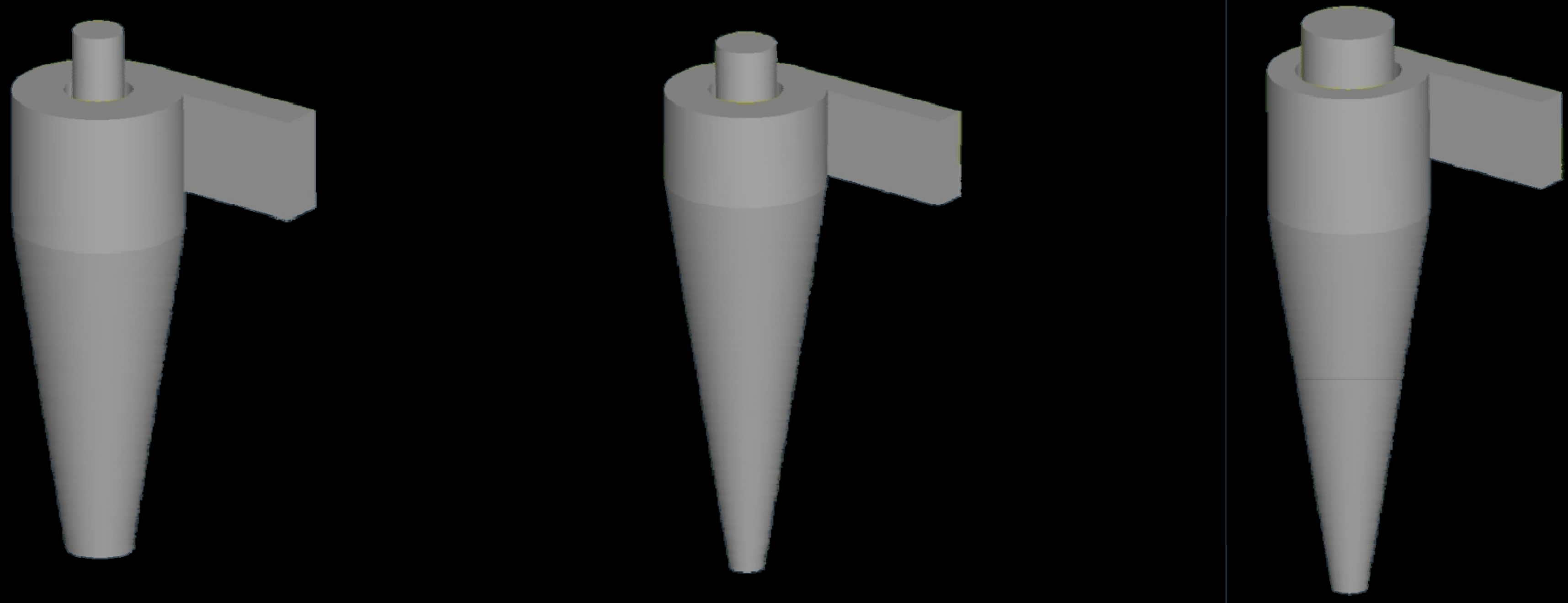
mF Optimisation Workflow



mF Optimisation Results: η vs. Δp



mF Optimisation Results



Baseline	η_{max}	Δp_{min}
η = 98.10%	η = 98.93%	η = 98.10%
Δp_0 = 2232.9 Pa	Δp_0 = 2236.8 Pa	Δp_0 = 996.0 Pa

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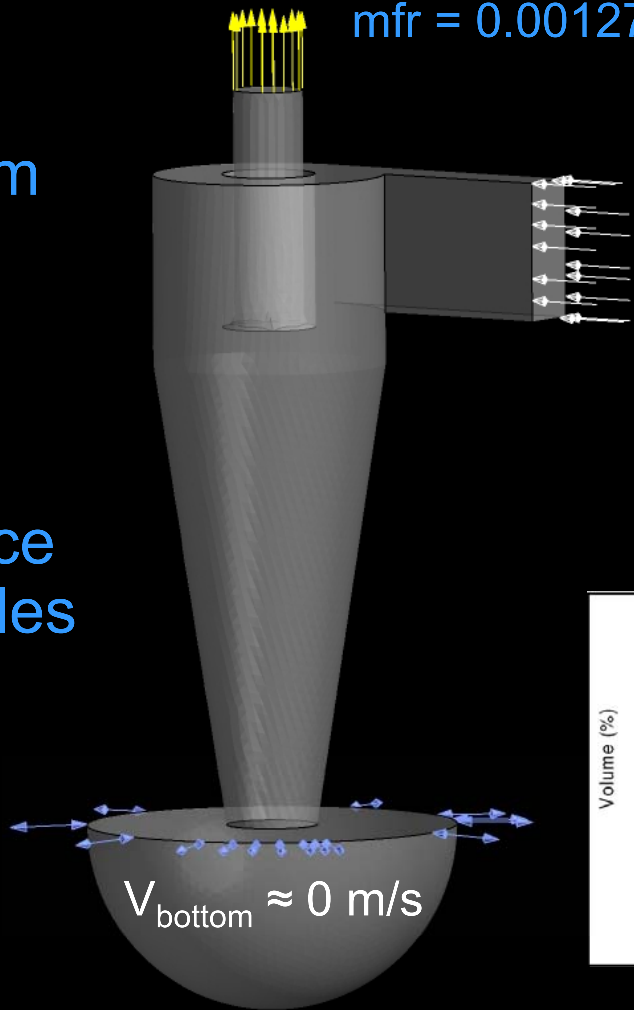
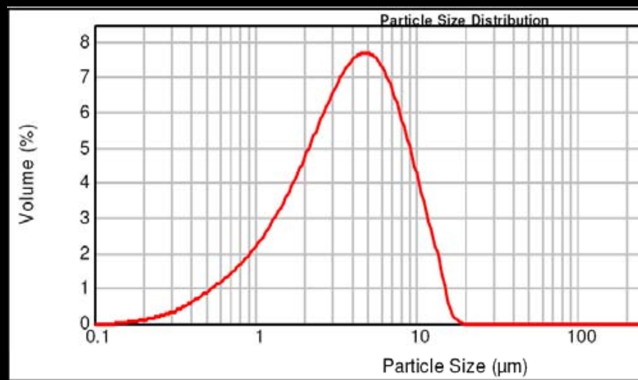
CFD Validation Model: CFX

- Steady-state flow
- Air constant properties evaluated at 25ºC and 1atm
- Turbulence → BSL RSM
- Uncoupled Lagrangian particle tracking
- Gravity, drag and turbulence effects evaluated on particles
- Particles do not stick or deposit at walls

OUTLET
mfr = 0.0012795 kg/s (1.08L/s)

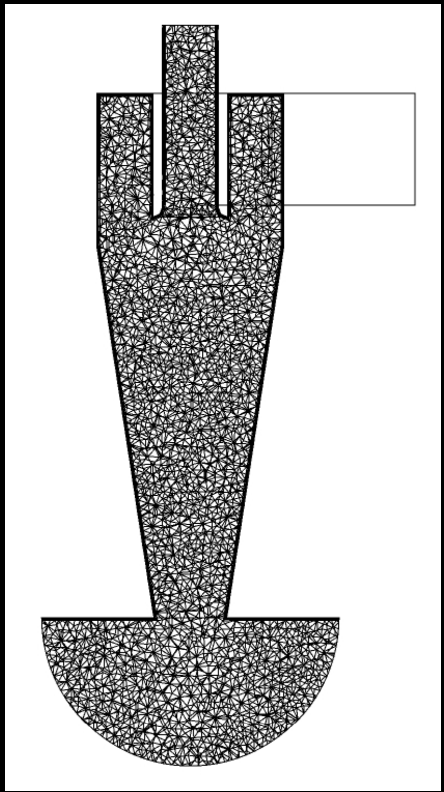


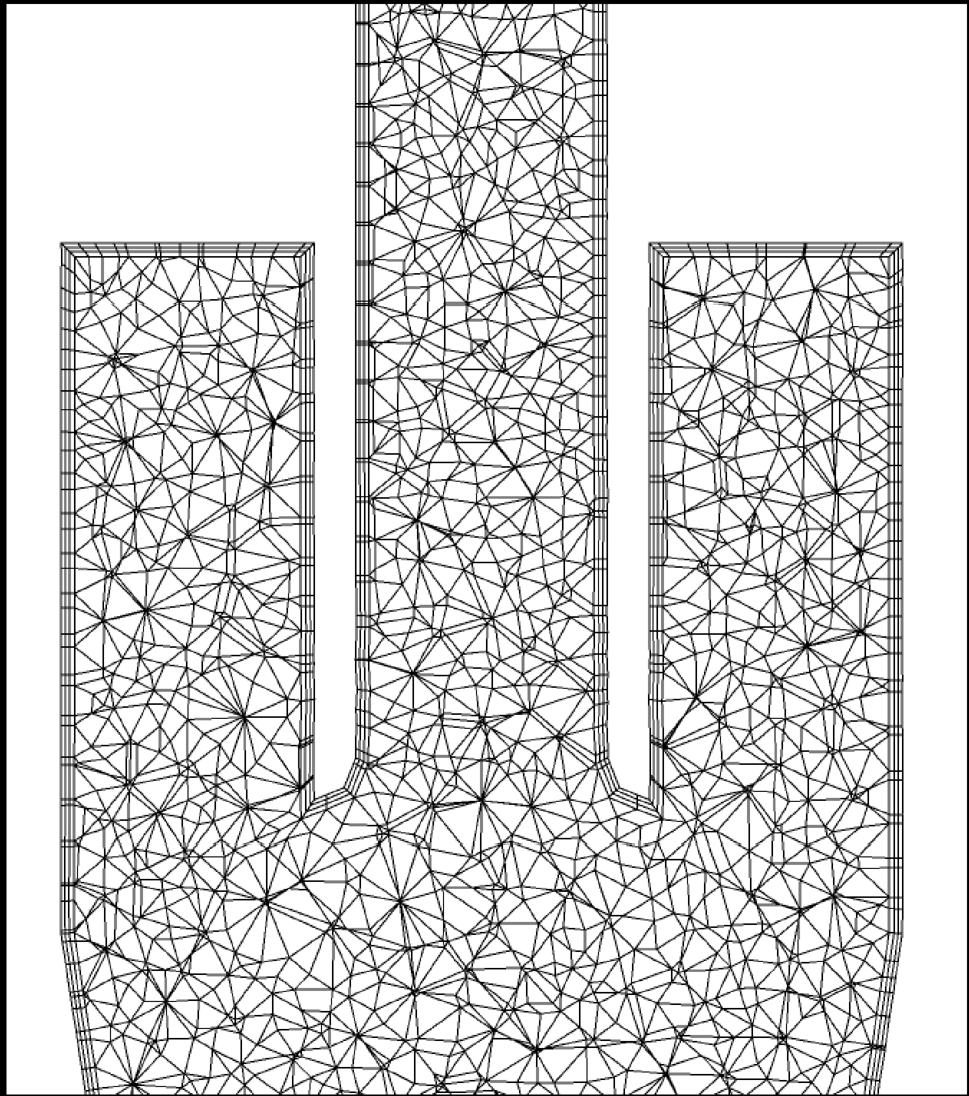
INLET
- $\Delta p_0 = 0$ Pa
- Flow normal to face
- Medium turbulence
- Kaolin kg/s = 1% of air
- 100k particles injected
- PDF for particle sizes



CFD Mesh: ANSA

- CFD Mesh → 200k Cells
- CFD mesh algorithms



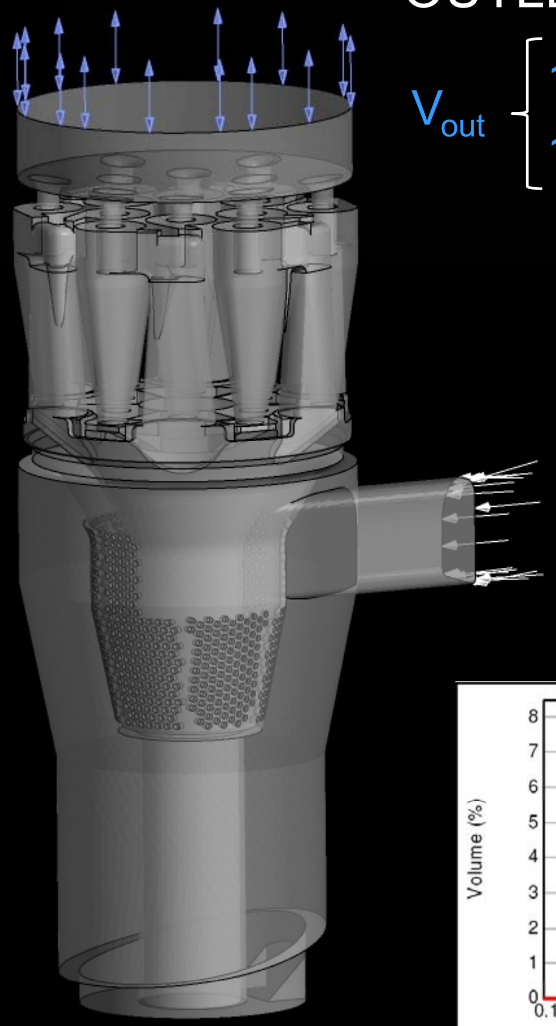


MM Validation

		CFD Model	Muschelknautz Model
Baseline	η	98.73%	98.10%
	Δp_0	750.5 Pa	2232.9 Pa
η_{max}	η	98.07%	98.93%
	Δp_0	1075.17 Pa	2236.8 Pa
Δp_{min}	η	97.28%	98.10%
	Δp_0	650.15 Pa	996.0 Pa

CFD Model: Ansys CFX

- Steady-state flow
- Air constant properties evaluated at 25ºC and 1atm
- Turbulence → BSL RSM
- Uncoupled Lagrangian particle tracking
- Gravity, drag and turbulence effects evaluated on particles
- Particles do not stick or deposit at walls

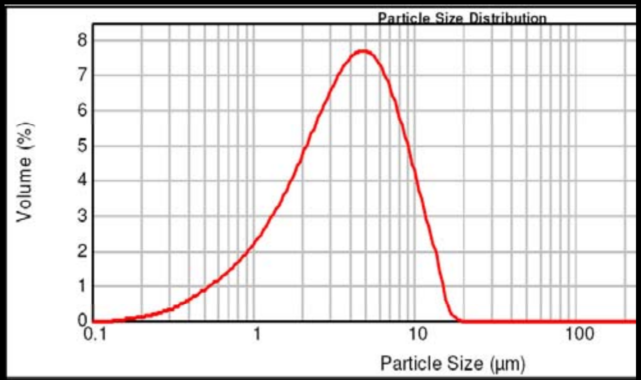


OUTLET

V_{out} { 1.179m/s for 13L/s; 1.904m/s for 21L/s

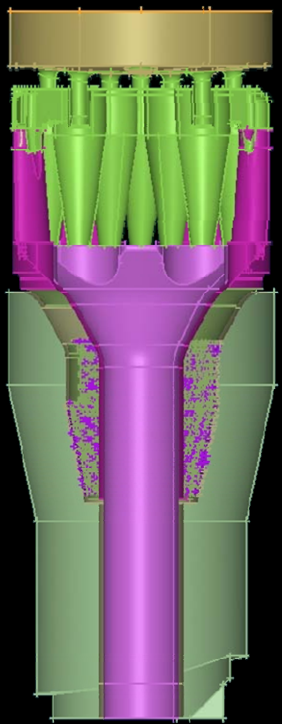
INLET

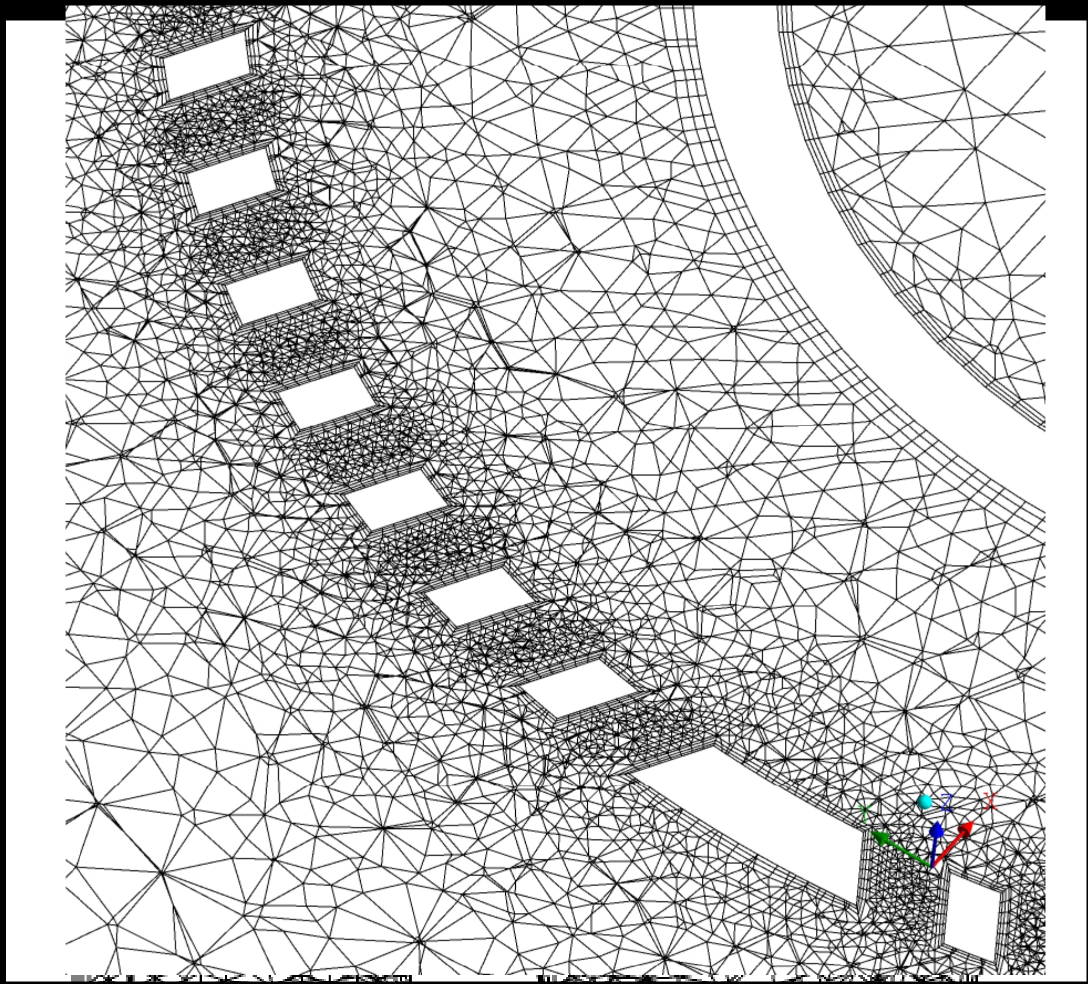
- Δp_0 = 0 Pa
- Flow normal to face
- Medium turbulence
- Kaolin kg/s = 1% of air
- 100k particles injected
- PDF for particle sizes



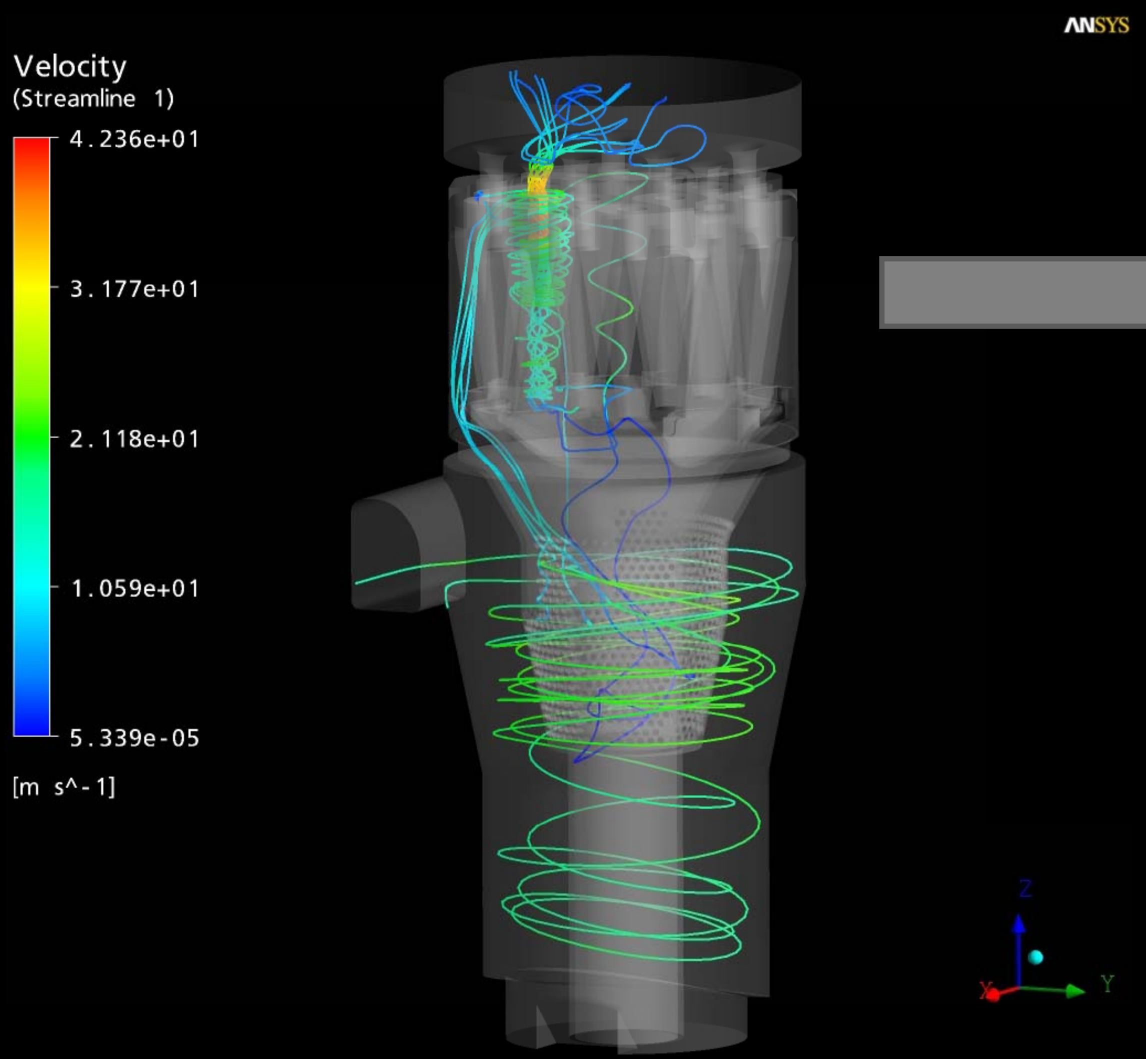
CFD Mesh: ANSA

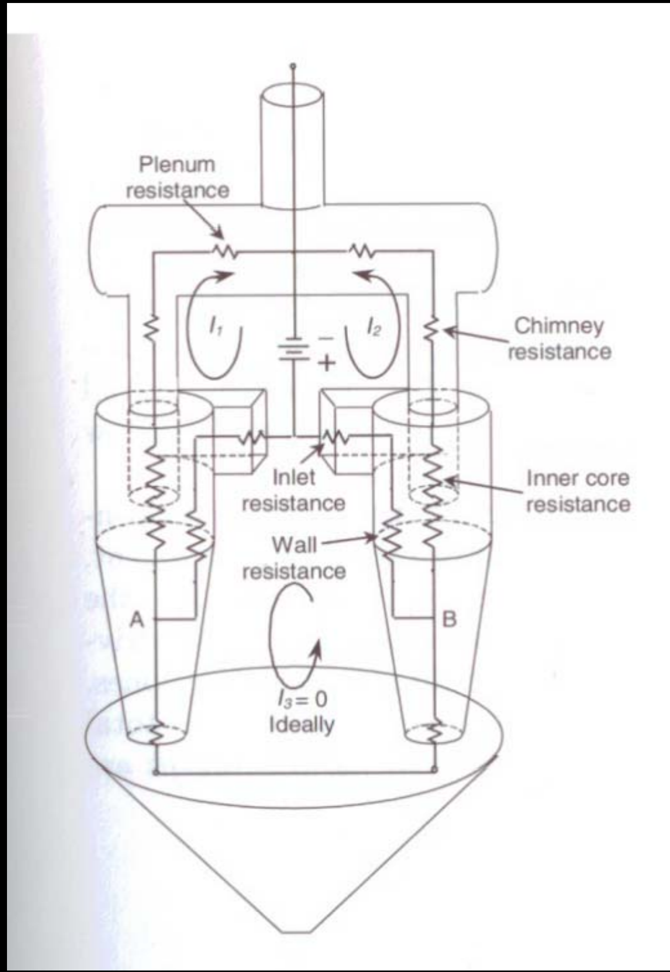
- CAD preparation
- CFD Mesh → 17.2M Cells
- CFD mesh algorithms



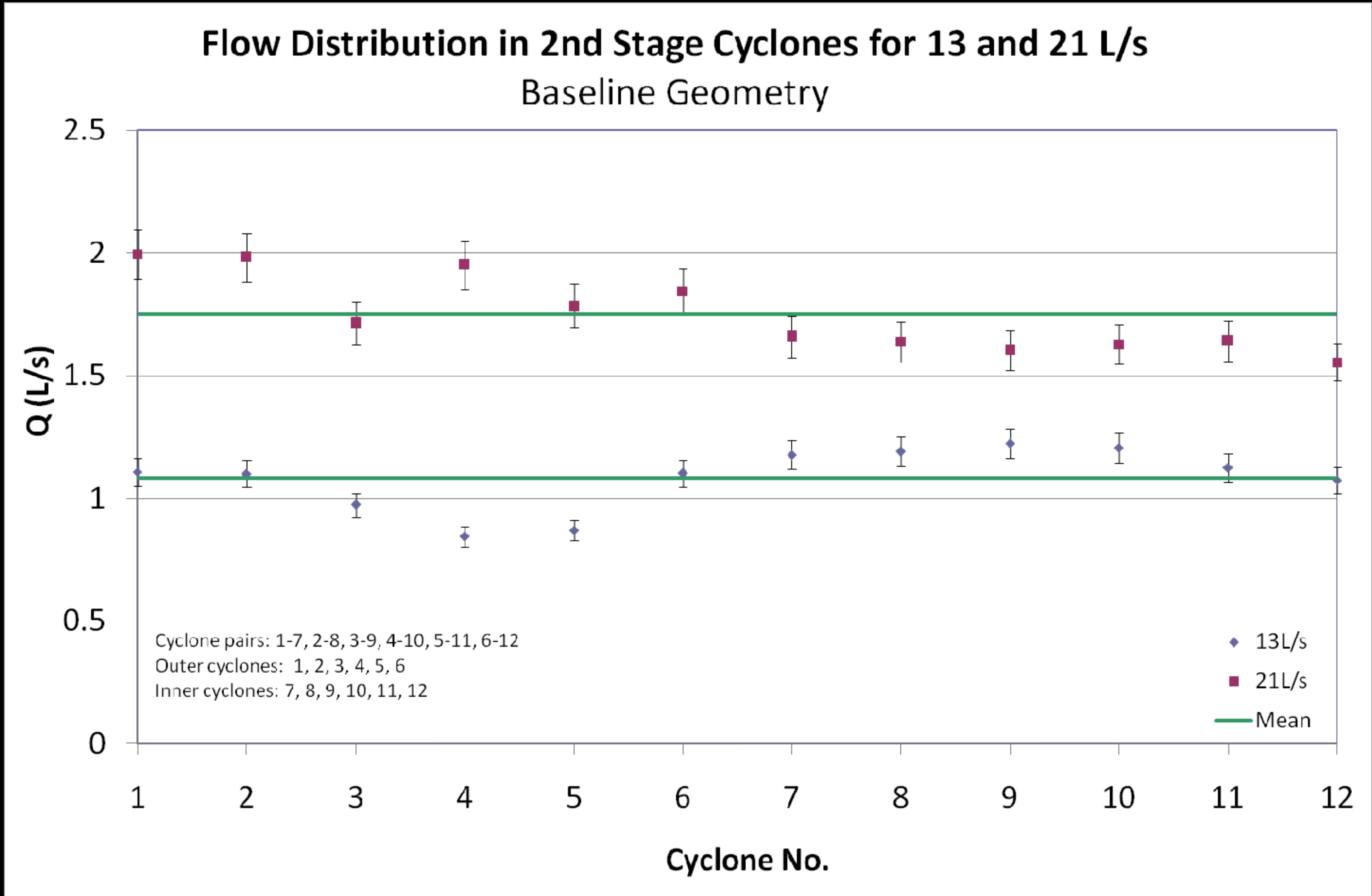


Results: Hopper Cross Flow

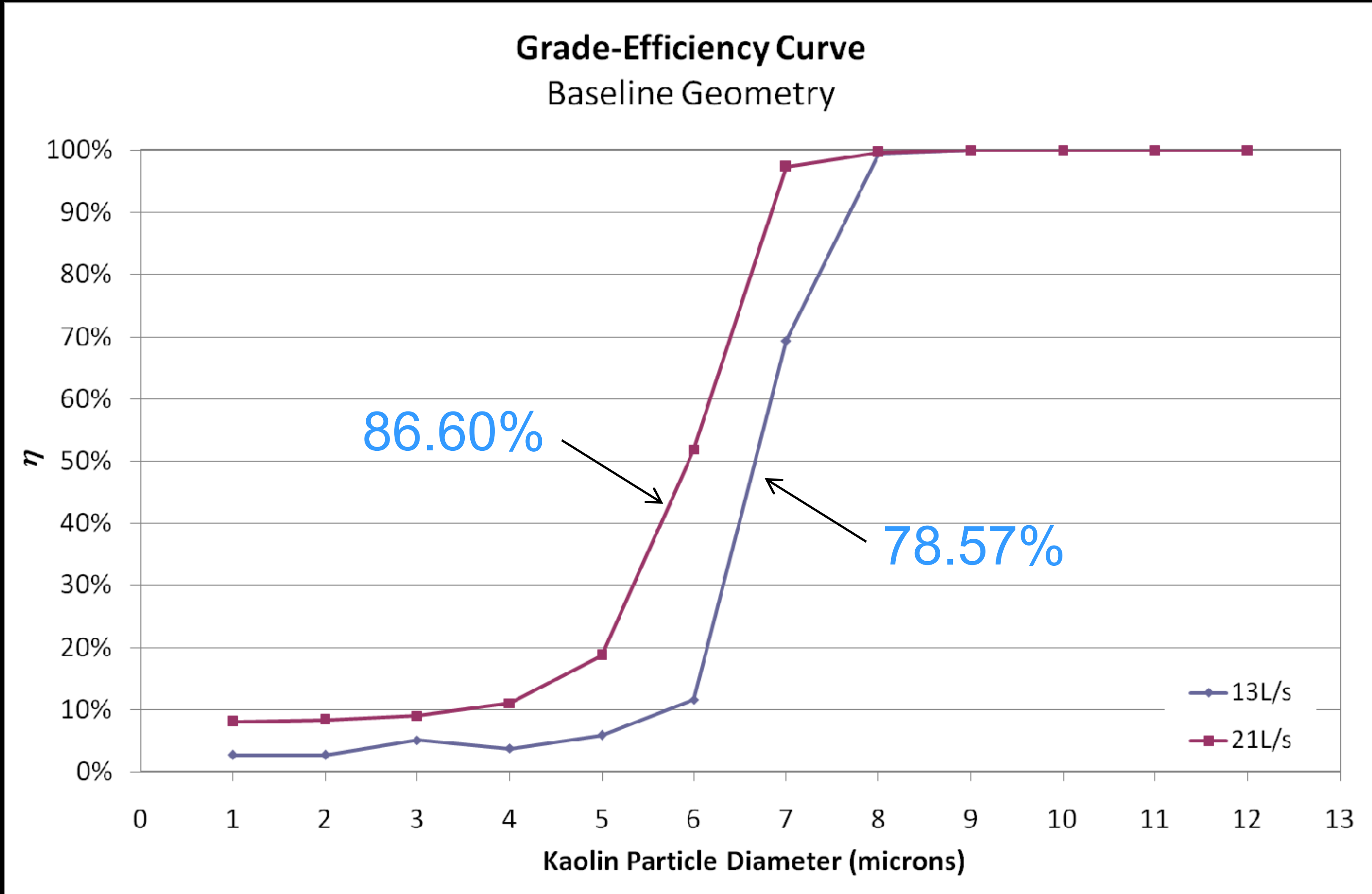




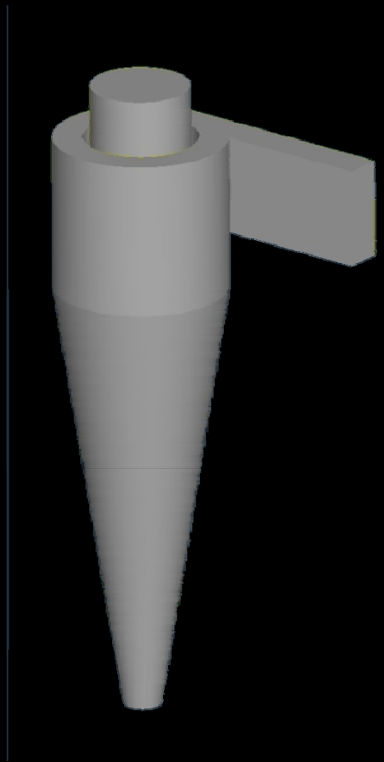
Results: Flow Balance



Results: Separation Efficiency



CFD Analysis: Modified Design



New 2nd Stage Cyclone

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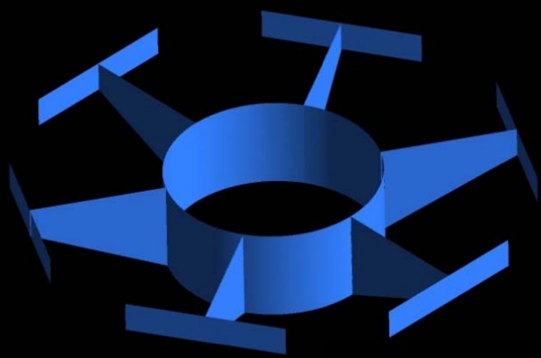

Corrective device for preventing hopper cross flows

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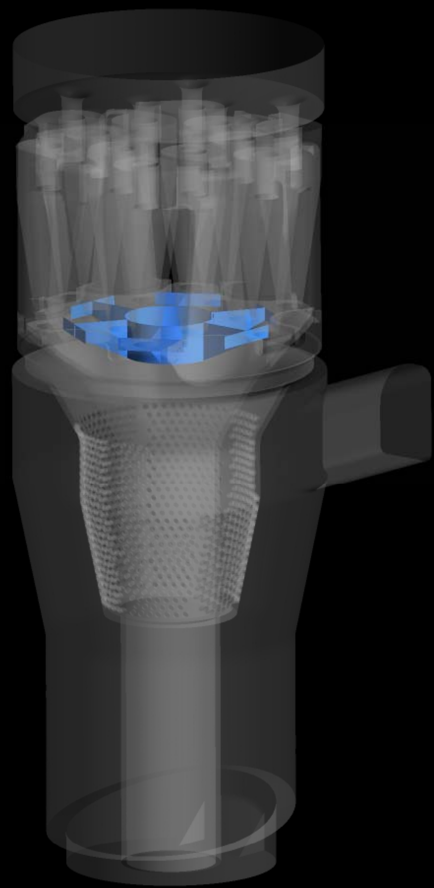

Modified Design

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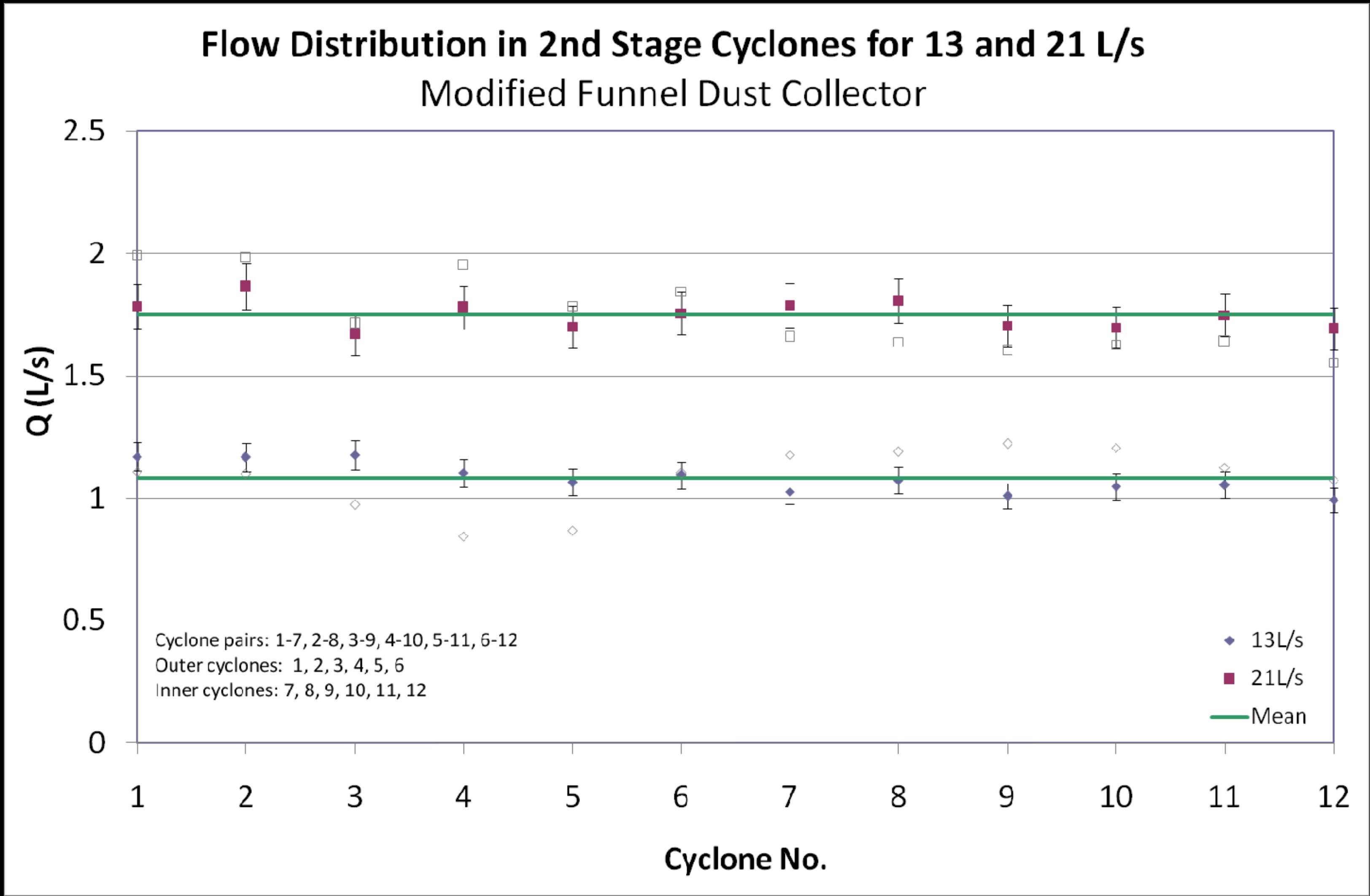
Results: Flow Balance



CFD Analysis Optimised Design

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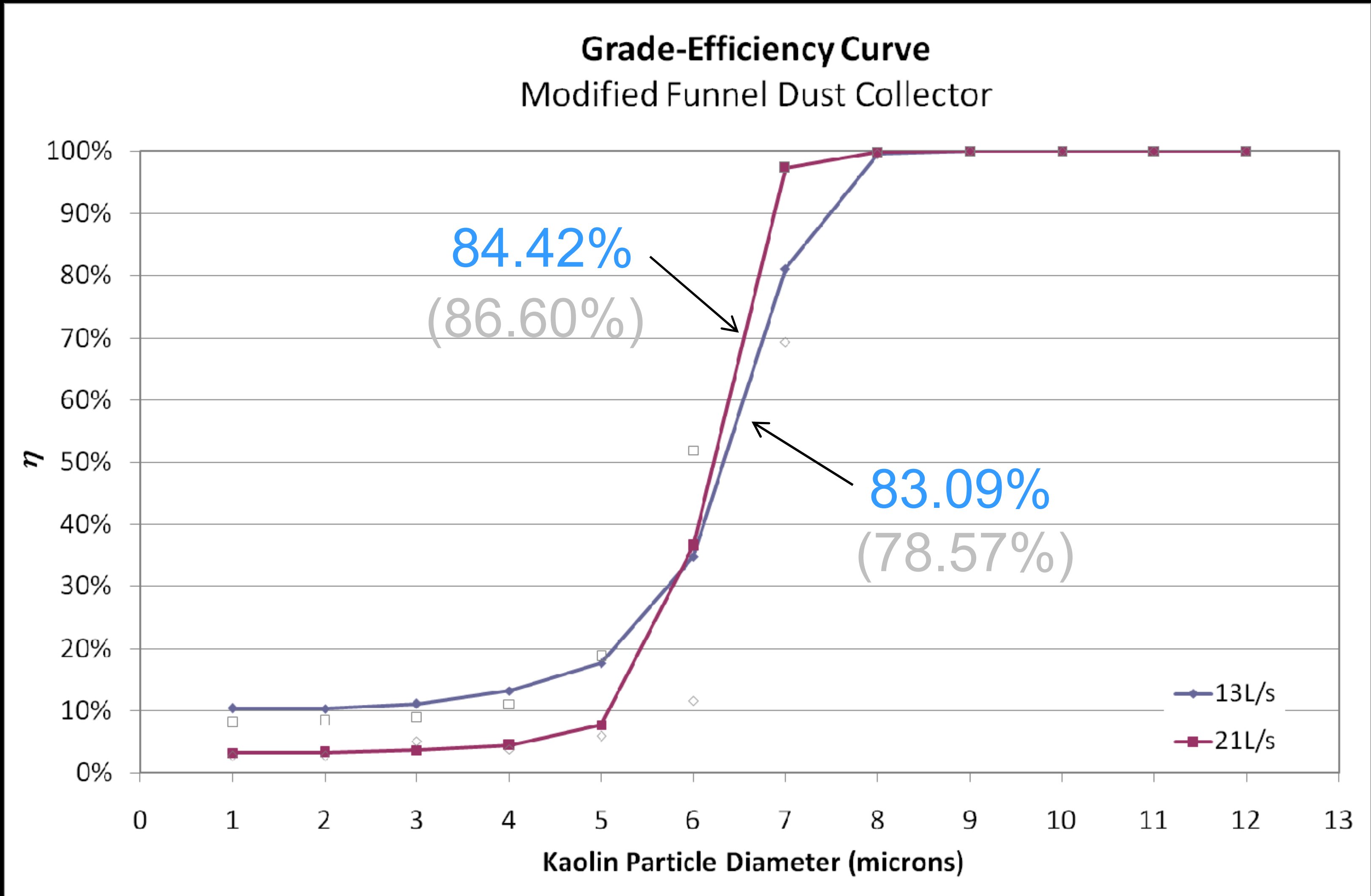
Results: Separation Efficiency



Conclusions

- A CFD methodology combining 1D analysis, modeFrontier, ANSA and CFX was developed to:
  - Estimate performance parameters
  - Understand existing/potential flow related phenomena not seen in experiments
  - Propose design modifications and verify their effects
- Benefits to Hoover Candy:
  - Ability to reduce prototyping
  - Ability to reduce testing
  - Better, cheaper and greener vacuum cleaners

Thank you for your attention

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