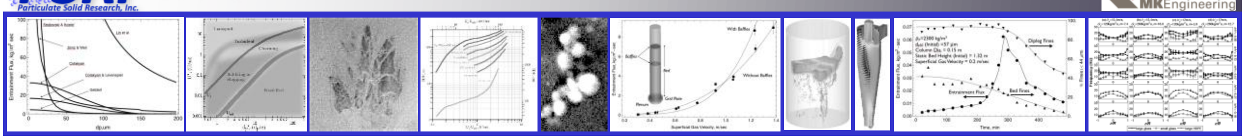
CFD simulations of primary cyclones with and without an eccentrically positioned vortex finder

Ray Cocco[1)], Ulrich Muschelknautz[2)], Ben Freireich[1)], S.B. Reddy Karri[1)], Ted Knowlton[1)]

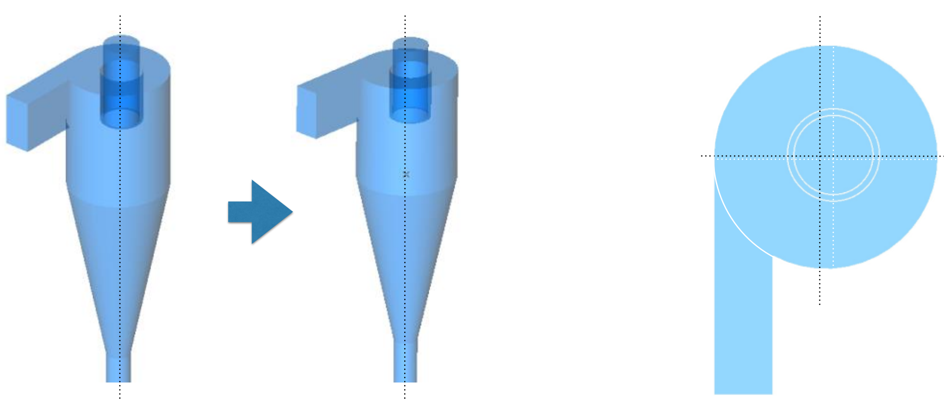
Fluidization XVI

[1)] Particulate Solid Research Inc. (PSRI), Chicago, IL, USA [2)] MK Engineering – Dust Removal Technology, Heidelberg, Germany

PSRI *Applying the Fundamentals*



Objective



Concentric Cyclone Eccentric Cyclone

- Use CFD to better understand the gas-particle flow hydrodynamics around the vortex finder in order to better define future experimental work in large-scale cyclones

History of the Eccentric Vortex Finder

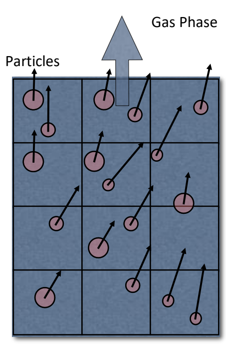
- The asymmetric inlet of a cyclone generates eddies in the lower pressure region behind the vortex finder near it's wall [Trefz, 1992; Trefz, Muschelknautz, 1993]
- The flow around the vortex finder is laminar because of the very stable stratification of the boundary layer which can be easily disrupted by these eddies and cause leakage into the vortex finder [Muschelknautz and Muschelknautz, 1999]
  - Such leakage is more prevalent in high loaded cyclones
- An eccentric shift of the vortex finder uniforms the flow around the vortex finder and increases the cyclone collection efficiency [Muschelknautz and Muschelknautz, 1999]
  - Initial verification was done with cold flow models
- Commercial application by MK Engineering in 16 boilers, amongst others
  - Two boilers at Energieversorgung Offenbach
  - Five boilers at RWE (Rheinbraun(1), Berrenrath(2) and Goldenberg(2))
  - Boiler at Electricité de France, Gardanne

Technical Data	Energiever sorgung Offenback, DE11	Energiever sorgung Offenback, DE12	Rheinbraun Berrenrath	Rheinbraun Wachtberg	Gardanne	Goldenberg DE K	Goldenberg DE J
Steam Generation, t/hr	110	110	250	175	750	400	290
Cyclone Barrel Diameters, mm, and number	3120 (2)	3120 (2)	6290 (2)	5330 (2)	7400 (4)	5500 (4)	3710 (4)
Eccentric Shift, mm	40	40	150	200	300	190	135
Median Particle Size of Circulating Ash, microns	110 -> 95	100 -> 110	160 -> 145	175 -> 155	210 -> 175	210 -> 170	200 -> 170
Addition of sand or ash, t/hr	-> 0	-> 0	20 -> 8	12 -> 2	stayed 0	900 -> 100	100 -> 0
Operating Behavior	More stable, increase thermal efficiency, return of ash no longer needed	More stable, increase thermal efficiency, return of ash no longer needed	More stable with sharp reduction in sand	More stable with sharp reduction in sand	More stable, increase thermal efficiency, reduced water injection	More stable with sharp reduction in sand	More stable, reduced temperature in upper portion, reduced sand addition

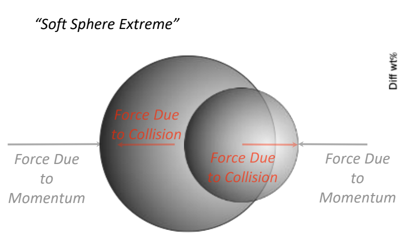
Trefz M (1992). Die verschiedenen Abscheidevorgänge im höher und hoch beladenen Gaszyklon unter besonderer Berücksichtigung der Sekundärströmung. VDI-Fortschr.-Ber., VDI-Verlag, Düsseldorf, Reihe 3, No. 295.
Trefz, M., and Muschelknautz, E.(1993), Extended cyclone theory for gas flow with high solids concentration. Chem. Eng. Technol. 16, pp. 153 – 165.
Muschelknautz U, Muschelknautz E (1999). Separation efficiency of recirculating cyclones in CFB combustions. VGB PowerTech 4/1999, pp. 48 – 53.
Ipsen C, Roschek D, Muschelknautz U (2014) Optimierung eines Zyklonabscheiders einer zirkulierenden Wirbelschichtfeuerung. VGB PowerTech 4/2014, pp. 75 – 79

Simulations using Barracuda VR®

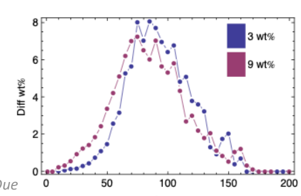
COMPUTATIONAL PARTICLE FLUID DYNAMICS



MP-PIC: Multiphase Particle-in-Cell

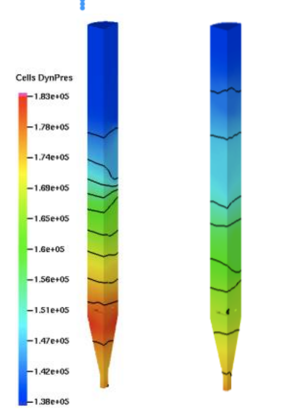


Particles are tracked but collisions are not



Reported	dp50, µm	% Fines, (< 44 µm)
3 wt%	80.4 µm	2.7%
8 wt%	81.0 µm	8.6%

Allows the simulation of the whole particle size distribution including fines



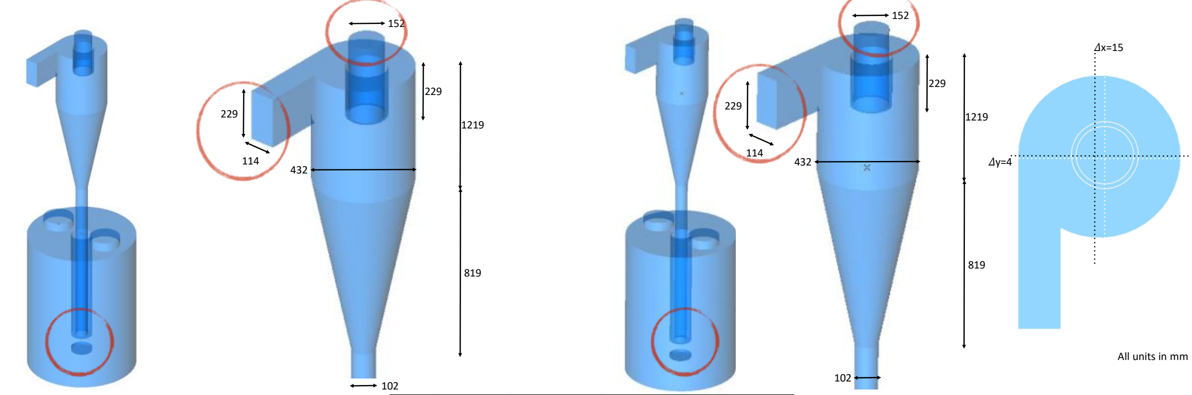
3% Fines with Flux 9% Fines with Flux

Particle fines can have a significant effect on fluidized Geldart Group A Powders

CFD Simulation of Previous Cold Flow Study

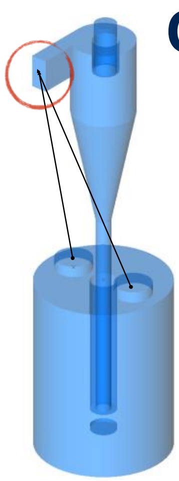
Based on the Muschelknautz and Muschelknautz Concept [1999] and PSRI Equipment

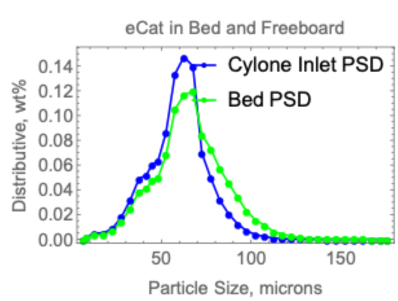
Concentric VF: Cases 1 and 3 — Eccentric VF: Cases 2 and 4



Case Number	Vortex Finder	Inlet Velocity	Solids Flow Rate	Mass Ratio
1	Concentric	18 m/sec (59 ft/sec)	9.24 kg/sec (20.3 lb$_m$/sec)	18
2	Eccentric	18 m/sec (59 ft/sec)	9.24 kg/sec (20.3 lb$_m$/sec)	18
3	Concentric	18 m/sec (59 ft/sec)	18.5 kg/sec (41 lb$_m$/sec)	36
4	Ecentric	18 m/sec (59 ft/sec)	18.5 kg/sec (41 lbm/sec)	36

Conditions at Cyclone Inlet



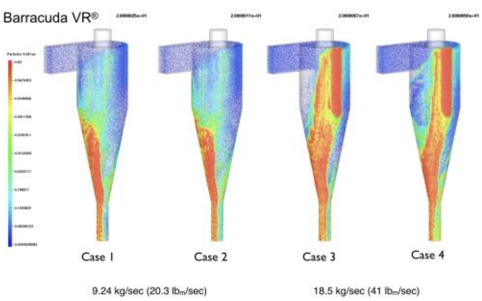


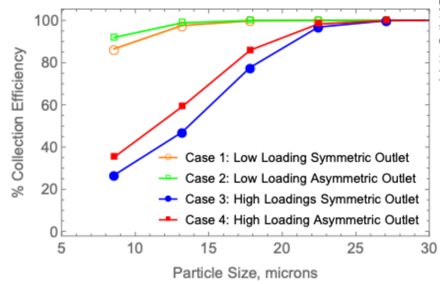
Max Entrainable Particle Size, dpt, microns	181.4804198
Cluster Size, dpc, microns	62.16036941
TDH, meters	3.687533299
Entrainment Rate, kg/sec — Not Used	12.90853688

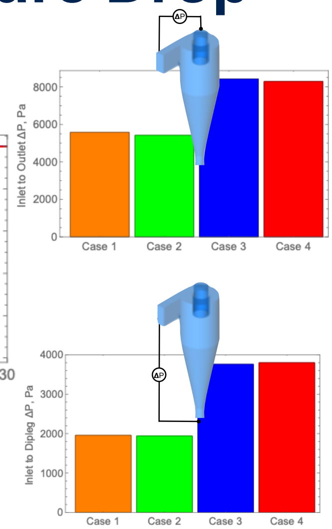
0.9 meter diameter fluidized bed with a bed height of 1.2 meters in a 3.7 meter high vessel and a superficial gas velocity of 0.9 m/sec through a bed of FCC eCat (ρ_p=1500 kg/m^3) at ambient conditions

PSRI Entrainment Rate Calculation was used to predict the PSD of the particles entering the cyclone. The entrainment rate was not used

Grade Efficiency and Pressure Drop



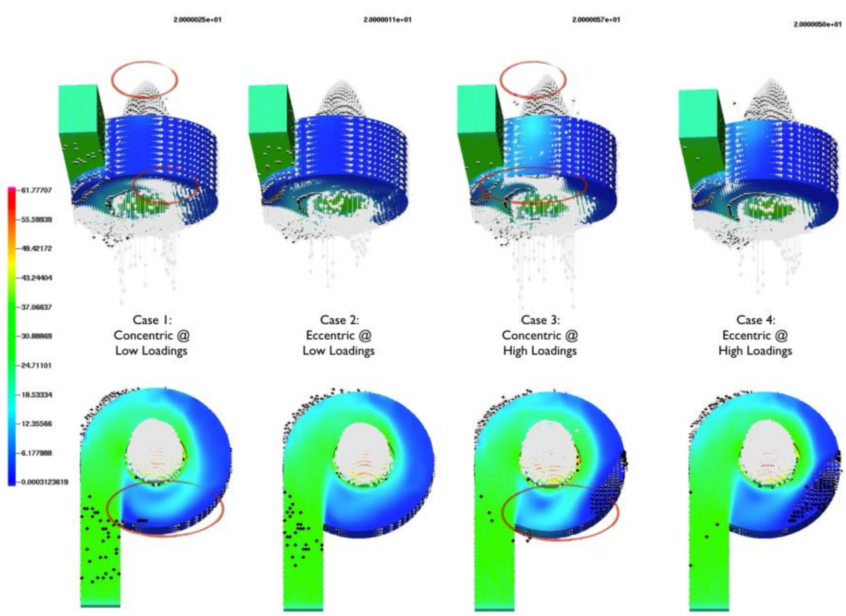




Case	Cut Size, microns
Case 1: Low Loading Symmetric Outlet	9.15
Case 2: Low Loading Asymmetric Outlet	8.92
Case 3: High Loadings Symmetric Outlet	13.2
Case 4: High Loading Asymmetric Outlet	12.

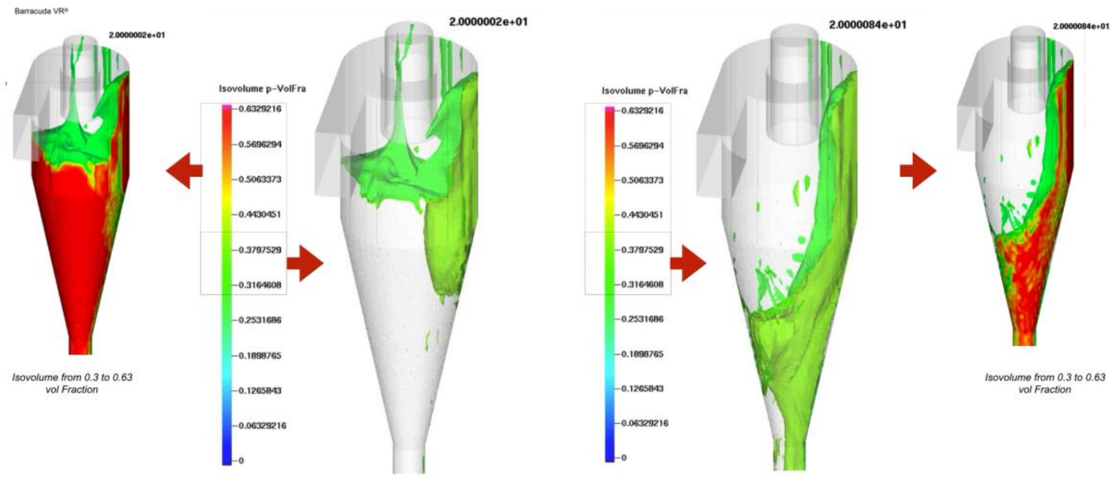
- Improved grade efficiency with eccentric vortex finder with minimal impact on pressure drop

Upper Barrel Hydrodynamics as Gas Velocity Magnitude and Particle Velocity Vectors



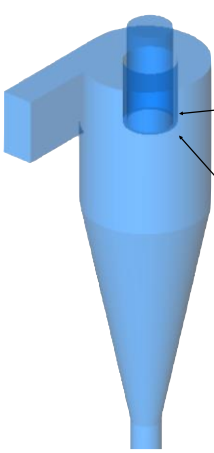
Leakage to Gas Outlet

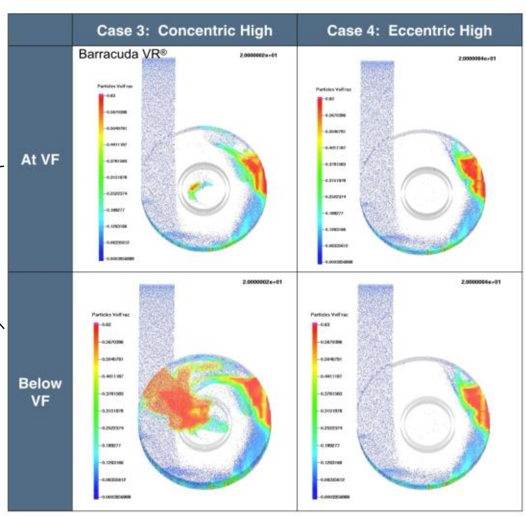
Case 3: Concentric @ High Loadings *Case 4: Eccentric @ High Loadings*



Isovolume from 0.3 to 0.4 vol Fraction: Highlighting Flow Into Vortex Finder

Particle Hydrodynamics: Solids Volume Fraction





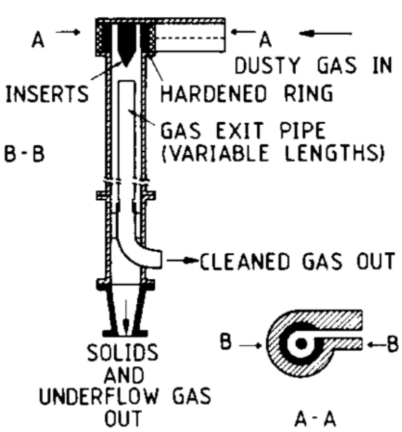
- Significant leakage near bottom of vortex finder for the concentric case (Case 3)
- It appears that interaction of the solids coming around the cyclone with the inlet generates a large eddy that promotes this leakage
- Shifting the vortex finder minimizes this eddy and the corresponding leakage

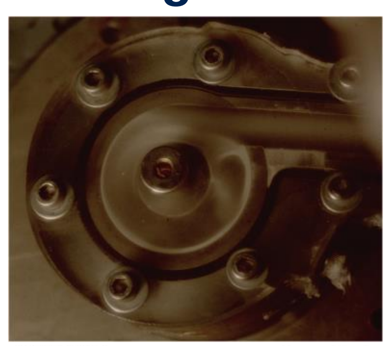
Standard Cyclone with Tangential Inlet

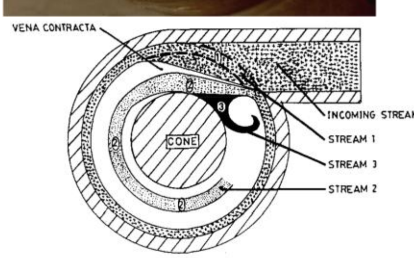
Cyclone Diameter: 54 cm
Loading: 32 kg/m^3
Inlet Velocity: 18 m/sec

Uniflow Cyclone with Tangential Inlet

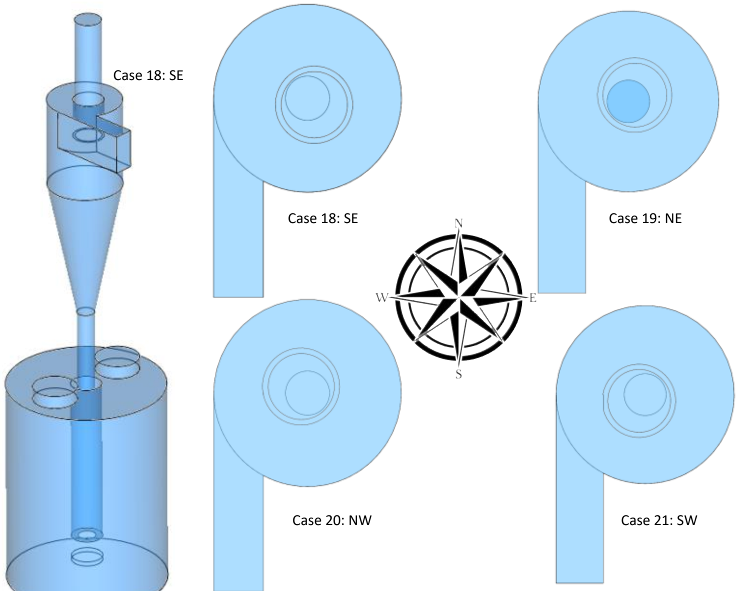
Cyclone Diameter: 5 cm





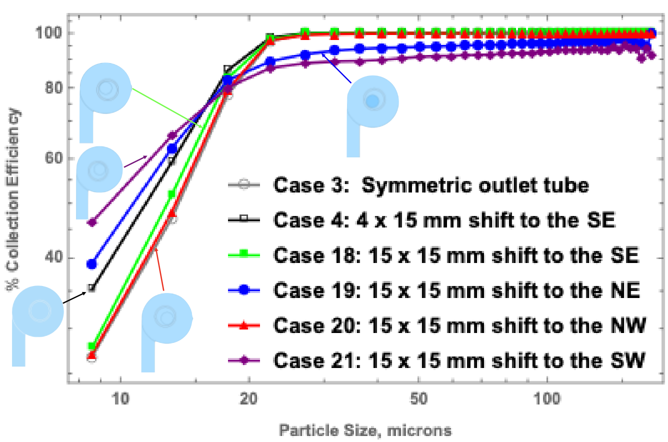


T.A. Gauthier, C.L. Briens, M.A. Bergougnou, P. Galtier, Powder Technology, 62 (1990) 217-225.



Parametric Study on Vortex Finder Position

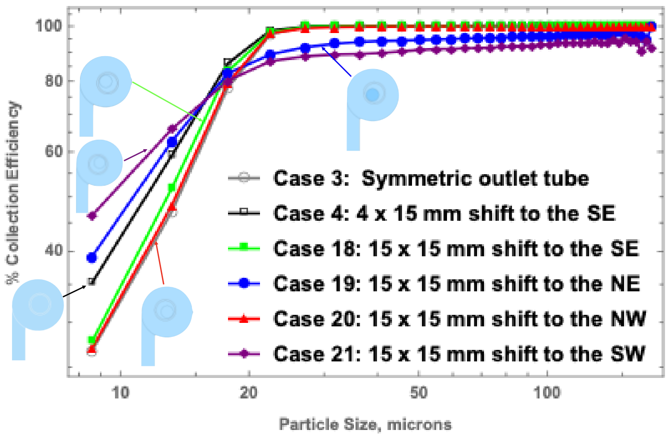
Case Number	Vortex Finder Eccentric Position, mm	Inlet Velocity	Solids Flow Rate	Mass Ratio
18	S 15 x E 15	18 m/sec (59 ft/sec)	18.5 kg/sec (41 lb_m/sec)	36
19	N 15 x E 15	18 m/sec (59 ft/sec)	18.5 kg/sec (41 lb_m/sec)	36
20	N 15 x W 15	18 m/sec (59 ft/sec)	18.5 kg/sec (41 lb_m/sec)	36
21	S 15 x W 15	18 m/sec (59 ft/sec)	18.5 kg/sec (41 lb_m/sec)	36

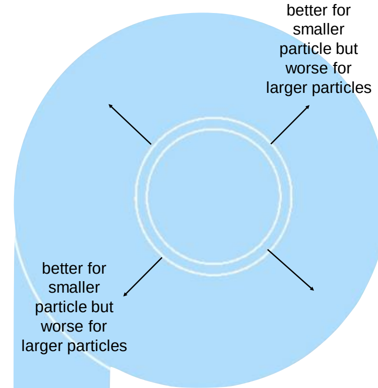


Grade Efficiency Comparison

- Pure SW shift results in a poorer collection of fines than the original Muschelknautz and Muschelknautz [1999] shift with cyclone vortex finder
- Shift towards or away from the inlet resulted in better fines collection but worse collection efficiencies for larger particles
- Shift in the NW direction resulted in a similar collection efficiency as the control case with no shift

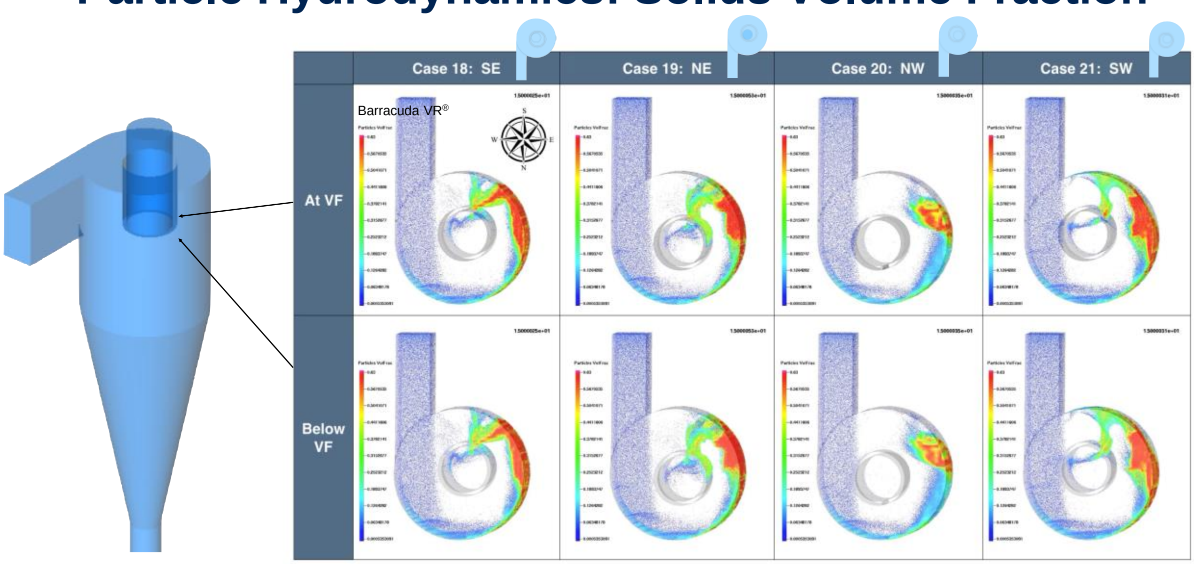
Case	Cut Size(50%), microns	Cut Size (90%), microns	% Overall Efficiency
Case 3: Symmetric outlet tube	13.6	20.8	99.77
Case 4: 4 x 15 mm shift to the SE	11.4	19.3	99.813
Case 18: 15 x 15 mm shift to the SE	12.9	20.	99.772
Case 19: 15 x 15 mm shift to the NE	10.7	23.8	94.882
Case 20: 15 x 15 mm shift to the NW	13.4	20.6	99.728
Case 21: 15 x 15 mm shift to the SW	9.44	43.2	91.165



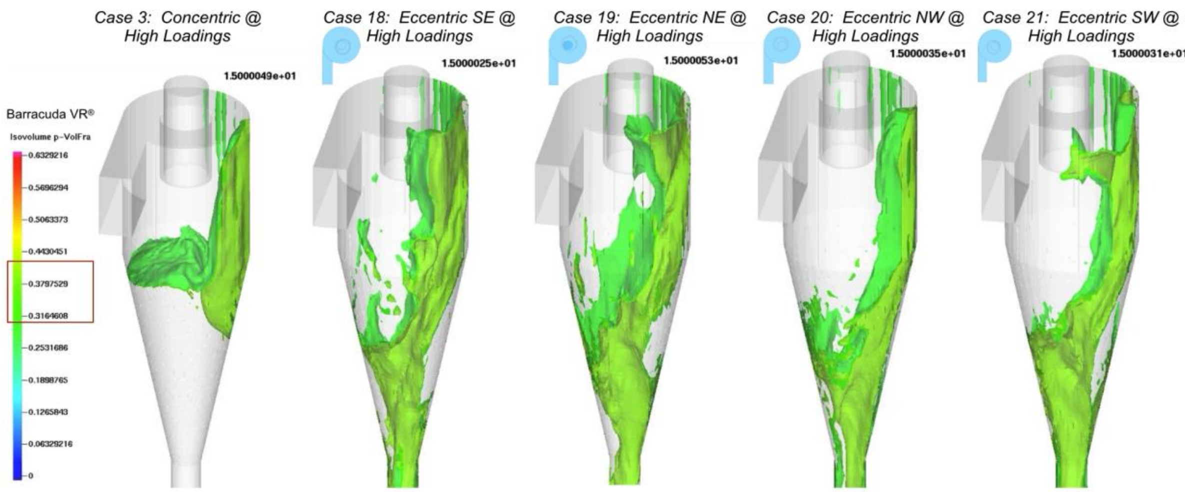


Case	Cut Size(50%), microns	Cut Size (90%), microns	% Overall Efficiency
Case 3: Symmetric outlet tube	13.6	20.8	99.77
Case 4: 4 x 15 mm shift to the SE	11.4	19.3	99.813
Case 18: 15 x 15 mm shift to the SE	12.9	20.	99.772
Case 19: 15 x 15 mm shift to the NE	10.7	23.8	94.882
Case 20: 15 x 15 mm shift to the NW	13.4	20.6	99.728
Case 21: 15 x 15 mm shift to the SW	9.44	43.2	91.165

Particle Hydrodynamics: Solids Volume Fraction

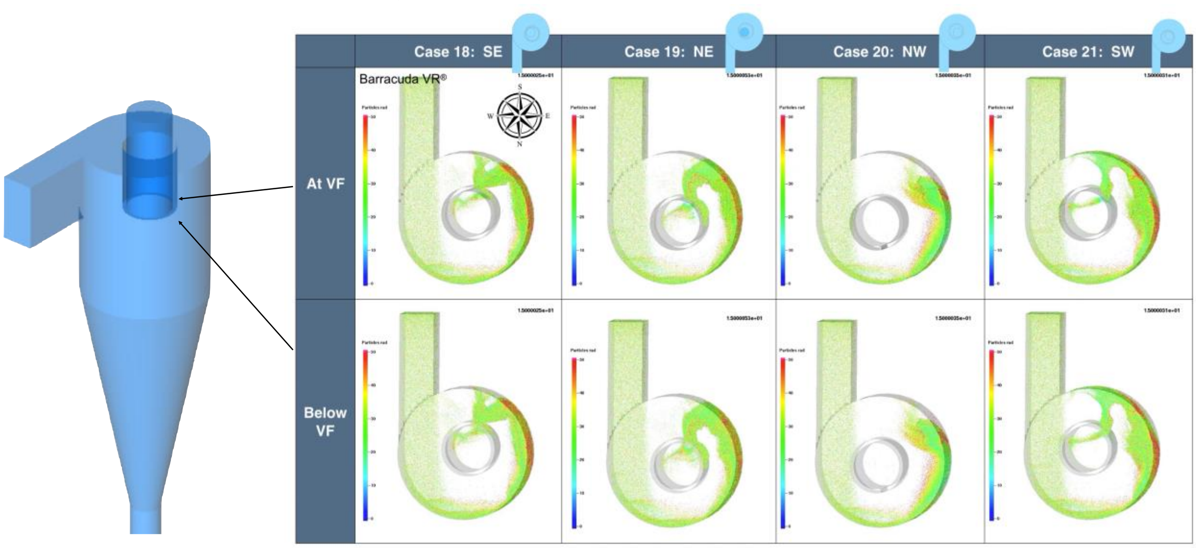


Leakage to Gas Outlet

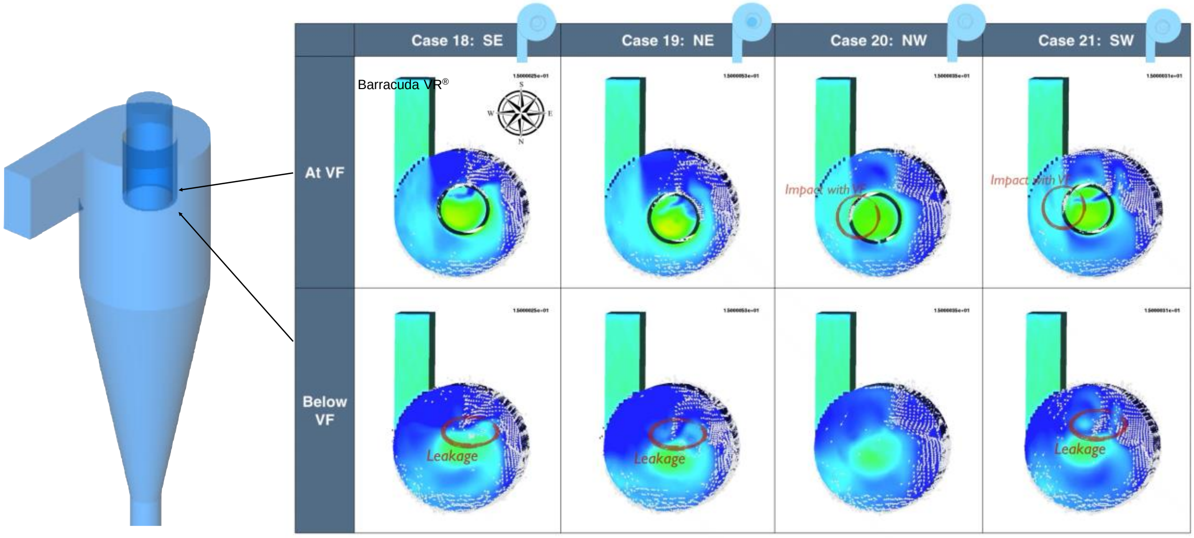


Isovolume from 0.3 to 0.4 vol Fraction: Highlighting Flow Into Vortex Finder

Particle Hydrodynamics: Particle Size

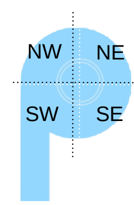


Gas Velocity Magnitude and Particle Velocity Vectors



Note: Impact with VF could be minimized by using a volute inlet instead of a tangential inlet

Summary



- CFD simulation of the complex gas-particle hydrodynamics in high loaded cyclones indicates
  - Large and small eddies do exist along with inner and outer vortices
  - Eccentrical shift of the vortex finder may result in better collection efficiency over a wide range of loadings without compromising pressure drop
  - Varying the vortex finder position (SW, NW, NE, SE) shifts collection of particles towards small or large sizes!
  - The SW or NE shift results in considerable less collection efficiency than the Muschelknautz and Muschelknautz [1999] design (Case 4)
  - Muschelknautz and Muschelknautz [1999] design (Case 4) still found to be optimal with cases examined (Cases 4, 18, 19, 20, 21)
  - There appears to be two mechanisms causing particle leakage into gas outlet:
    1) Impact of entering particles with the vortex finder
    2) Interaction of particles coming around the cyclone with the inlet generates a large eddy that promotes particle leakage
  - Future work needs to look at pure N, E, and S shifts

- What about cyclones with volute inlets or cyclones with helical roofs?