Cyclonic Glass Bead Media Separation System

LTEC ENGINEERING

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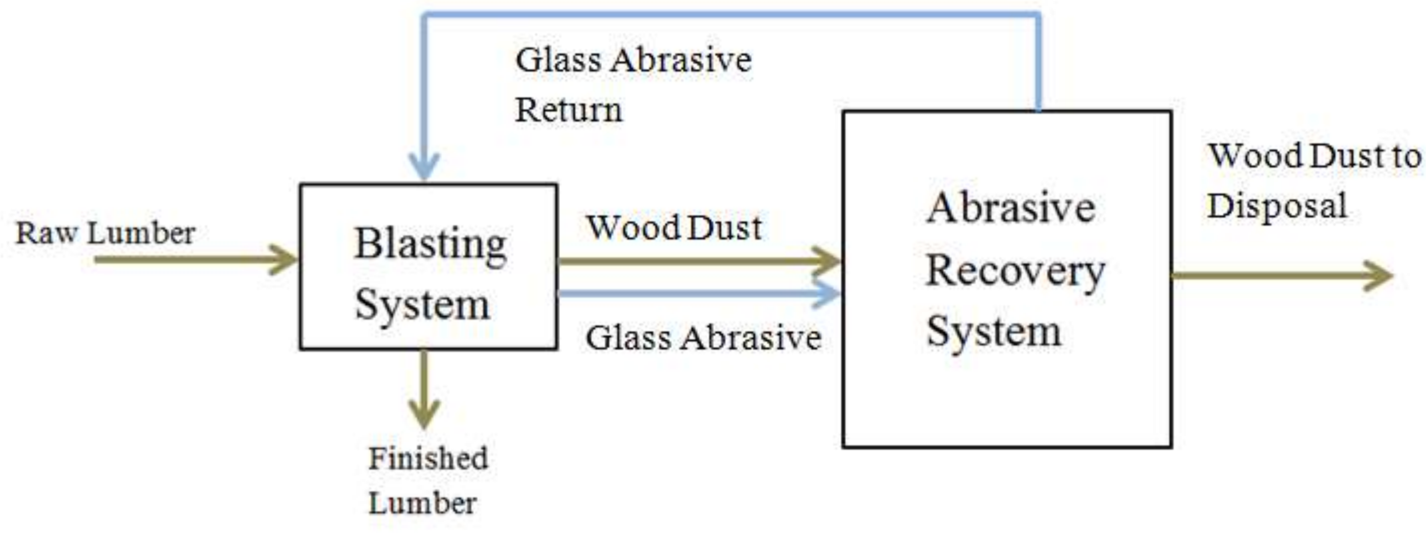
Overview

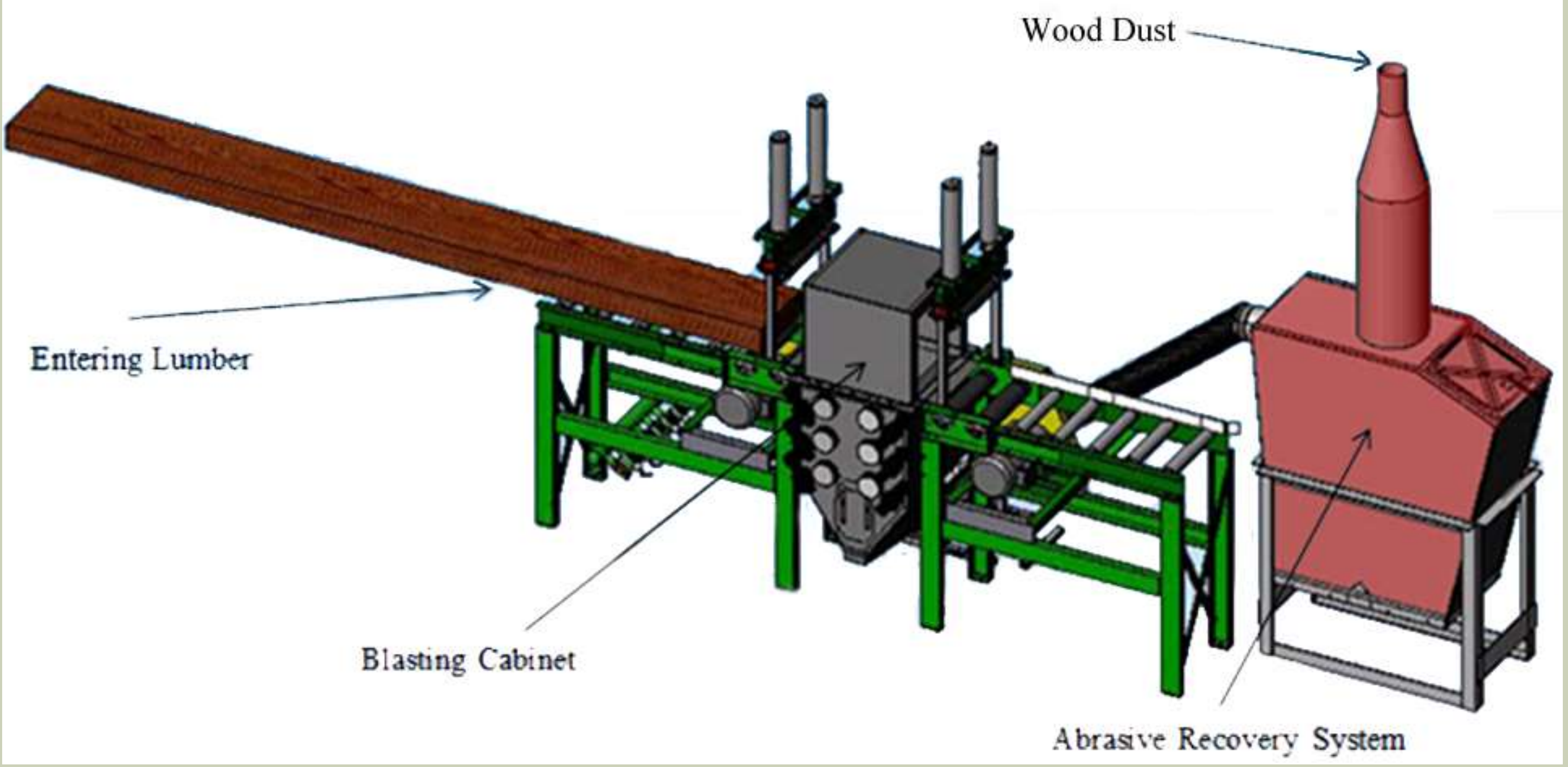
- Background & Problem
- System Design
- Proof of Concept Scaling
- Fabrication & Compliance Testing
- Performance Review
- Recommendations

Background

- Project Sponsor - RBM Lumber of Colombia Falls, Montana
- WTM contracted to design wood texturing machine in 2006
- Machine functioned by blasting glass abrasive into lumber to create desired finish



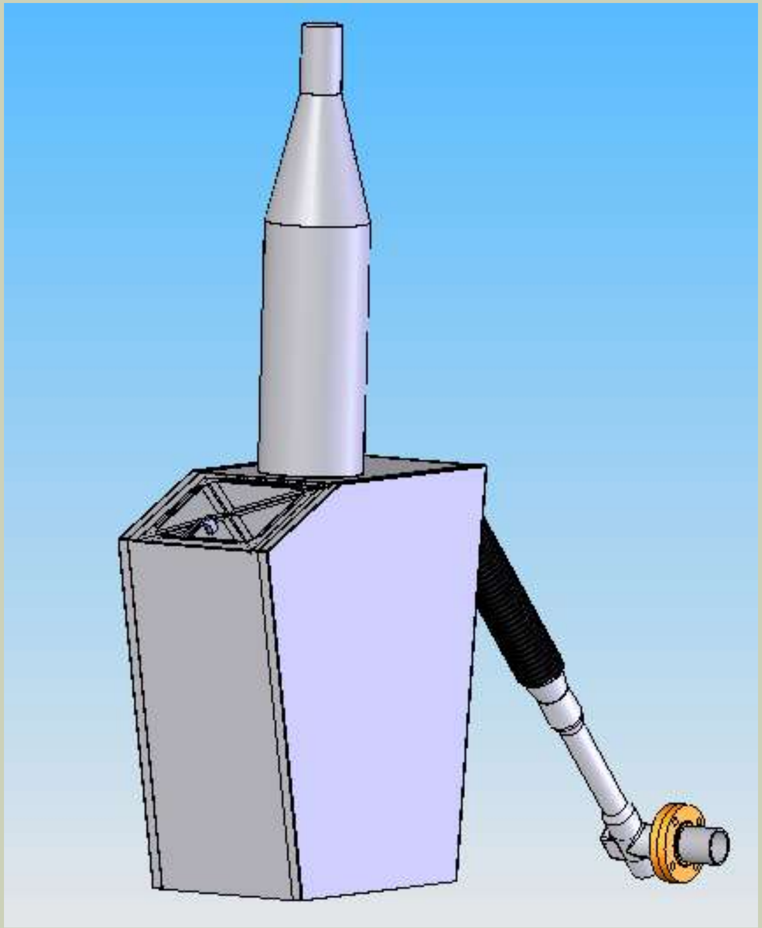
Background


Wood Dust
Entering Lumber
Blasting Cabinet
Abrasive Recovery System

Problem

- Abrasive recovery system did not meet specifications

- Parameters for new system:
  - 600 cfm nominal airflow from blasting cabinet
  - Solids entering the flow at approximately 21 lb_m/min (19 lb_m- glass, 2 lb_m- wood dust)
  - Glass abrasive 80-120 microns in effective diameter



WTM Abrasive Recovery System

Wood Dust Characterization

- RBM Lumber unable to provide wood dust from system
- Experiment designed to match the blasting conditions at RBM
- Blasted Larch & Douglas Fir and collected wood dust
- Majority of wood dust particles below 53 microns in effective diameter

Design Specifications

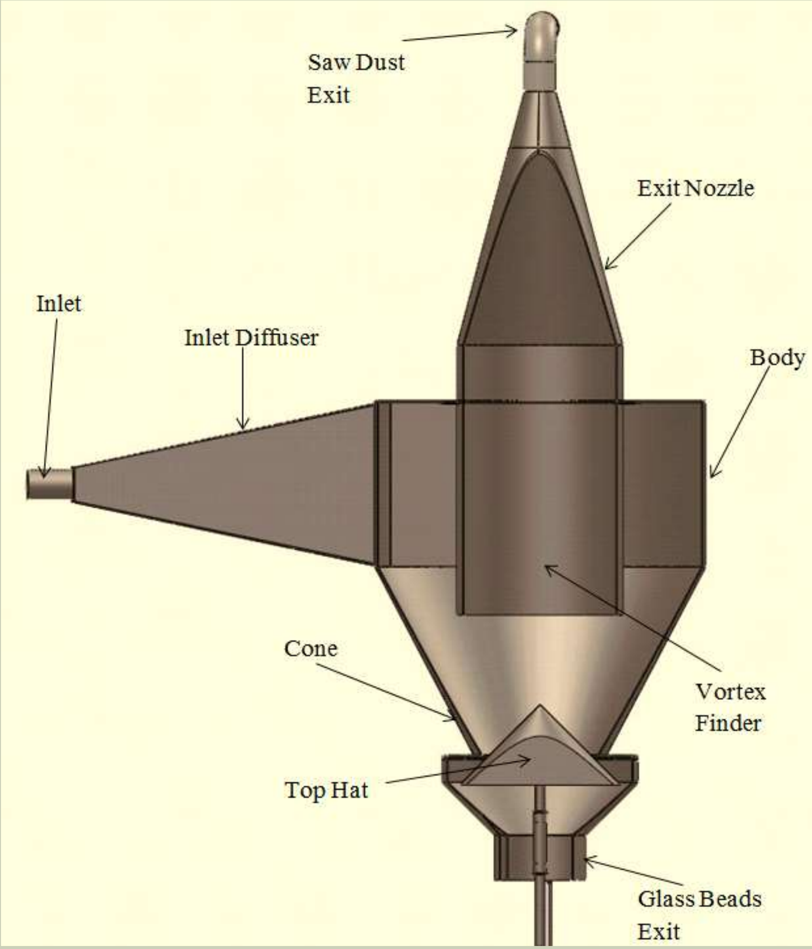
- 95% recovery of glass abrasive > 40 μm in diameter
- Transport wood waste ≤53 μm to disposal site
- Integrate with existing wood texturizing machine
- Maintain a safe working environment for operators

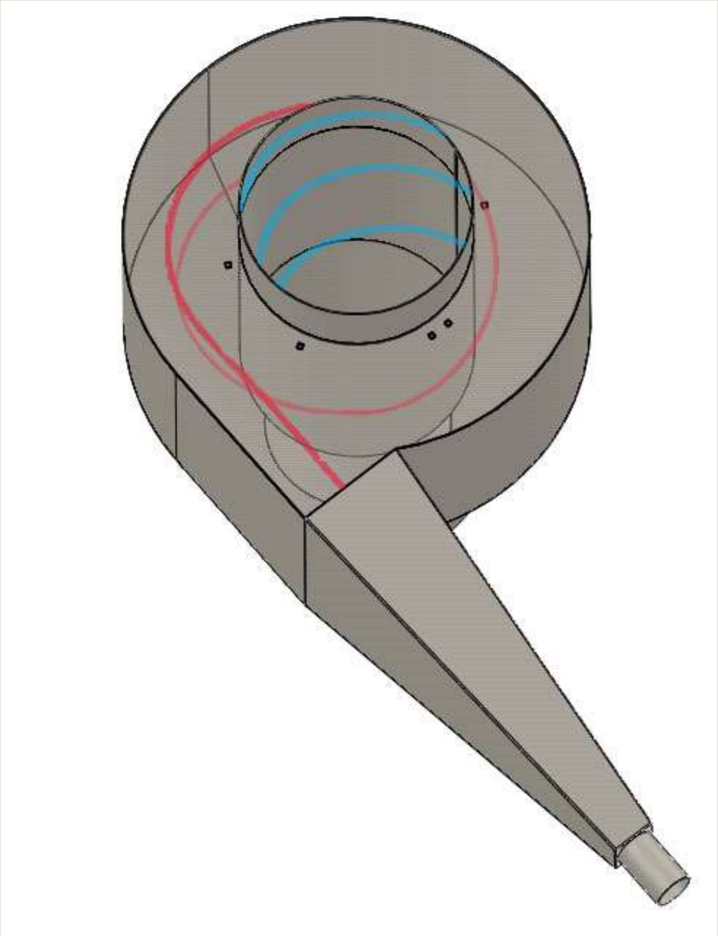
Design Considerations

- Focused investigation of three separation systems
  - Settling chamber
    - Reduce flow velocity to settle glass abrasive out of air stream
  - Magnetic field separator
    - Apply Lorentz force to separate glass abrasive from wood dust via particle charge
  - Cyclonic separation
    - Utilize density difference between glass abrasive and wood dust

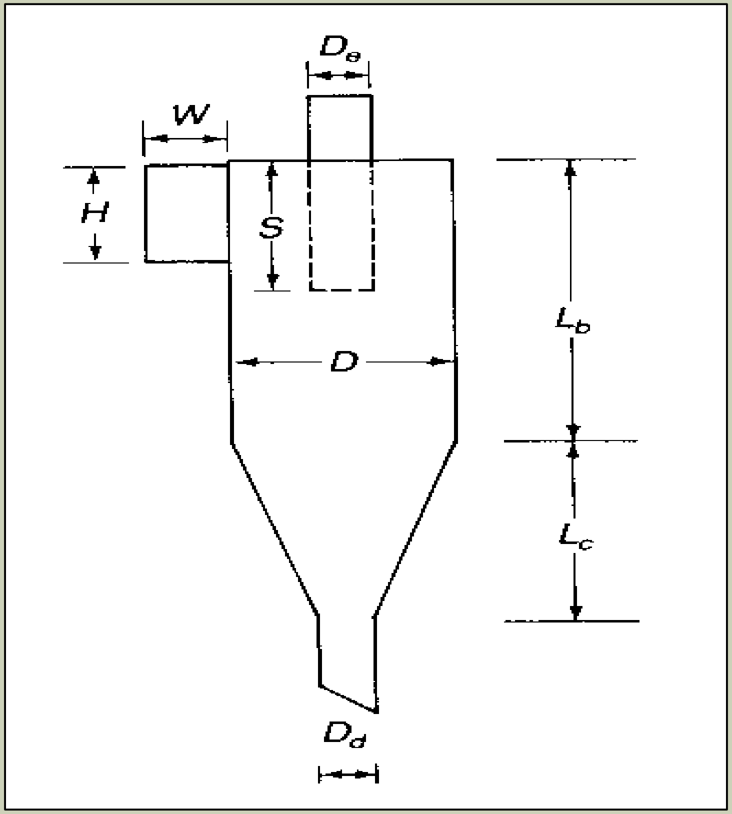
- Cyclonic separation chosen as most feasible method

Cyclonic Separation





Cyclone Design



Cyclone Relationships

Cyclone Design

- Analysis based on worst case glass bead particle
  - Number of turns

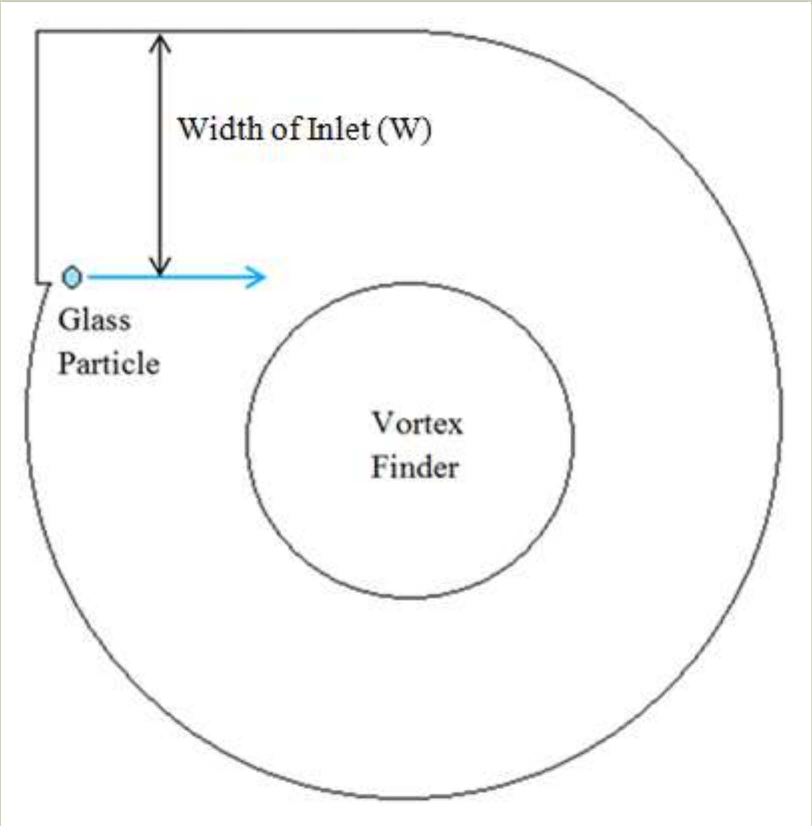
$$N_t = \frac{1}{H} * \left(L_b + \frac{L_C}{2}\right)$$

  - Gas residence time

$$\Delta t = \frac{\pi D N_t}{V_i}$$

  - Necessary Radial Particle Velocity

$$V_{rn} = \frac{W}{\Delta t}$$



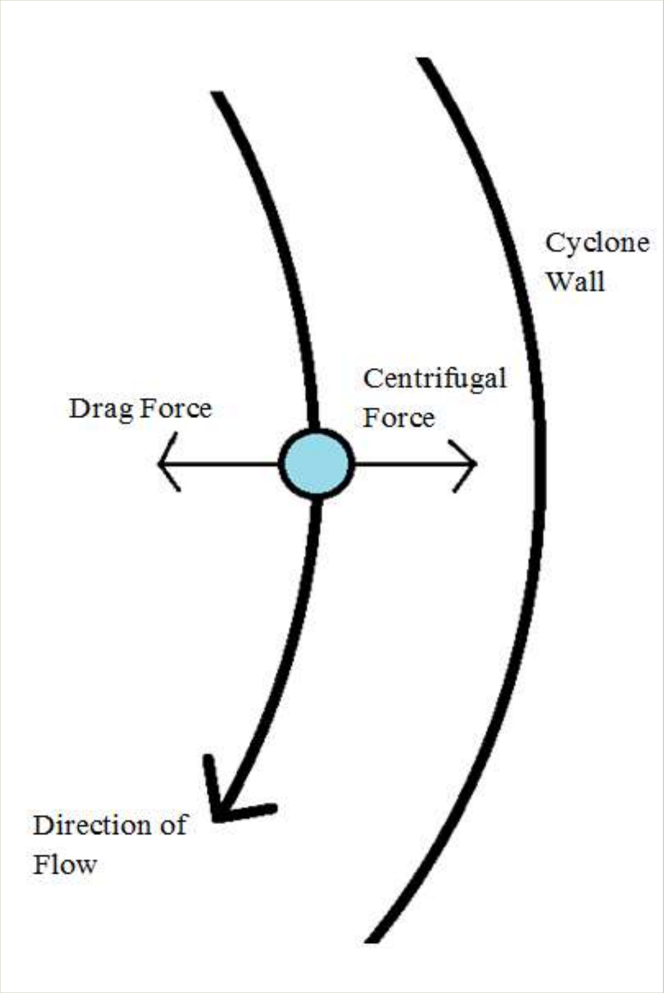
Cyclone Design

- Calculate Terminal Velocity
  - Summation of forces in radial direction

$$\sum F_r = F_C - F_D = \text{ma}$$

  - Assume Stokes flow
    - Reynolds number for particle less than 1
  - Terminal velocity

$$V_t = \frac{d_p^2(\rho_p - \rho_f)V_i^2}{9\mu D}$$



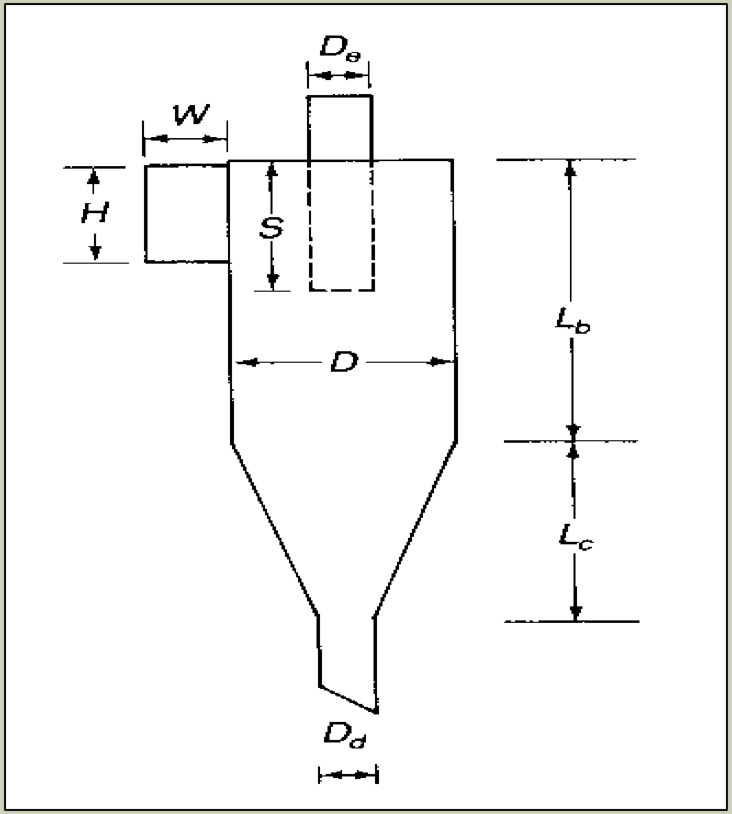
Cyclone Design

- Through substitution

$$d_p = \left(\frac{9\mu W}{2\pi N_e V_i(\rho_p - \rho_f)}\right)^{\frac{1}{2}}$$

- Enter number of turns equation and cyclone relationships

$$D = \left(\frac{d_p^2 \pi \dot{V}(\rho_p - \rho_f)\left(L_B + \frac{L_C}{2}\right)}{9\mu W^2 H^2}\right)^{\frac{1}{3}}$$



Design Modification

- Optimal dimensions for separation found:
  - Cyclone height reached 20 ft
  - Inlet velocity very slow at 3 ft/s
  - Modifications were necessary

- Improvements:
  - Cyclone height decreased to 4 ft
  - Inlet velocity increased to 7 ft/s

Proof of Concept - Scaling

- Dimensional Analysis – Buckingham Pi Theorem

$$\eta(d_p) = fnc\left(\frac{D\rho v_{ch}}{\mu}, \frac{\Delta\rho d_p^2 v_{ch}}{18\mu D}, \frac{\rho_{part} - \rho_{gas}}{\rho_{gas}}\right)$$

  - Unable to maintain both Reynolds and Stokes numbers
    - Experimentation has shown for Re=10^5 – 10^6, Stokes=constant (Hoffmann & Stein, 2008)
  - Scaling based solely on Stokes number yields

$$\frac{v}{D} = \frac{v_m}{D_m}$$

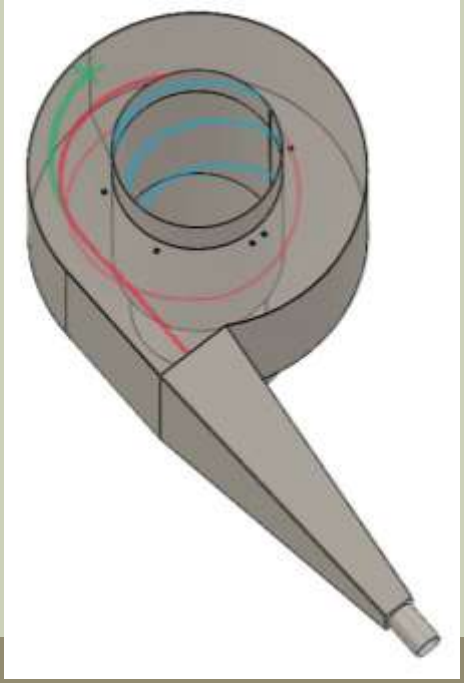
Proof of Concept - Scaling

- Scaling factor of 0.54
  - Diameter decrease from 41 inches to 22 inches
- Reynolds number
  - Full scale cyclone - 2.86E+05
  - Proof of concept cyclone - 8.27E+05

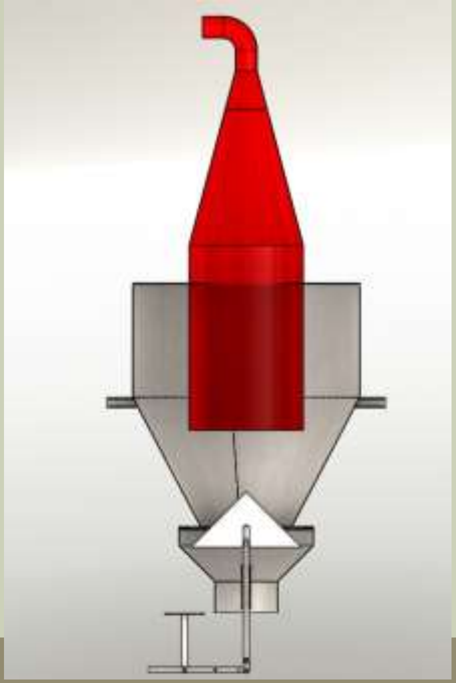
Proof of Concept - Adjustability

- Adjustability was desired to account for unanticipated factors
- Three point of adjustability were added

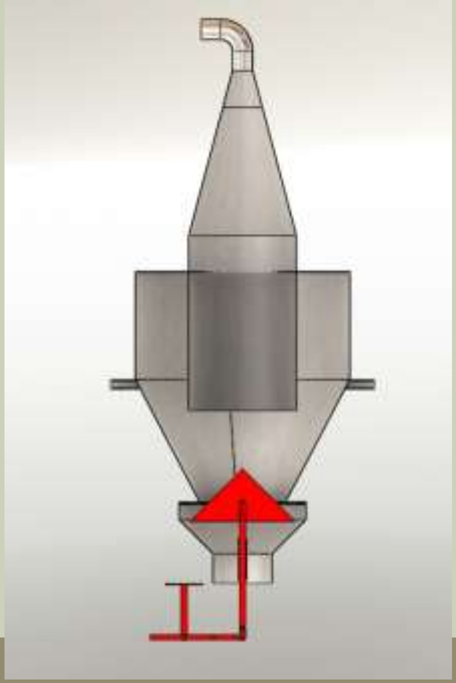
Flow Rate



Vortex Finder



Top Hat



Proof of Concept – Materials & Cost

- Cyclone constructed from low carbon steel sheet
  - Weldability
  - Easily formed
  - Low cost
- 10 gage steel for high stress flat parts
- 16 gage steel for rolled parts
- 24X48 inch sheet size

- Total cost of materials:
  - $520

Proof of Concept - Fabrication

Complete Fabrication

Compliance Testing - Experimentation

- Necessary to assure design specifications are met
- Experiment 1 – Maximum Pressure
  - Ensure stress is within design tolerance
  - Measure strain at maximum pressure using strain gauge
- Experiment 2 – System Seal
  - Maintain air flow
  - Protect operator from respiratory hazards
    - OSHA 1910.1000 – glass particulate limited to 5 mg/m^3
  - Apply soap solution to cyclone surfaces

Compliance Testing - Experimentation

- Experiment 3 – Sound Level
  - Protect operator from occupational noise exposure
    - OSHA 1910.95 – sound levels less than 85 dB
  - Measure with sound level meter

- Experiment 4 – Collection Efficiency
  - Optimize separation performance
  - Introduce solid media separately
    - Vary adjustable parameters
    - Iterate for best compromise
  - Combine solids at expected ratio
    - Ensure specified performance

Compliance Testing - Experimentation

Compliance Testing - Results

- Experiment 1 – Maximum Pressure
  - Maximum stress 3.2 ksi at critical point for 1.3 psi internal pressure
- Experiment 2 – System Seal
  - System leaks were found
  - Sealed with acrylic latex caulk
- Experiment 3 – Sound Levels
  - Maximum sound level 82 dB

Compliance Testing - Results

- Experiment 4 – Collection efficiency
  - Optimal iteration
    - Inlet velocity approximately half of design

Particle Size (µm)	Glass Abrasive Collected (%)	Wood Dust Removed (%)
<53	98	34
53<73	99	31
74<150	>99	14
>150	>99	10

  - Vortex finder and top hat adjustment proved negligible

Performance Review

Design Specifications	Performance Results
95% recovery of glass abrasive > 40 µm in diameter	99 % recovery of glass abrasive
Transport wood waste ≤ 53 µm to disposal site	34 % wood dust transported to disposal site
Integrate with existing wood texturizing machine	Inlets and exits of cyclone mate to WTM system
Maintain a safe working environment for operators	Meets OSHA noise and respiratory hazard standards ○ No PPE required

Recommendations to RBM Lumber

- Obtain representative sample of solid media from RBM Lumber
- Redesign full scale cyclone for representative samples
- Addition of flow rate control
- Remove vortex finder adjustability

Questions

LTEC ENGINEERING WOULD LIKE TO THANK

RBM LUMBER – BEN THOMPSON
DR. PAUL DELLENBACK, DR. JAY SITARAMAN
MR. SCOTT MORTON
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Work Cited

- Hoffmann, A. C., & Stein, L. E. (2008). Gas Cyclones and Swirl Tubes:Principles, Design and Operation. New York: Springer