TECHNICAL PUBLICATION

Feasibility Study to Improve the Performance of Mill System Components for Biomass Applications

by

Vlad Zarnescu, Ph.D
Principal Engineer
Riley Power Inc.

Jilin Zhang
Engineer
Riley Power Inc.

John Rath
Engineer
Riley Power Inc.

Joseph Bianca
Manager, Pulverizer Engineering
Riley Power Inc.

Presented at

Clearwater Coal Conference 2010
Clearwater, Florida

Riley Power Inc.
5 Neponset Street
Worcester, Massachusetts 01606
www.babcockpower.com

T-215

FEASIBILITY STUDY TO IMPROVE THE PERFORMANCE OF MILL SYSTEM COMPONENTS FOR BIOMASS APPLICATIONS

by:

Vlad Zarnescu, Ph.D
Principal Engineer
Riley Power Inc.

Jilin Zhang
Engineer
Riley Power Inc.

John Rath
Engineer
Riley Power Inc.

Joseph Bianca
Manager, Pulverizer Engineering
Riley Power Inc.

presented at:
Clearwater Clean Coal Conference 2010
Clearwater, FL

ABSTRACT

Utility companies face growing challenges to effectively implement the use of biomass co-firing as one of the lowest cost carbon neutral technologies available. The sustainable use of biomass is regarded as a cost-effective, proven method to reduce net greenhouse emissions. However, full-scale use of biomass for power generation includes additional challenges related to fuel supply, biomass properties, fuel transport and firing that need to be addressed. One important consideration is the milling system and its components. Due to the variation in biomass characteristics, the ability of mill components to handle biomass fuel directly affects system performance.

In 2009 Riley Power Inc. (RPI), a Babcock Power Inc. company, conducted a study to evaluate the performance of mill system components for biomass applications. This paper describes RPI's approach to evaluate the airflow and particle distributions in the various mill system components and gain insight into the key factors affecting performance. Separate components of the mill system were analyzed, including fuel transport pipes, mill body, and the classifier. Experimental runs were conducted using the wood pellet fuel and the results used as input to the CFD modeling. The current design was evaluated with regard to air and particle flow dynamics, pressure drop, and particle distributions. The different configurations, modeling results, and their impact on performance are discussed in detail.

INTRODUCTION AND BACKGROUND

In 2009 Riley Power Inc., a Babcock Power Inc. company, conducted a feasibility study for an electrical utility to evaluate the performance of mill system for biomass applications[1]. Evaluation of any pulverizer/mill system requires determination of whether the system has grinding, thermal or transport limitations; therefore, the study included review and evaluation of the existing and proposed mill capacity, mill characterization, fuel pipe velocities and distributions as well as mill air and particle flow evaluations.

The subject utility pulverizes sub-bituminous coal with vertical ball-and race mills with integrated static centrifugal classifiers. Hot primary air passes through a rotating throat where it entrains pulverized coal from the lower grinding race and carries it vertically into the classifier. Small coal particles remain entrained in air and exit the top of the classifier, while larger particles are rejected centrifugally before returning to the grinding zone for additional grinding. Typical fineness requirements for suspension firing of coal are 70% passing 200 mesh (74 m) and 98% passing 50 mesh (297 µm), and likewise the classifier and milling system is designed to achieve these levels.

This paper focuses on transport evaluation, namely the modeling and evaluation of the separate mill system components such as fuel pipes, mill and classifier.

MILL SYSTEM LIMITATIONS

Evaluation of the mill system led to the conclusion that mill capacity did not appear to be controlled by grinding or thermal limitations imposed by the wood pellet fuel, the mill itself or the PA system. Mill capacity was most likely controlled by transport limitations within the mill and fuel pipes. To study this in more detail CFD modeling of the mill and transport piping was undertaken. Since particle flow was of primary interest, an estimate of the wood particle size after grinding was needed.

The particle size of wood pellet fuels is primarily dependent on pre-pelletization processing of the constituent wood products (tree chips, wood residue, etc). The wood products are ground into a sawdust-like consistency with particle sizes ranging from ~0.1-4 mm before being pelletized. Laboratory testing using a bench-scale ball and race mill was performed on wood pellets to predict particle size reduction to be expected from the coal pulverizer.

Results indicated that the pulverizer will break the pellets down, but little reduction in particle size beyond the original (pre-pelletizing) particle size is expected. The pulverized pellets show only a slight decrease in particle size (see Figure 1) when compared to disintegrated pellet (disintegration involved soaking the pellets in water and then drying them to the moisture level of the original pellet).

The particles are approximately an order of magnitude larger in size than coal particles needed for coal combustion. Due to higher wood volatility and ease of combustion, these particle sizes have been shown acceptable for most suspension firing, but the classifier is not designed to allow particles this large to pass. Classifier rejection of large particles will result in excessive over-grinding of qualified wood particles, leading to unnecessary mill power consumption, pressure drop, and bottlenecking.

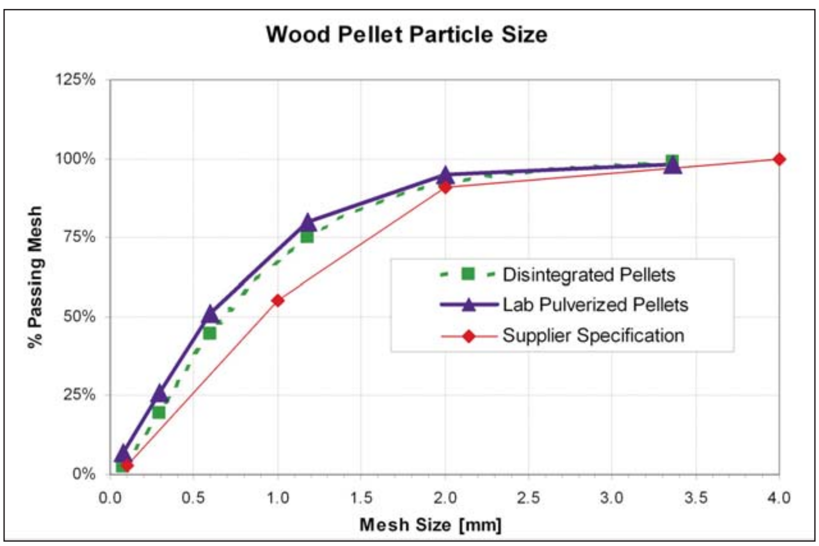

Figure 1. Typical Wood Pellet Particle Size Distribution

CFD ANALYSIS OF FUEL TRANSPORT LIMITATIONS

Computational fluid dynamics (CFD) modeling was conducted on the fuel pipes, mill, and classifier as three separate sub-projects. The three sub-projects of this analysis are briefly described below.

1. Fuel Pipe Transport Evaluation

Perform CFD modeling of a typical coal pipe arrangement from the pulverizer outlet to the burner inlet to improve understanding of air-particle mixture flows in terms of the primary airflow dynamics, wood particle concentrations and pressure drop.

2. Mill Air & Particle Flow Evaluation (No Classifier)

Perform CFD modeling of the mill to evaluate the flow distribution of air and particles inside the mill and pressure drop. This task is to study the mill air & particle path from mill inlet to outlet with the classifier removed entirely. The model shows discrete phase (particle) concentrations and predicts particle traces by different sizes.

3. Classifier-Only Evaluation

Perform CFD modeling of the existing static classifier, as a standalone unit using simplified boundary conditions. Evaluate operation/performance on pulverized wood pellet fuel. The classifier model also includes the upper part of the mill that connects with the classifier. The air/particle inlet plane is located inside the mill and the model outlets are the same with the mill air & particle model.

1. Fuel Pipe CFD Modeling

A full-scale 3-D fuel piping system configuration from the mill to the burner was simulated in the CFD model as shown in Figure 2. The model of this fuel piping system includes three major parts. The first component is a 28" main fuel pipe which runs from one outlet of the mill to a 4-way venturi distributor as the second component. The 4-way venturi distributor connects the main fuel pipe to the third component consisting of four 14" secondary fuel pipes, which terminate at four burner heads. CFD operating conditions of this fuel pipe model are listed in Table 1.

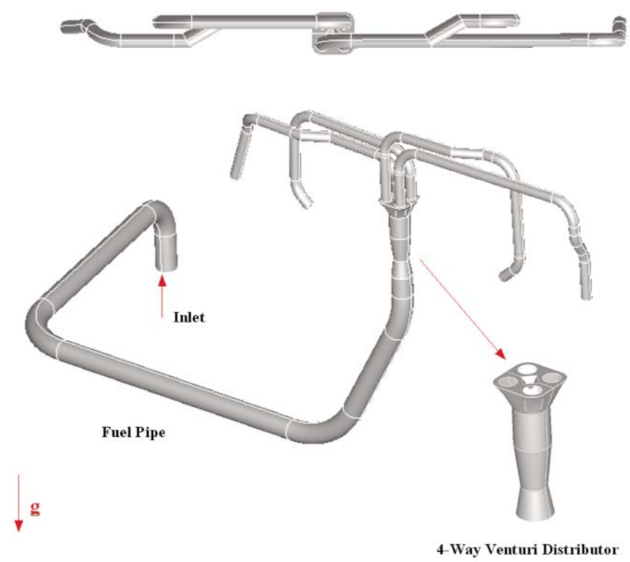

Figure 2. Fuel Pipe Geometry

Table 1

Operating Conditions for the Fuel Pipe Simulations

Parameters	Units	Value
Air Flow Rate	lb/hr	76,582
Wood Particle Flow Rate	lb/hr	35,277
Wood Particle Size Range	mm	0.05 ~ 3.0
Pressure @ Outlets	iwg	10

Model Results

Figures 3 and 4 illustrate the magnitude of primary air velocity and wood particle concentration at the center cross-sectional plane of the fuel pipe and the four secondary fuel pipe outlets, respectively. Primary air is uniformly introduced through the model inlet, but is quickly disturbed before and after every turn with local maximum and minimum velocities present at each bend. The velocity profiles and particle concentrations at the four outlet planes clearly show that both the primary air and wood particles are unevenly distributed into the four secondary fuel pipes. The average air velocity at outlet-1 is the lowest of the four pipes but has the highest wood particle concentration, which indicates pipe-to-pipe imbalance. An uneven distribution of fuel particles at each fuel pipe outlet at the burner as observed in Figure 4 is a potential limiting factor for reductions in the CO and NO_x emissions[2, 3].

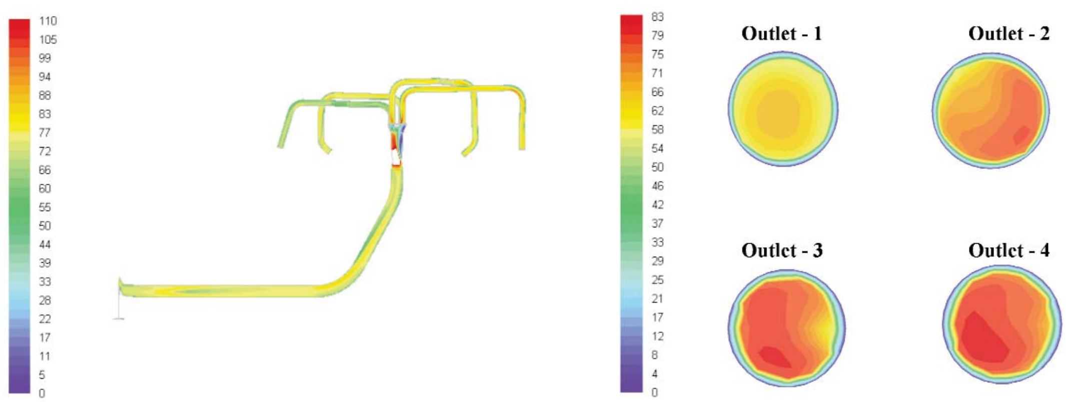

Figure 3. Velocity Magnitude Contours of the Fuel Pipe (ft/s)

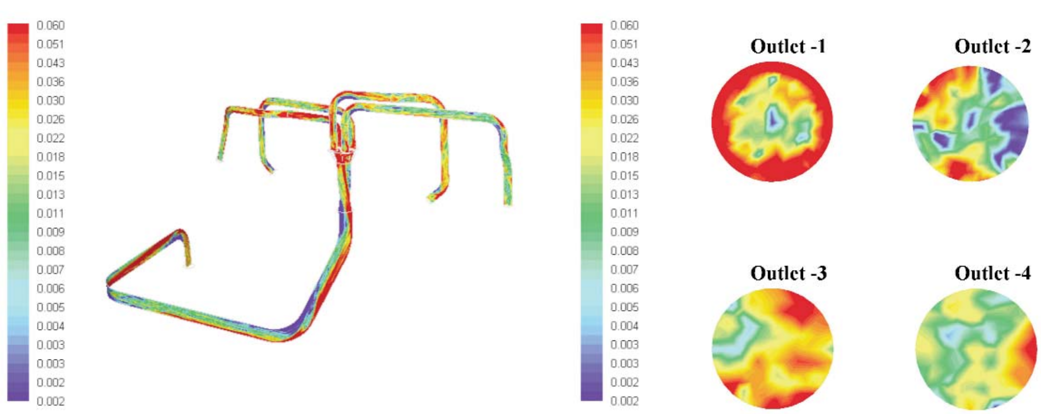

Figure 4. Wood Particle Concentration of the Fuel Pipe (lb/ft³)

Table 2

Distribution of Air and Particle Flows at Fuel Pipe Outlets

Flow Uniformity of Air & Fuel	Units	Outlet - 1	Outlet - 2	Outlet - 3	Outlet - 4
Air Flow Rate	lb/s	4.65	5.42	5.54	5.66
Deviation from Average	%	-12.6	1.9	4.2	6.4
Wood Particle Flow Rate	lb/s	5.3	1.4	2.8	1.5
Deviation from Average	%	93	-49	2	-46

The deviation of air and particle flows at model outlets is presented in Table 2. Airflow distribution between the pipes is relatively even with the exception of the secondary fuel pipe-1, which is 12.6% lower than average and particle throughput is 93% higher than average in this pipe.

Due to the centrifugal forces provided by a bend, the wood particles flow towards to the outer wall of the bend and form a dense particle flow referred to as a “rope”. Figure 5 clearly shows a close-up view of the rope-like particle paths in the 4-way venturi distributor and the end parts of the secondary fuel pipes corresponding to outlets 3 and 4, respectively. The venturi distributor did not eliminate dense flow but directed the rope across to the opposite side, where it impacts the top of the distributor off-center, resulting in very fuel-heavy pipes. In addition, the presence of the venturi distributor contributes 43% to the pressure drop of the entire fuel piping system. Based on these results, it was concluded that the 4-way venturi distributor has poor performance in the turbulent aerodynamics and fuel particles transport, leading to the pipe-to-pipe imbalances and uneven fuel particle distributions entering the burners and the furnace.

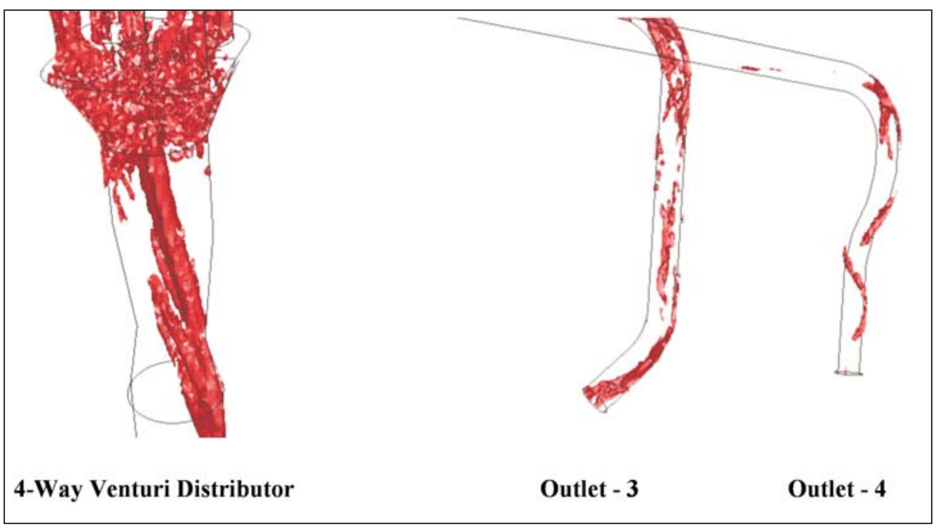

Figure 5. Close-up View of Wood Particle Flows (lb/ft^3)

2. Mill Air & Particle Flow CFD Modeling (No Classifier)

For the second application, a 3-D mill model was created with the internal classifier removed as shown in Figure 6. For this model, spherical wood particles are released from an imaginary plane just above the mill throat to simulate the actual pulverized wood particles coming out from the layer between the pulverizer ball and grinding table. Primary air is uniformly introduced through two primary air (PA) inlets at the base of the mill. The primary air flows around the grinding table and then up through the mill throat, which consists of 24 inclined open channels and a 0.5” gap. The air carrying wood particles is discharged out of the mill through two outlets at the top of the mill.

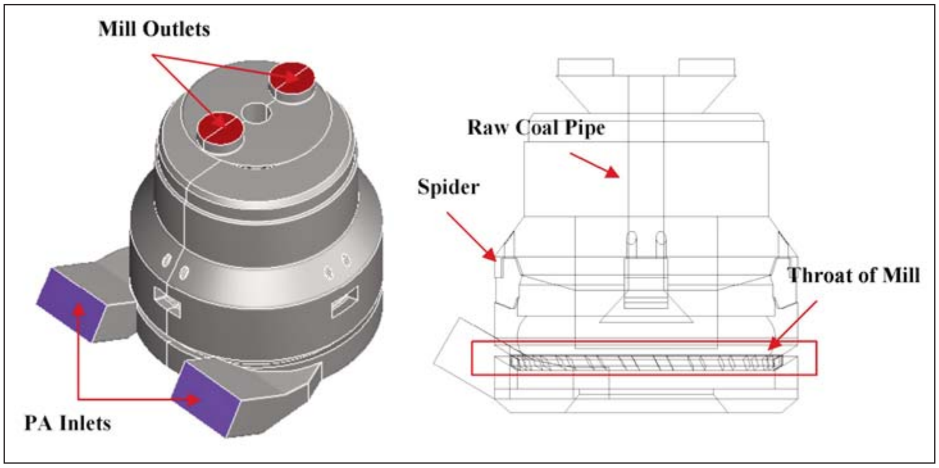

Figure 6. Model of Mill Air & Particle Path

The discharge pipes and all other classifier components have been removed from the model, leaving a completely free space from the grinding section to the discharge turret. The raw coal pipe and its reject cone were left in place. Typical operating parameters used in the CFD simulation of the two-phase mixture are listed in Table 3. For consistency purposes, the same values were also used for the classifier-only model. The particle size distribution (0.05 mm — 6.8 mm) for fuel particles takes into account the effect of un-crushed wood pellets mixing with the primary air above the mill throat.

Table 3

Overall Operating Conditions for the Mill Simulations

Parameters	Units	Value
Air Flow Rate	lb/hr	189,900
Wood Particle Flow Rate	lb/hr	94,952
Wood Particle Size Range	mm	0.05 ~ 6.80
Pressure @ Outlets	iwg	45.7

Model Results

Figures 7 and 8 illustrate contours of air velocity magnitude and particle concentrations at different vertical and horizontal cross-sectional planes (Sections 1, 2, 3, 4 and 5). Areas colored in white and surrounded by red represent areas of the velocity magnitude or particle concentration outside the selected maximum range as shown by the color map on the left of the figure. The air velocity below the grinding table (see section 2) opposite the air inlets is very low, indicating that the air from both PA inlets meets at this location and stagnates. Above the throat, high velocity jets can be observed exiting the throat openings and the small gap described earlier. As expected, the air is well distributed by the throat with relatively uniform air velocity coming through each opening or gap in the throat. As a result of the air velocity change, the pressure drop across the mill throat and gap is approximately 11 inches of water. The velocity of air entering the center area of the mill quickly decreases and stagnates at the wall along the top-grinding race, all the way to the bottom.

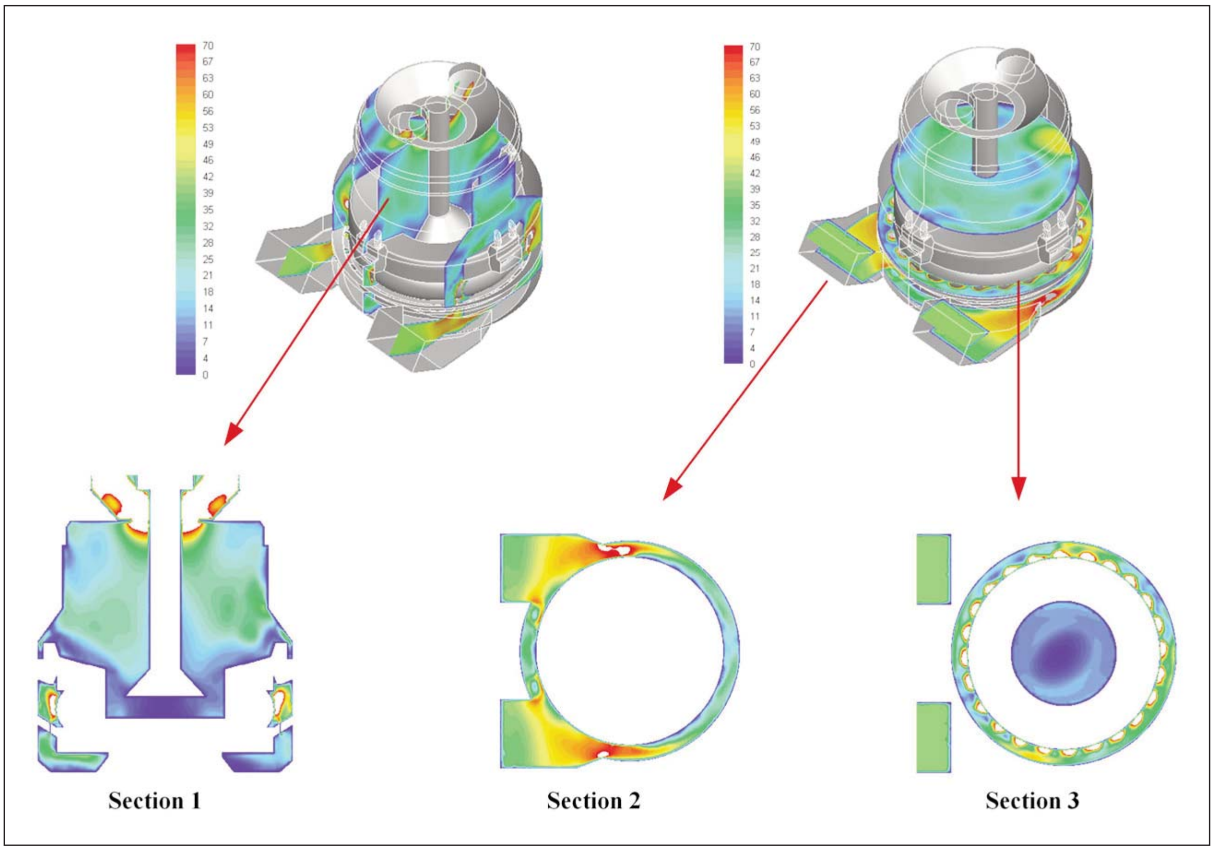

Figure 7. Contours of Velocity at Different Sectional Planes (ft/s)

Figure 8 shows the concentration of wood particles throughout the mill during steady-state mill operation. Section 4 is the center cross-sectional plane of the mill and Section 5 is considered to be the position of the annulus inlet for the third application, classifier modeling. Flows in Section 4 and Section 5 indicate that the fine particles follow the rotational path of the air emanating from the mill throat, while coarse and uncrushed particles fall back into the grinding area from the perimeter of the mill to be rejected at the bottom wall of the grinding zone. As illustrated in Section 4, by comparison to the center area of the mill, particle concentration in the mill discharge turret area is low, which means a large portion of the wood particles could not be transported to the mill outlets by air. Instead, the particles aggregate in the center portion of the mill or return to the grinding zone, a phenomena that can cause mill congestion. Particle traces shown in Figure 9 provide more insight into the fuel flows inside the mill.

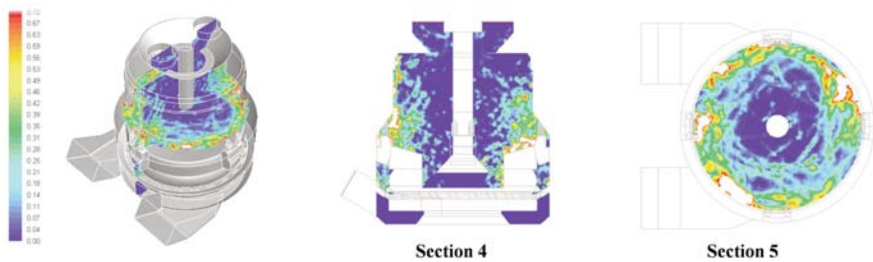

Figure 8. Particle Concentration at Different Sectional Planes (lb/ft^3)

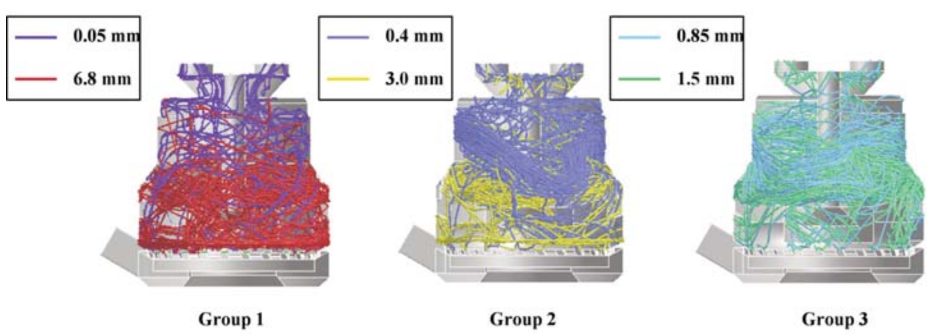

Figure 9. Mill Particle Traces Colored by Size (mm)

For clarity, particle traces in Figure 9 are presented in three different groups (Group 1, 2 and 3) with different wood particle sizes and only a portion of particle traces is selected for each group to represent the simulation results. As shown in Group 1, the finest wood particles (0.05 mm) are easily transported to the mill outlets with limited rotation and circulation. The uncrushed wood particles (6.8 mm) circulating in the lower portion of the mill or stagnating above the throat could not be transported out of the mill. In Group 2, most of the 0.4 mm wood particles rotate and circulate in the upper portion of the mill before exiting the mill. The coarse wood particles (3 mm) behave like the 6.8 mm wood particles, but a small fraction of this size particle is transported out of the mill by the primary air. Group 3 shows particle traces of two different sizes: 0.85 mm and 1.5 mm.

The air distributed by the mill throat reaches a velocity high enough to convey both of these two particle sizes above the lower portion of the mill with limited rotation and circulation. Then, these particles start to drop out of the conveying air, circulate in the upper portion of the mill and fall back to the grinding zone in a similar way. A small fraction of the particles eventually exits the mill after they enter the discharge turret. Comparing the behavior of particles of different sizes demonstrates that the level at which the particles circulate in the mill decreases as the particle size increases. Similarly, the quantity of particles observed at the mill outlets is dependent on particle size. The 0.85 mm particles remain above the upper grinding race due to the high velocity air passing between the mill wall and the race. The 3.0 mm particles appear to exit the grinding area but are too large to be transported to the upper half of the mill.

3. Classifier Modeling

For the third sub-project, a 3-D model of the classifier was generated as shown in Figure 10. The as-built classifier model includes the upper part of the ball-and-race mill, fixed vanes at 45° from vertical, and adjustable vanes with an orientation of 30° counter-clockwise from the radial direction at fully open position. For simplicity, primary air and wood particles were uniformly and upwardly introduced through the annular inlet, at the same elevation of the Section 5 as shown in Figure 8. Primary air carrying a portion of wood particles is discharged out of the mill through the two (2) outlets at the top of the mill. The rest of wood particles are either released out of the classifier model from the annular inlet or the bottom wall of the classifier.

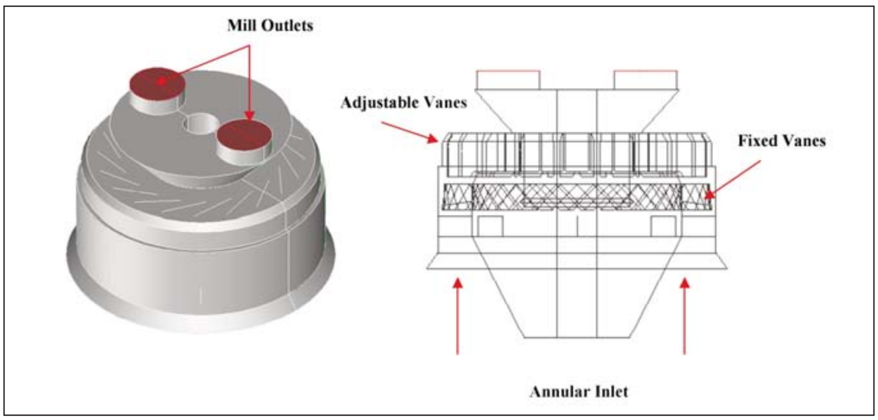

Figure 10. Classifier Model

Typical operating conditions used in the CFD modeling of the two-phase mixture for the classifier are listed in Table 4. For consistency, they are the same as the values used in the mill air & particle flow modeling.

Table 4

Overall Operating Conditions for the Classifier Simulations

Parameters	Units	Value
Air Flow Rate	lb/hr	189,900
Wood Particle Flow Rate	lb/hr	94,952
Wood Particle Size Range	mm	0.05 - 6.80
Pressure @ Outlets	iwg	45.7

Model Results

Figure 11 shows the velocity magnitudes at different cross sectional planes in the classifier. Primary air is uniformly introduced through the annular inlet in the classifier model. Air velocity in the mill discharge passageway can reach localized values greater than 130 ft/s but in most other locations in the mill is lower than 30 ft/s. Wood particle concentrations in two cross-sectional planes are shown in Figure 12. Wood particles are uniformly injected from an annular inlet. Large particle concentration above the annular inlet and the classifier bottom means a significant portion of the wood particles is rejected from either the annular inlet or the bottom of the classifier and only a small portion of particles were transported out of the mill by primary air. This is more clearly illustrated by the particle traces shown in Figure 13. The particle traces show typical transport paths of wood particles, colored by particle size.

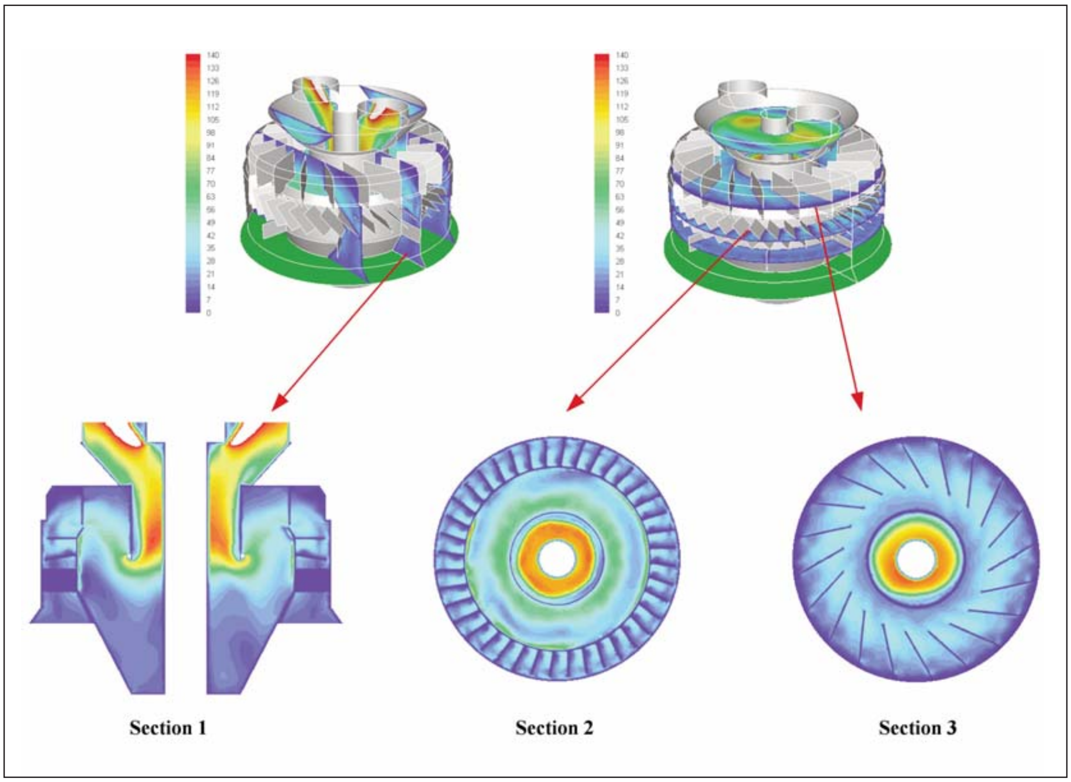

Figure 11. Contours of Velocity at Different Sectional Planes (ft/s)

For clarity, particle traces in Figure 13 are presented in three different groups (Group 1, 2 and 3) with different wood particle sizes and only a portion of particle traces are selected for each group to represent the simulation results. As shown in the three groups, primary air with low velocity entering the classifier model prevents particles greater than 1.5 mm from being carried into the classifier. These particles are directly rejected from the annular inlet and actually fall back into the lower part of the mill. Only the particles smaller than 0.4 mm can leave the classifier through the outlets of the mill. Almost all 0.85 mm wood particles fall back to the grinding area after entering the classifier section.

Comparing these results to the second sub-project particle traces shown in Figure 9, it can be seen that the 1.5 mm wood particles attain high velocities in the throat area and have enough momentum and adequate trajectories to be carried to the top of the mill and even transported out of the mill in some cases.

The CFD results of the classifier-only model indicate over-classification of the wood particles. A significant percentage of the wood particles are rejected by the classifier, forcing the grinding section of the mill to re-grind large quantities of wood, including qualified particles. Re-grinding increases mill power consumption and causes additional pressure drop in the mill as a result of the re-circulating particles. In contrast with the typical objective of increasing coal fineness in utility boilers, classification needs to be decreased to achieve acceptable performance from the pulverizers with wood pellets as the requirements for biomass particle and coal particle sizes are different[4].

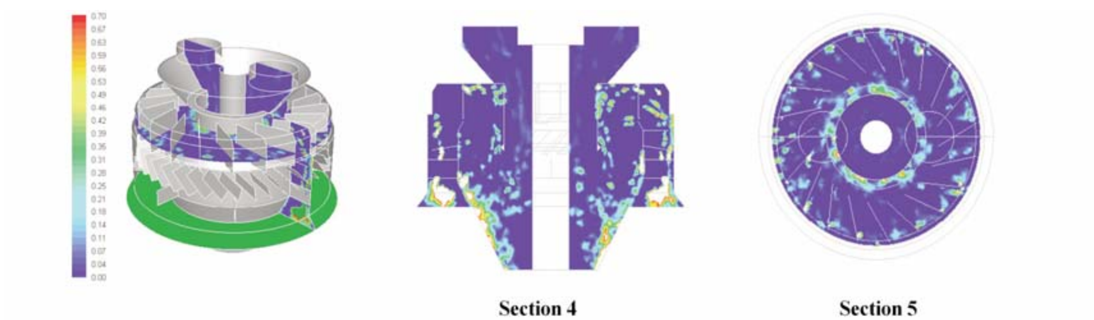

Figure 12. Particle Concentration at Different Sectional Planes (lb/ft^3)

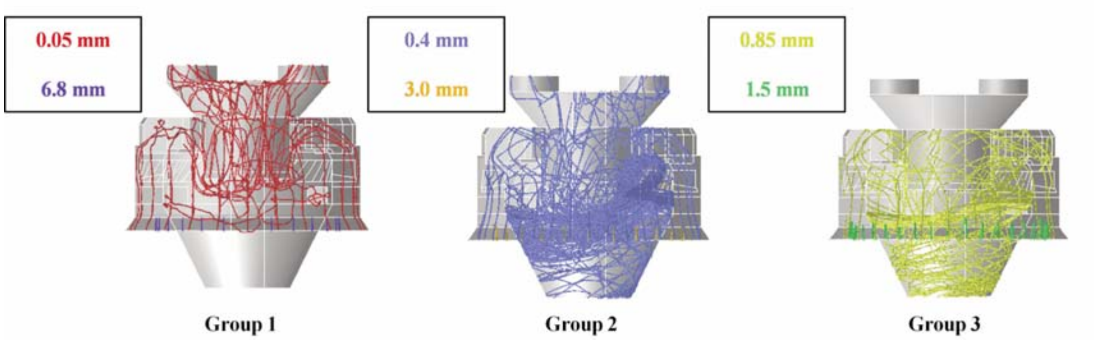

Figure 13. Classifier Particle Traces Colored by Size (mm)

CONCLUSIONS

In the fuel pipe transport model, the wood particles are effectively transported by primary air without significant circulation and deposition observed. However particles appear to mix poorly with air, with particle "roping" occurring in the fuel pipe. The venturi distributor produces very poor particle distribution between the four secondary fuel pipes and increases the pressure drop.

In the mill-only model (without classifier), high velocity primary air is well distributed through the mill throat but quickly decelerates as soon as it enters the large free flow area. Most particles smaller than 0.85 mm are transported out of the mill to the fuel pipe. A large portion of the wood particles greater than 1.5 mm falls back to the grinding zone. The absence of the classifier results in insufficient air velocity to transport the larger particles out of the mill. The undesired classification of the pulverized wood pellets will lead to over-grinding and reduced mill throughput. Reducing the mill flow area could increase the air velocity to a level suitable for transporting larger particles out of the mill.

In the third sub-project, the combination of centrifugal forces caused by the classifier vanes and the downward momentum of the particles eliminates most wood particles 0.85 mm and greater from the air path, causing them to be rejected back to the grinding section. Simulation results confirm that the classifier, originally designed for pulverized coal applications over-classifies qualified wood particles, leading to unnecessary re-grinding. It is recommended that the classifier is modified to increase the cut-size or removed altogether to eliminate classification. The second part of this project, however, indicates that classifier removal alone will not be satisfactory due to gravitational classification that occurs in the large open volume of the pulverizer with the classifier removed. Further CFD modeling is necessary to develop effective mill body modifications to accommodate this different fuel.

REFERENCES

1. Riley Power Inc. Internal Contract Report, December 18, 2009

2. Levy, A. , Mason, D. J., "The effect of a bend on the particle cross-section concentration and segregation in pneumatic conveying system," Powder technology 98 (1998), 95-103

3. Paulrud, S., Nilsson, C., "The effects of particle characteristics on emissions from burning wood fuel powder" Fuel 83 (2004), 813-821

4. Mroczek, K., "Analysis of Coal Mill Operation at Co-milling of Wood Biomass", Chemical and Process Engineering (2009) 30, 83-98