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PREDICTION OF DUST LOSS FROM CONVEYORS USING CFD MODELLING

Peter WITT, Ken CAREY and Tuan NGUYEN

CSIRO Minerals, Clayton, Victoria 3169, AUSTRALIA

ABSTRACT

Dust lift-off from conveyors forms a significant environmental and operational problem for operators in the mining, power generation and process industries. One means of reducing dust lift-off is to provide airflow deflectors or other aerodynamic modifications to the conveyor. A CFD model has been developed to take into account the effect of wind direction, velocity and conveyor guarding on the dust loss from conveyors. The model is developed in the framework of CFX-4. Experimental measurements of dust lift-off from the surface of a bed of ore in a wind tunnel at different wind velocities are used to characterise the dust. Based on the experimental data a model for predicting the mass and particle size distribution lifted from the bed surface at different air velocities is developed. The dust loss model is coupled to a Lagrangian particle-tracking model to predict particle trajectories. Validation of the model is undertaken by comparing CFD predictions against wind tunnel test work and shows good agreement. Results are presented for a typical conveyor design. The combination of experimental and CFD modelling is found to be a powerful tool for analysing dust loss from conveyors and can be extended to stockpiles and other situations where dust loss is a problem. The model can readily be extended to account for heat and moisture transfer in beds of porous materials.

NOMENCLATURE

D particle diameter [m]
F_A force due to gravity [N]
m mass of ore lifted-off [kg/m^2]
v_{crit} critical velocity at which dust lift-off will occur [m/s]
v velocity [m/s]

α parameter in Smitham and Nicol model.
β parameter in Smitham and Nicol model.
ρ gas density [kg/m^3]

INTRODUCTION

Conveyors are widely used in the mining, power generation and process industries for the transport of crushed particles from one location to another. Often conveyors have little or no guarding and particles from the belt surface can be entrained by air motion and be carried away from the conveyor. This dust loss has a number of detrimental effects including environmental concerns from nearby residents, a loss of product being transported and the dust can cause maintenance problems in bearings and other components of the conveyor system. Therefore, dust is an issue that contributes to increased maintenance and hygiene costs around materials handling equipment and living amenities. Loss of product from the belt can be of order 1.5% and can increase maintenance costs by up to 20%.

Smitham and Nicol (1991) built a wind tunnel and studied the amount of dust lift-off from coal stockpiles as a function of velocity, particle size and moisture content. Their work demonstrated a strong dependence on the mass of coal lost from the coal bed with sample moisture content and wind velocity. Smitham and Nicol (1991) investigated the mechanisms of dust lift off and derived a simple model to describe the phenomena.

In the present work an experimental program is undertaken to characterise an ore sample and thus obtain data to calibrate the dust lift-off model proposed by Smitham and Nicol (1991). The dust lift-off model is then incorporated in a CFD model. This CFD model is then used to investigate the air flow and dust lift-off around a bed of particles on a conveyor belt.

EXPERIMENTAL WORK

The wind tunnel facility at CSIRO Minerals was modified by adding a baghouse to trap fines and dust lifted from the surface of test material by the air stream. A 1.1kW extraction fan was used to overcome the pressure drop across the filter medium. A false ceiling for the tunnel was used in conjunction with combinations of the blower and extraction fan to provide a range of air velocities over the test area. The nominal cross section of the tunnel was 650 mm width and 380 mm height, but this reduced to 255 mm with the false ceiling inserted for high velocity runs. The main section of the tunnel was used for this work, measuring some 6 m in length. The downstream section of the tunnel was ducted directly into a 1.2 m x 1.2 m x 1.8 m high baghouse. A diagram of the overall layout is shown in Figure 1.

A material sample tray measuring 480 mm long x 400 mm wide and 10mm deep, supported a 8 mm thick section of conveyor belt. The tray was pivoted at the centre to allow rotation through 360°. As a benchmark for CFD modelling, the majority of tests were conducted in a flat bed configuration. To investigate the effects under plant conditions, a trough (scaled down from the full size dimensions) was made up to simulate the incline of the conveyor belt rollers and fitted within the sample tray. A piece of conveyor belt was then fitted to the trough so that material could be loaded to the desired plant profile.

Using the flat bed configuration, horizontal velocities for each of the three selected inlet velocities were measured using a pitot tube. This velocity information was used in development of the dust lift-off model. A minimum duration time for each wind tunnel test was set at 15 mins,

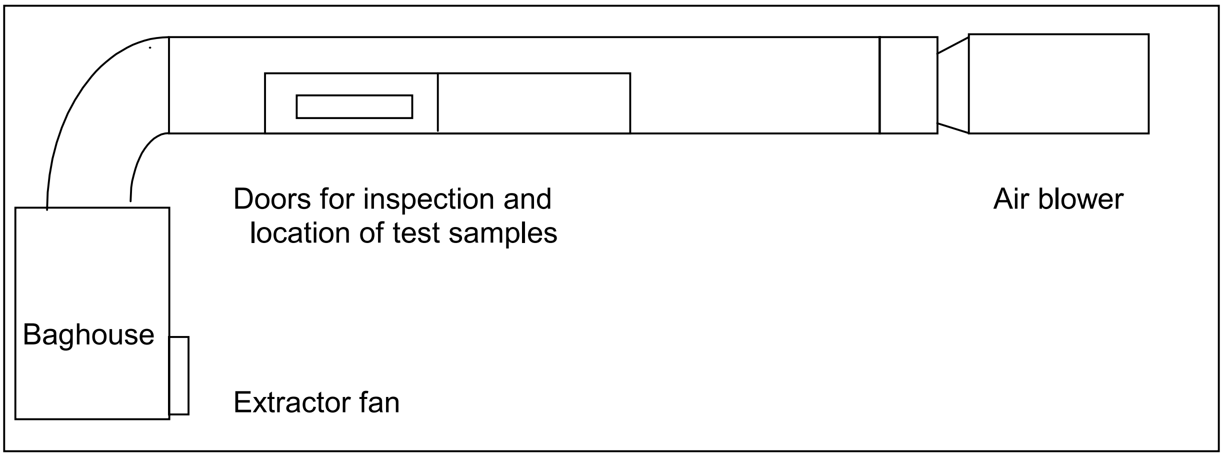

Figure 1 Overall layout of the wind tunnel and collection system.

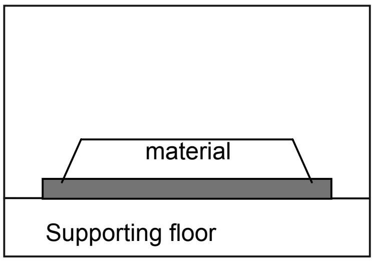

Figure 2 Flat bed configuration in wind tunnel.

which is a typical time required for material on large industrial conveying systems to travel the length of the conveyor. This time can be important due to local surface drying of the ore and can significantly alter the dust loss behaviour of the ore.

Effect of Wind Velocity

Using 10kg samples 15-minute tests were carried out under the three different tunnel velocities. Dust and fines collected in the tunnel ductwork were swept into the baghouse filters under suction of the extractor fan. The moisture loss from the material during each test was also determined. The velocities shown in Table 1 are average velocities calculated from the measured velocity profiles. The size distributions of dust and fines collected from each test were measured using a Malvern Mastersizer and recorded for use in the model development. Ore specific gravity was determined to be 4.34 by pycnometry.

Velocity [km/hr]	Total Dust Lifted Off [g]	Average Particle Size [mm]	Final Material Moisture [%]
22.2	2.2	0.29	6.6
26.5	7.4	0.49	6.3
48.3	33.4	0.64	6.2

Table 1 Effect of wind velocity on the mass of material lifted off the test bed.

Dust lift off was not visible during the time of each test (as commonly depicted by dust clouds). At the end of each test, only the surface material, perhaps 1-2 mm, was dry while the bulk of the material retained its moisture. The final material moisture content was determined by oven-drying the whole sample.

CFD MODELLING WORK

Air flow around the conveyor structure, belt, ore and guarding is complex and cannot be determined from analytic models.

Model Description

The model is based on solving the time averaged Navier-Stokes equations for the air flow and a Lagrangian particle tracking method to track dust particle motion. Turbulent fluctuations in the airflow are accounted for by the inclusion of the standard k-ε turbulence model of Launder and Sharma, (1977). The equations are solved on a co-located body fitted grid using the Rhie and Chow (1983) interpolation procedure to avoid chequerboard oscillations in the flow field variables and a modified form of the SIMPLE algorithm for pressure-velocity coupling described by Patankar, (1983). The commercial CFD code CFX4 (CFX, 1995) is used to solve the equations for the air flow and particle motion around the conveyor system.

To predict the mass of particle lost from the ore bed by airflow over the ore bed required modification of the particle tracking routines to allow prediction of the mass flow rate of particles lifted-off based on the local air velocity. Smitham and Nicol (1991) analysed coal dust loss from a fixed bed in a wind tunnel. By considering the drag force from the air velocity as being the main driving force for particle lift-off and neglecting the neighbouring particles they obtained the following equation for the minimum air velocity, v_{crit}, at which dust lift-off will occur;

$$v_{crit} = \sqrt{\frac{\tan(\beta)F_A}{3\pi\alpha\rho D^2}} \quad (1)$$

where β =30º, α=√3/2, ρ is gas density, D particle diameter and F_A the gravitational force.

Combining the minimum lift-off velocity calculated from equation (1) with the particle mass loss data collected from the experimental work at three different air velocities a simple relationship for mass loss with air velocity can be derived. To limit the number of particle sizes used in the model the experimental particle size information was collected to form six size distributions. For each of the six particle sizes a quadratic curve was fitted to the experimental velocity points and the minimum lift-off velocity to obtain the equations in Table 2 relating air velocity to mass lift-off from the ore surface.

Particle Size Range	
<60μm	$m = 0.00006v^2 - 0.0002v + 0.0001$
60-130μm	$m = 0.00009v^2 - 0.0004v + 0.0002$
130-250μm	$m = 0.0001v^2 - 0.0003v + 0.0002$
250-500μm	$m = 0.0002v^2 - 0.0011v + 0.0014$
500μm-2mm	$m = 0.0002v^2 - 0.0019v + 0.0039$
>2mm	$m = 0.00004v^2 - 0.0002v - 0.0003$

Table 2 Relationships between air velocity and particle mass lift-off for various particle diameters.

In the model two particle sizes are used to represent each of the six size ranges. The relative mass flow rate of each particle size range is determined by the initial particle size distribution of the ore sample.

The experimental work indicates that dust lift-off is strongly dependent on moisture content of the ore. In future it would be possible to include heat and mass transfer in the model, which would allow the effect of moisture and drying of the porous ore bed to be included.

Model Validation

To validate the model, the geometry of the CSIRO wind tunnel with and without the false roof for a flat bed of fines was set up in CFX. The grid used for the simulation was 16 cells across, 26 cells high and 91 cells along the length of the tunnel. The model was run for the three tunnel velocities investigated experimentally with 10kg of bed material. A total of 40 starting locations for the particles gave adequate resolution.

For the high velocity case Figure 3 shows the general layout of the wind tunnel in the area near the ore sample and a plot of gas velocity vectors along the centre of the tunnel. The ore bed is the located at the rear of the reduced area section and is colored in red. A recirculation region behind the ore bed is evident due to the rapid expansion of the wind tunnel cross section. Figure 4 shows the predicted particle trajectories again for the high velocity case. The experimental and predicted mass loss values are compared in Figure 5 and shows reasonable agreement. Note that the predicted values are calibrated using the total mass loss value for the high velocity case.

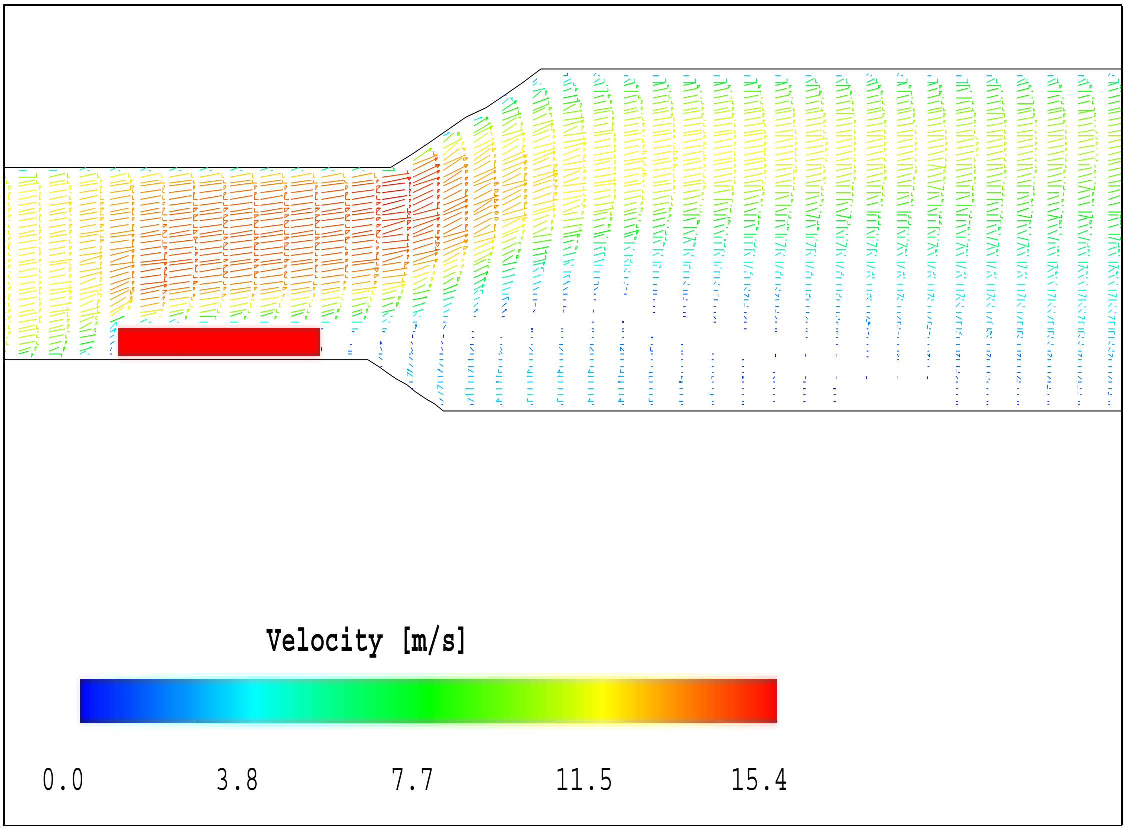

Figure 3 Predicted velocity vectors for the high velocity case.

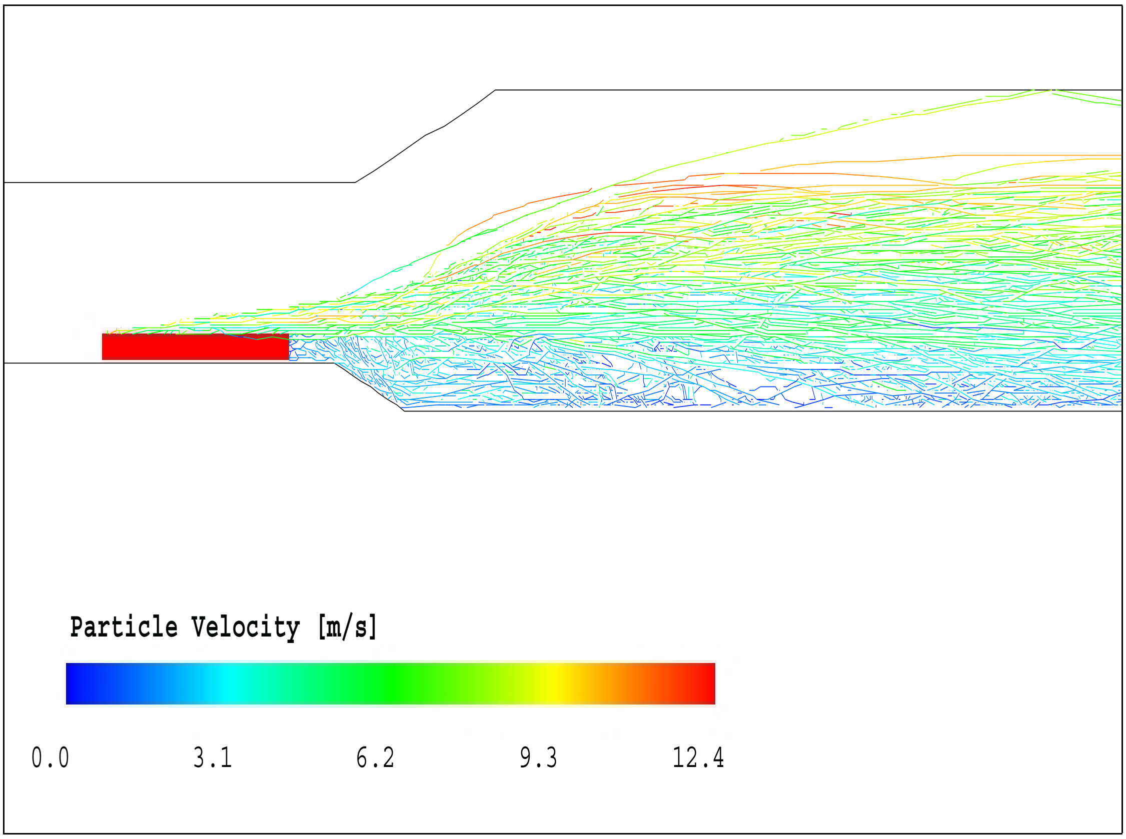

Figure 4 Predicted particle trajectories for the high velocity case.

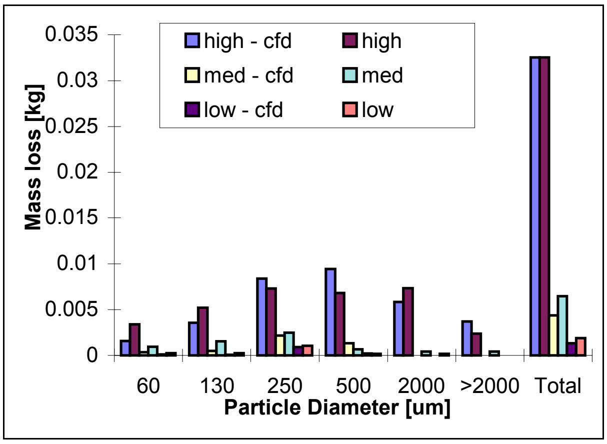

Figure 5 Comparison of predicted and experimental mass loss results for a flat bed at three air velocities.

Analysis of a typical conveyor system

To study the dust behaviour of a conveyor system the geometry for two sets of rollers were generated using CFX-MESHBUILD. Included in the geometry are the conveyor belt, return belt, rollers, and support structure. Shape of the ore profile on the conveyor belt is based on discharge angle data for material being feed on to the conveyor. Also included in the geometry is a typical wind deflector design. To represent the geometry including upstream and downstream areas of the flow domain 142500 cells are required. To account for the belt movement a velocity of 3.8m/s is set on the ore surface. A uniform air velocity is set at the model inlet. For a solution independent of the number of particles, 80 starting locations were used. The use of periodic boundary conditions allows different wind directions to be accounted for. Figure 6 shows the physical layout of the section of the conveyor modelled with plate type wind deflectors in place.

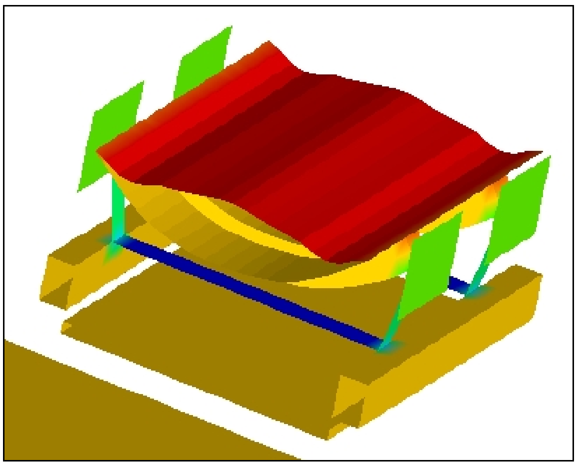

Figure 6 Geometry setup for a typical conveyor design.

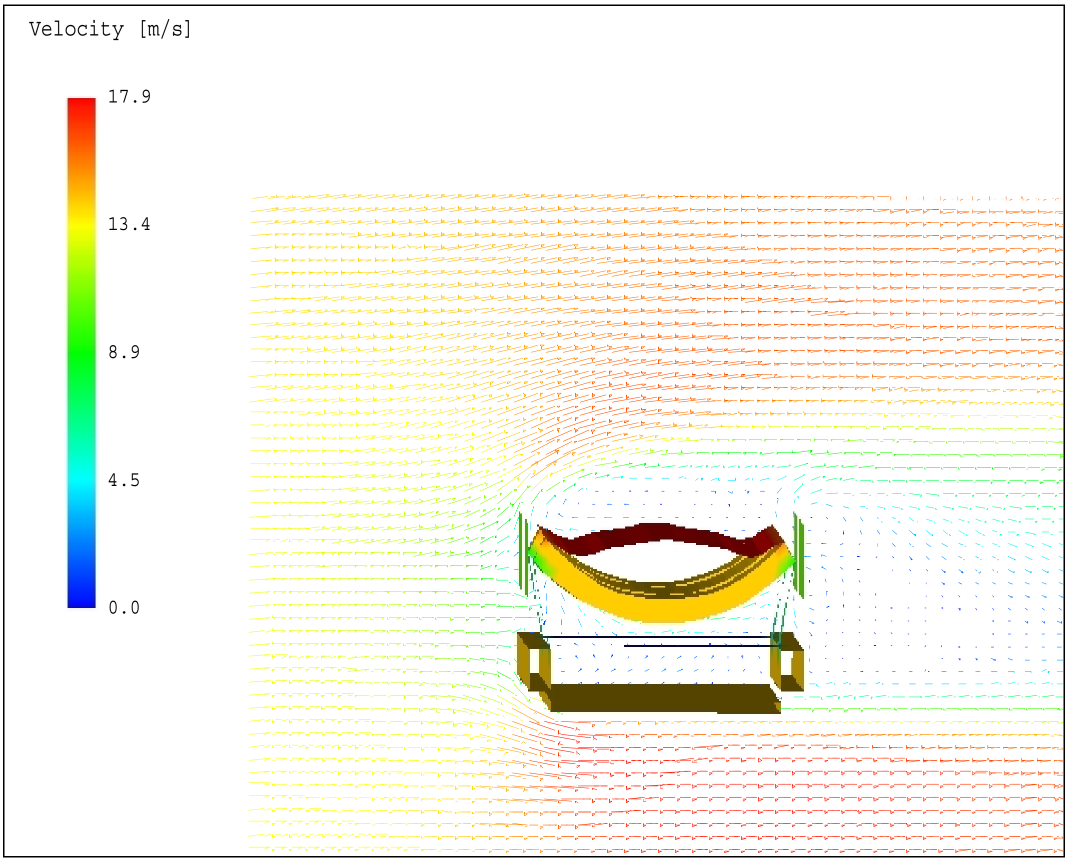

Figure 7 Predicted Velocity Vectors with plate type wind deflectors.

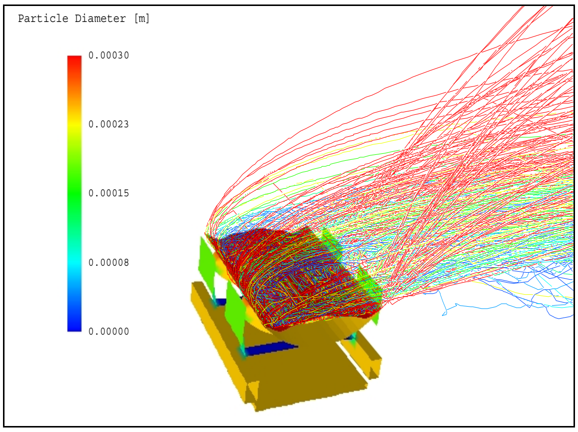

Figure 8 Predicted particle trajectories with plate type wind deflectors.

Effect of Wind Speed and Direction

For the geometry shown in Figure 6 the model was run with a wind velocity of 13.9m/s which corresponds to a wind speed of 50km/hr. This value was chosen being the upper wind speed for which the conveyor line is likely to experience. More typical wind speeds fall into the 11-20km/hr range but as this study is interested in the worst case the higher value is used. Wind direction varies depending on the time of year and prevailing conditions. To determine the ability of the model to account for variations in wind direction and speed the model was run for 50 and 37.5km/hr with the wind direction normal to the conveyor line. The effect of wind direction was assessed at the higher wind speed by altering the wind direction 45° either side of the normal direction and 32° towards downward end of the conveyor. A summary of the predicted dust loss and particle size information is given in Table 3.

Particle Size [μm]	37.5 [km/hr] Angle 0°	50 [km/hr] Angle 0°	Angle 45°	Angle -45°	Angle 32°
<60	0.3	0.6	1.2	1.1	1.1
60-130	0.9	2.0	3.2	2.1	2.6
130-250	1.5	3.3	6.8	5.0	5.5
250-500	0.9	2.6	9.6	6.1	6.9
500-2000	2.4	6.9	6.6	2.7	4.5
>2000	0.5	2.2	2.2	1.5	1.4
Total	6.5	1.8	29.6	18.4	22.0

Table 3 Predicted Dust Loss Values for Current Design **.**

The model results predict a 63% reduction in dust loss when the wind speed is reduced by 25%. This is consistent with the experimental work performed in the wind tunnel. Also shown by the results is the effect of wind direction on dust loss. With the wind perpendicular to the conveyor the current design is most effective, with changes in wind direction resulting in some increase in dust loss due to a reduction in wind shadowing by the deflectors.

Effect of Ore Profile

Two profiles for ore on the conveyor belt were assessed and the dust loss values are compared in Table 4. The raised profile is a typical ore profile and the flat profile is obtained by maintaining the same ore volume on the belt but using a simple flat profile. The results indicate that flattening the ore profile would slightly increase the dust loss.

Particle Size [µm]	Std. Profile	Flat Bed Profile
<60	0.60	0.85
60-130	1.95	2.04
130-250	3.27	5.04
250-500	2.58	3.62
500-2000	6.88	8.42
>2000	2.22	2.77
Total	17.50	22.74

Table 4 Effect of Ore Profile on Dust Loss for Plate Design wind deflectors and a wind speed of 50km/hr.

CONCLUSION

A wind tunnel was used enable dust lifted from the surface of an ore bed to be measured. A number of tests were carried out to investigate the dust lift off characteristics of three ore samples at different wind velocities, directions and belt profiles.

A CFD model was developed using CFX4 to simulate the airflow around the conveyor with dust particle motion being simulated using a Lagrangian particle tracking technique. A dust lift-off model based on experimental data was developed to couple the dust loss to the local airflow. Validation of the CFD model was undertaken by simulating the wind tunnel test work and showed good agreement.

The CFD model was used to study airflow around a typical conveyor geometry at various operating conditions. The model can be used to investigate different wind deflector designs to determine which design would reduce the dust loss from the conveyor system. The model can readily be extended to account for heat and moisture transfer in beds of porous materials.

This work demonstrated that the combination of experimental and CFD modelling is a powerful tool for analysing problems of this nature.

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