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A novel dopant for improved safety and performance in wet scrubbing of coal mining operations

ABSTRACT: Respirable dust is a common environmental hazard caused during many mining operations. Wet Scrubbing is a well-known and established method of removing airborne dust and is commonly utilized in many different mines. The introduction of novel doping additives based on safe ionic liquid technology is demonstrated to achieve greater reduction of the respirable dust when compared to water alone.

The CDC scrubber provides effective knockdown of coal dust produced at the CM; testing indicated that significant increases in respirable dust were released. This prompted research into solutions to reduce this respirable dust and the exposure to the operators/staff at the mine face. The research outcome is an improvement of wet scrubber performance. This improvement can be seen by increases in the beta (β) with resultant dust removal for 1μm sized coal dust at 15lpm water feed rate. The results and potential advantages of the doping of wet scrubbers will be discussed, with focus particularly on the advantages of greater dust removal (for improved safety or increased mining activity at same dust levels) or for the potential to reduce water consumption significantly while using a modest dosage of 0.1% by mass in the water feed.

1 INTRODUCTION

"*Respirable dust, with particle diameter ≤ 10 μm, has the capability to penetrate beyond the terminal bronchioles and become deeply embedded in human lungs, leading to respiratory disease complications.*"

Further, *"Float coal dust is defined as coal dust with particle diameter ≤ 74 μm… with a proper mix of methane gas… and an ignition source"*[1] may lead to explosions.

Previous studies have shown that float coal dust reduction is possible using wet scrubbing[2].

The company CDC undertook some early research to quantify the effectiveness of wet scrubbing to remove respirable dust. As no data could be found on the effectiveness of respirable dust reduction by a wet scrubber, a sensor using the principle of laser scattering was employed to measure both mass concentration of particles and number concentration of particles upstream and downstream of a wet Fan Scrubber Box designed to reduce aerosolized particulate matter emanating from coal mining operations.

The measurement range of interest is particles with diameters:

0.3 < ø <= 0.5 μm [designated PM0.5]
0.3 < ø <= 1.0 μm [designated PM1.0]
0.3 < ø <= 2.5 μm [designated PM2.5]
0.3 < ø <= 4.0 μm [designated PM4]
0.3 < ø <= 10.0 μm [designated PM10]

As with conventional multicyclone gravimetric aerodynamic sizing of dust, each sampling bin of larger diameter necessarily includes all diameters smaller than its associated designation.

1.1 *What is efficiency of scrubbing/filtration*

The efficiency of a filtration system is determined from a value defined as beta (β) which is the ratio of incoming mass to outgoing mass. This can also be defined as how many particles enter the filtration media for one particle to leave:

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$$\beta = \frac{m_i}{m_o} \tag{1.1}$$

Where m_i = mass entering the filtration media and m_o = mass leaving the filtration media. This implies that a β value of 2 means that 2 particles enter, and 1 particle leaves the filtration media.

Efficiency eta (η) can now be calculated in the following manner (related to the β value):

$$\eta = \frac{m_i - m_o}{m_i} = 1 - \frac{1}{\beta} \tag{1.2}$$

Using the case of β = 2 this implies an efficiency η of 50%.

1.2 *What does a CDC Wet Scrubber look like.*

A wet scrubber [Fanbox X1763] was attached to a F1061 Fan as diagrammed below.

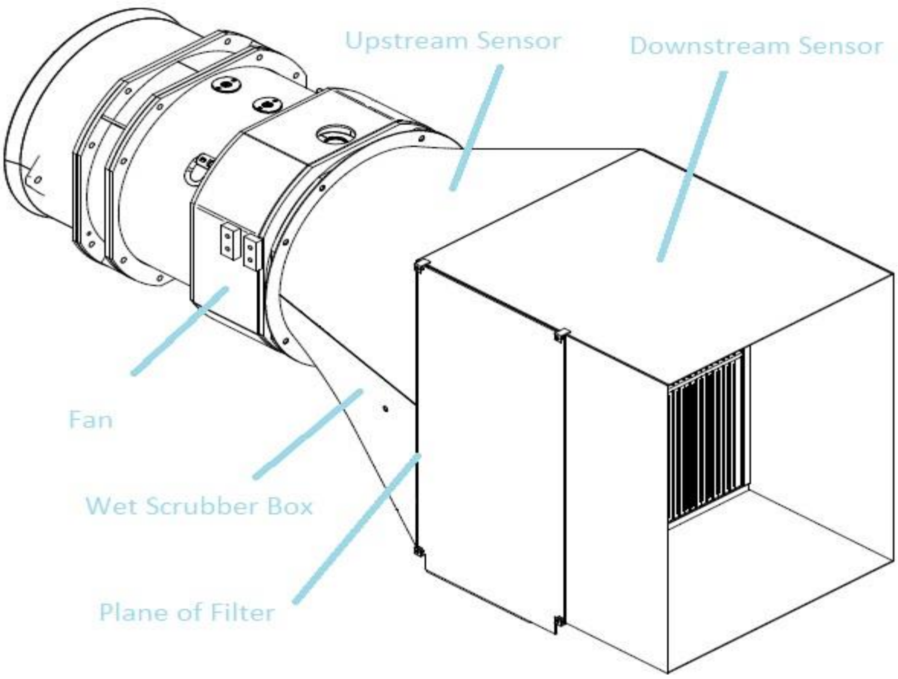

Figure 1: CDC wet scrubber layout

Air flow was verified to be symmetrical, with a measured Average Corrected Velocity of 23.4 m/s, and a Volume Flow of 14,1 m^3/s.

As airflow was symmetrical, sensors were placed on the centerline of the assembly, top dead center, on the inside of the assembly, as indicated above. This to restrict full submersion of the sensor in run-off water.

The sensing orifice of sensors were pointed in a downwind direction, so as to prevent fouling of the sensing orifice. Sensors Mass Concentration precision were verified to be within device-to-device variation of ±10µg/m^3 for PM1 and PM2.5, and ±25 µg/m^3 for PM4 and PM10, for Mass Concentrations up to 100 µg/m^3. Precision verified to be within 10% of measured value for larger Mass Concentrations.

Likewise, sensors Count Concentration precision were verified to be within device-to-device variation of ±100 counts/cm^3 for PM1 and PM2.5, and ±250 counts/cm3 for PM4 and PM10, for Count Concentrations up to 1000 counts/cm^3. Precision verified to be within 10% of measured value for larger count concentrations.

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1.3 *Efficiency and CDC wet scrubber*

Initial trials showed that the wet scrubber was effective for a great majority of coal particles above 4um in the float coal size range.

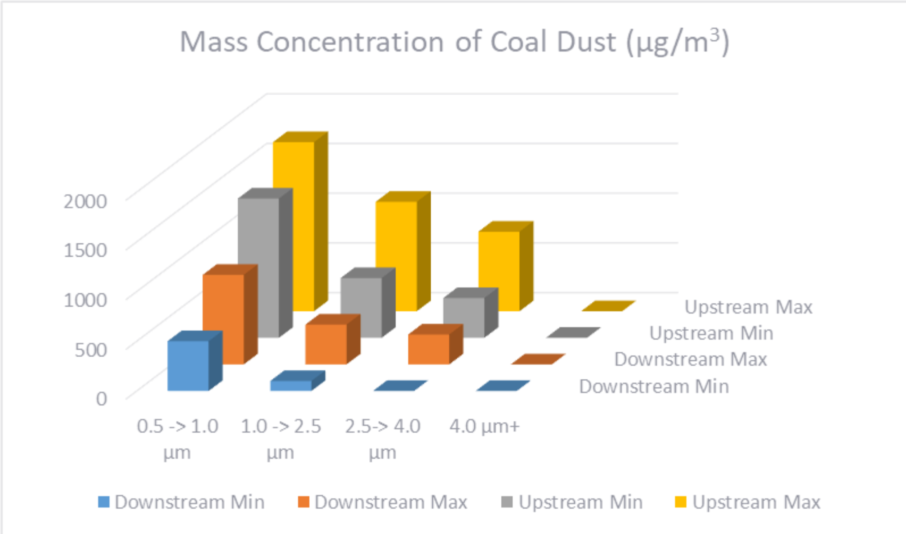

Figure 2: Particulate counts of normal CDC wet scrubber operation

The efficiency of the scrubbing in the lower ranges of 0.3 to 10um was found to have eta η values as per the following bar graph. The values are calculated as a minimum and a maximum value as recorded by the particle sensor used in this analysis.

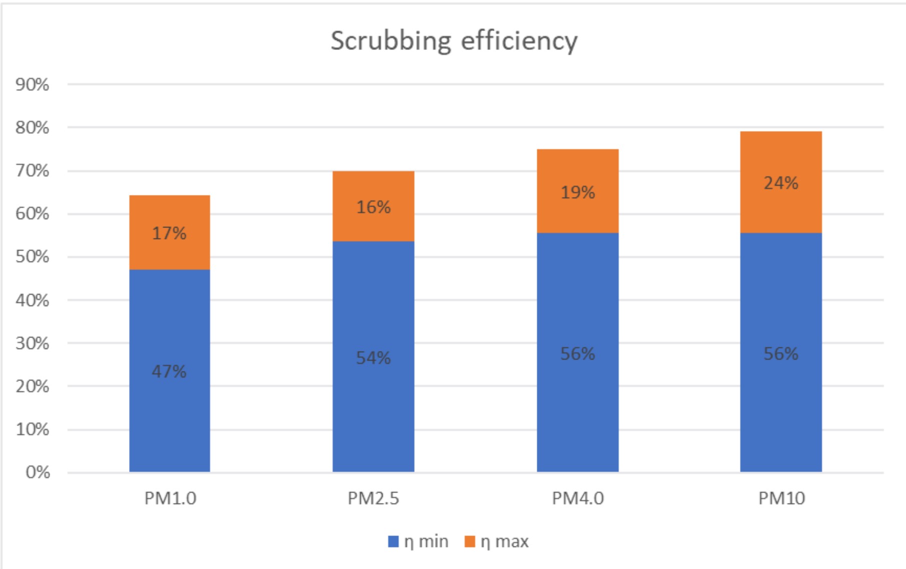

Figure 3: The efficiency of the wet scrubber showing range of results during operation

The efficiency eta of the wet scrubber for coal dust of this fine size was varying according to the particle size and was at its lowest for the smallest sized particulate material.

These testing results inspired the addition of a sensor at the neck position of the wet scrubber (to observe actual dry coal entering the system) and more advanced methods of data analysis in real time of the coal particulate matter.

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2 ADVANCED METHODS TESTING

The company now undertook a modified testing regime with new parameters and more sensors to determine more accurately what the coal dust is doing in the wet scrubber. The efficiency impact of a novel dopant (PEG-SIL) was also requiring determination. The particle counts were now determined live at high sampling rate and efficiency according to Eqn 1.1 and 1.2 was calculated from this data.

2.1 *Coal used in this study*

A graded coal with the following cumulative density function (CDF) was utilized for the study going forward. This assisted in determining whether the particle size distribution was changing or not. The pure coal at the Neck sensor should therefore follow the normal CDF of this graded coal.

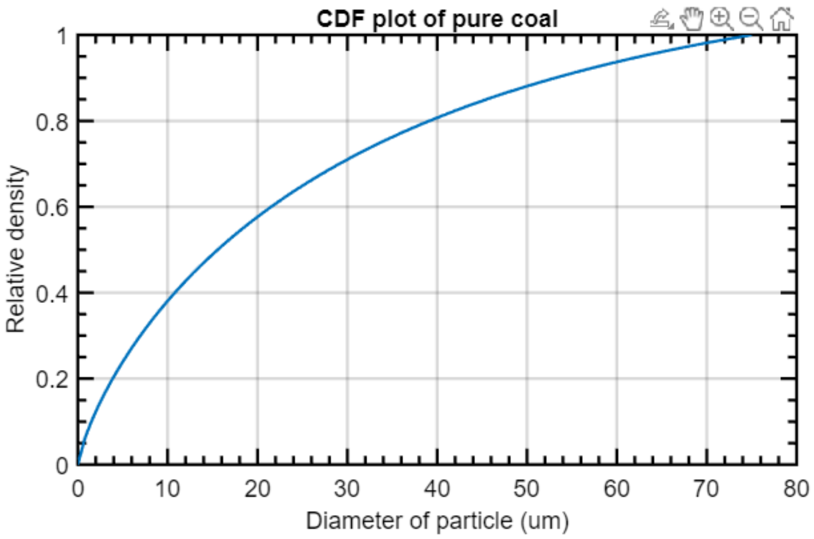

Figure 4: The particle size distribution as a cumulative density function of the pure graded coal used in this study

The percentage of the float coal in the PM10 or smaller size is approximately 38%.

2.2 *Efficiency and counts*

A complication arose when the particle sensors started to demonstrate that in real time there were strange perturbations in the counts especially at low particle size. The sensor in the neck position should be the actual density function of the coal entering the system, but the downstream sensor was showing that the actual counts of the small (respirable coal) was increasing. This is likely evidence of coal being deagglomerated in the testing rig during its interaction with the water and mesh screens. This meant the coal was changing its CDF and thus rearranging its particle size distribution due to the mesh interaction. This clearly meant that basic measurement of counts in and counts out were not completely sufficient to explain the efficiency of the system. Since this was a complication beyond the scope of this study the data was accurately reported as a function of counts in and out – even though the true efficiency will be shifted due to a change in the CDF of the actual coal in the system due to the system interactions. This finding also has a direct implication on the actual safety of wet scrubbing as the coal is changing its CDF and more of the respirable dust is being created.

2.3 *Improvements in data analysis and data collection*

The addition of pressure sensor data and extra particle size detectors in a section of only dust before the interaction with water and screen allowed for more advanced efficiency determinations. Some corrective terms for the base water and coal interaction were calculated and the efficiency could be determined continuously as the coal input varied. It was also noticed that the system parameters were most stable when the pressure differential across the screen was stable, and this allowed for calculations and determinations to be done using suitable regions of pressure data and the concomitant particle sensor readings.

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2.4 *Example of water and coal interaction*

A typical example of a testing run and resultant data is now shown in the graphic(s) to follow.

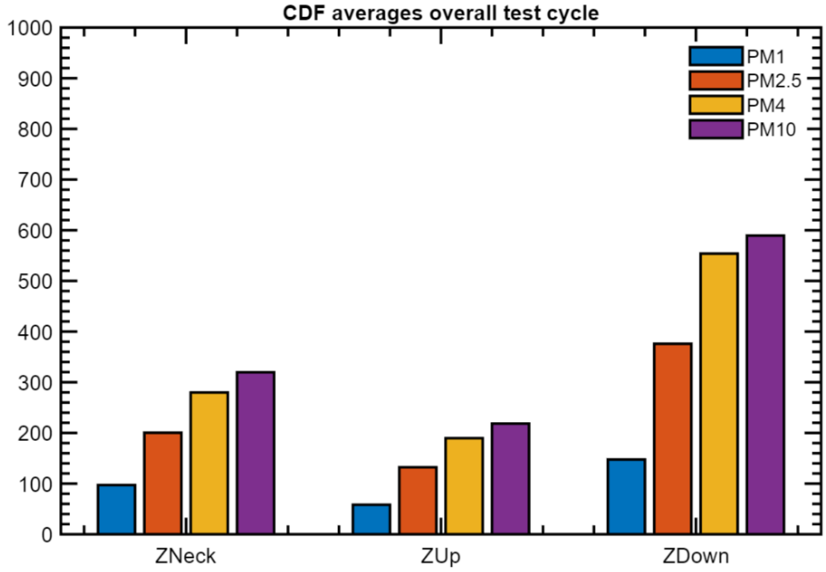

Figure 5: Cumulative Density Function of operation as averaged in different sensor locations

It is apparent the particle counts are higher in the downstream detector, and this means the system is not capable of calculating a usable beta or eta number. Furthermore, there is an indication that the system is an effective coal dust smasher. At this feed rate of coal entering the neck the system was overloaded.

2.5 *Efficiency of the basic operation at normal flow rate*[3]

This calculation is only determining the efficiency of the system at the respirable dust range. It is already effective at removing the bulk of the float coal (and higher sized material) this is now focusing on the small dust only.

10 lpm	**PM1**	**PM2.5**	**PM4**	**PM10**
Max counts	2.80	3.33	4.00	4.80
Min counts	1.89	2.15	2.25	2.25

Table 1: β values of normal CDC wet scrubber at flow rate of 10lpm

The Beta values are higher at the large particle sizes as water is ineffective in knocking down small particles (PM1 and PM2.5).

Normal flow rate	**PM1**	**PM2.5**	**PM4**	**PM10**
Max counts	64.30	70.00	75.00	79.20
Min counts	47.10	53.60	55.60	55.60

Table 2: η values of normal CDC wet scrubber at flow rate of 10lpm

It is apparent that the normal operation of the wet scrubber is effective at the majority of the float coal (sized <75um) but the efficiency eta is not as effective for the small particulate sizes as shown in Table 2.

From the mass counts it is apparent that the mass feed of coal is not a constant and this can result in feed rates that could potentially overload the scrubber. Since actual real usage of the wet scrubber will not have continuous coal supply at a constant rate this is likely more suggestive of true performance.

A method of continuous summation and averaging to a per second value is also useful as it then eliminates the error introduced by having a minimum and maximum counter (which as seen in Table 2 can results in a variable efficiency calculation.)

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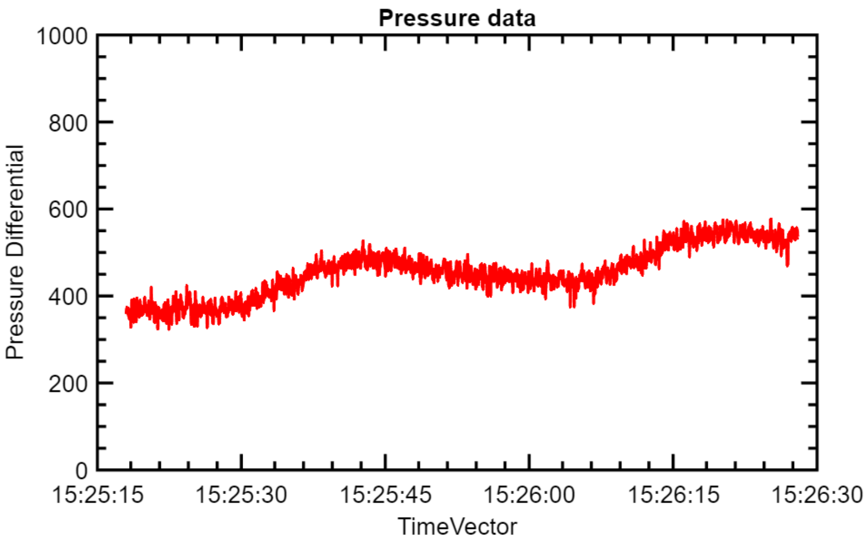

Figure 6: The pressure differential across the screen during operation. Note the pressure build-up correlating to the time of the large influx of coal as detected by the Neck sensor.

Note there is a correlation in the peaks of the neck position with the pressure differential across the mesh screen in the wet scrubber – this is also an indication of some overloading/decline in performance of the scrubber.

2.6 *Efficiency of the basic operation using normal flow rate and expanded data handling*

The efficiency of the system is now calculated using the data from the different sensors and summating as appropriate. The resultant mass counts of the different particle size detection windows can be used to determine the CDF as well as the beta performance of the system.

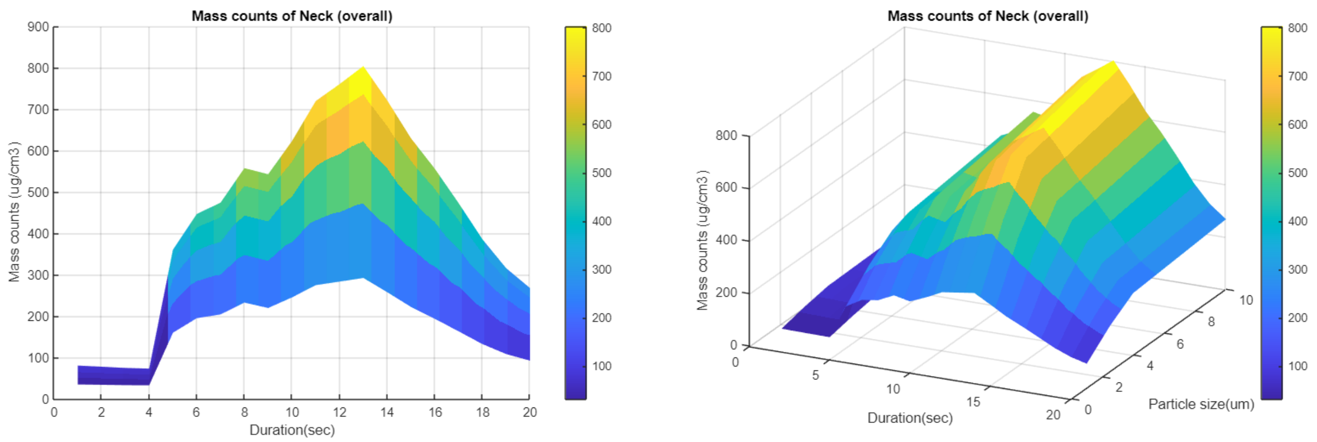

Figure 7: The mass counts in the Neck position for normal operation of the Wet scrubber

Using the data from the Upstream and Downstream sensors the beta β and eta η of the system can now be calculated.

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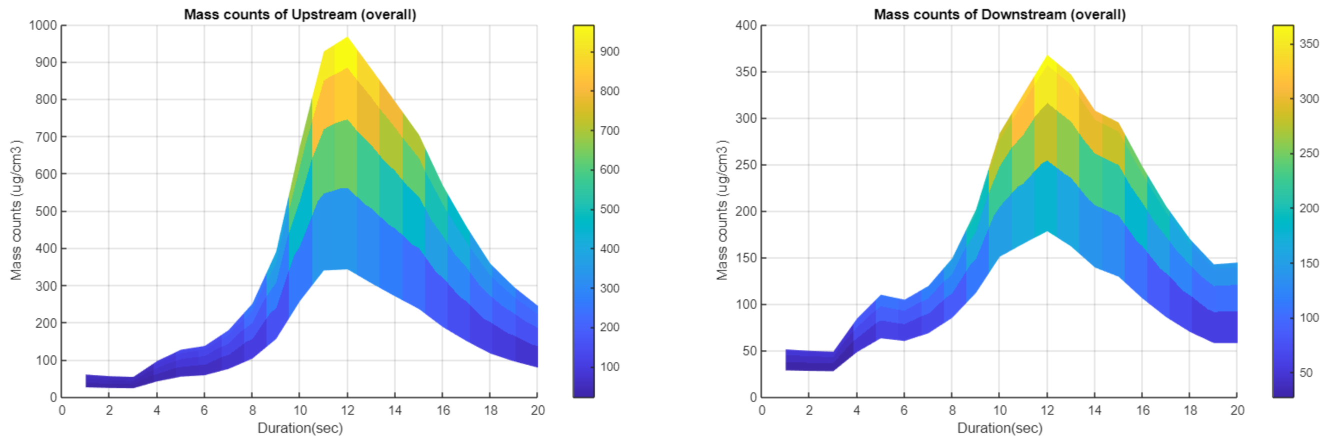

Figure 8: Sensor mass counts for the water and coal during normal operation

The ratio of the upstream to downstream counts will compute Beta as per Eqn 1.1 and the resultant mass counts are summated to yield a CDF average for this test window.

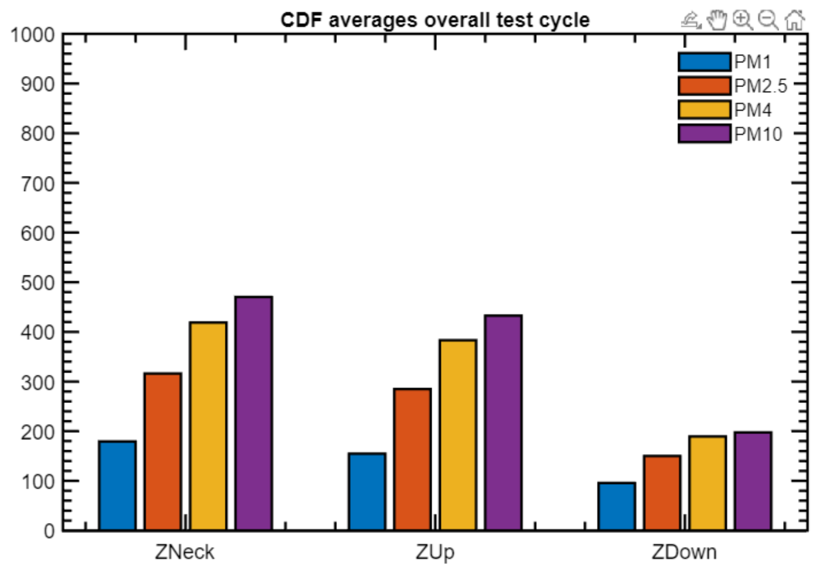

Figure 9: The CDF plot of the different sensor regions

BETA β of normal operation				
25 lpm	**PM1**	**PM2.5**	**PM4**	**PM10**
BETA	1.615	1.8976	2.0224	2.1916

Table 3: Beta values more accurately determined for standard operation

These Beta values can be used to compute the Eta values of the wet scrubber operation.

ETA η of normal operation				
25 lpm	**PM1**	**PM2.5**	**PM4**	**PM10**
ETA	38.10	47.30	50.55	54.37

Table 4: Eta values more accurately determined for standard operation at optimal performance

It is now apparent that the new method of calculation does achieve slightly different values for the Beta and Eta of the wet scrubber. This is likely a far more accurate calculation and will be used as the standard method of operation for any further testing. Note the efficiencies are only for that sized dust range. The higher order float coal was not detected by the system and was thus removed. This data set above was the highest performance we could achieve with the wet scrubber in normal operation.

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3 RESULTS WITH PEGSIL

The addition of a dopant into the water stream can potentially improve the performance of a wet scrubber[4]. Theory has suggested that surfactants can improve the capability of droplets to wet dust particles. The exact mechanism of how this improves efficiency is not completely explained and is beyond the scope of this study. A varying flow rate was studied and PEGSIL addition at 0.1% by mass into the water stream was utilized.

3.1 *Default performance of the scrubber*

The default performance of the wet scrubber was measured after some normal usage. This implied the system is loaded for a period of operation and then the calculations are performed.

An example of this history and the coal being fed are shown in the figure below.

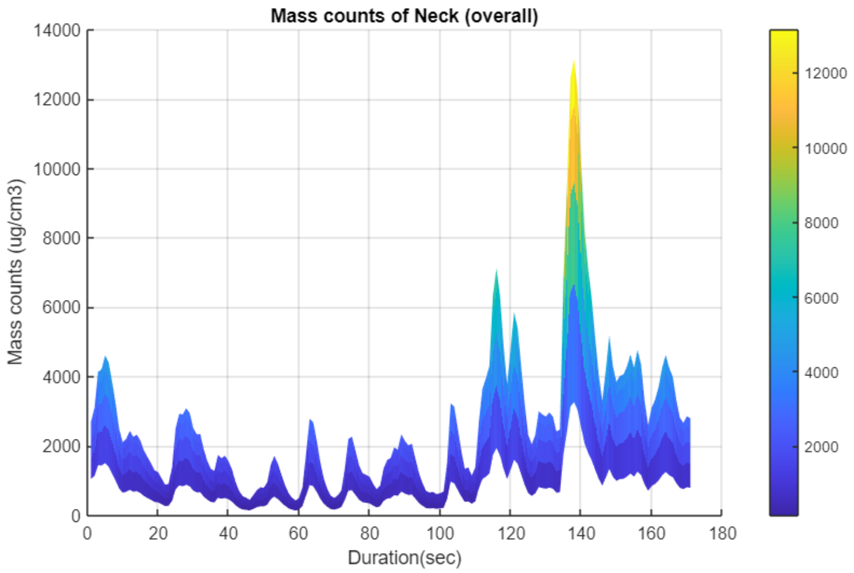

Figure 10: example of mass counts in the Neck region as the hopper is loading coal into the wet scrubber in a pulsed manner.

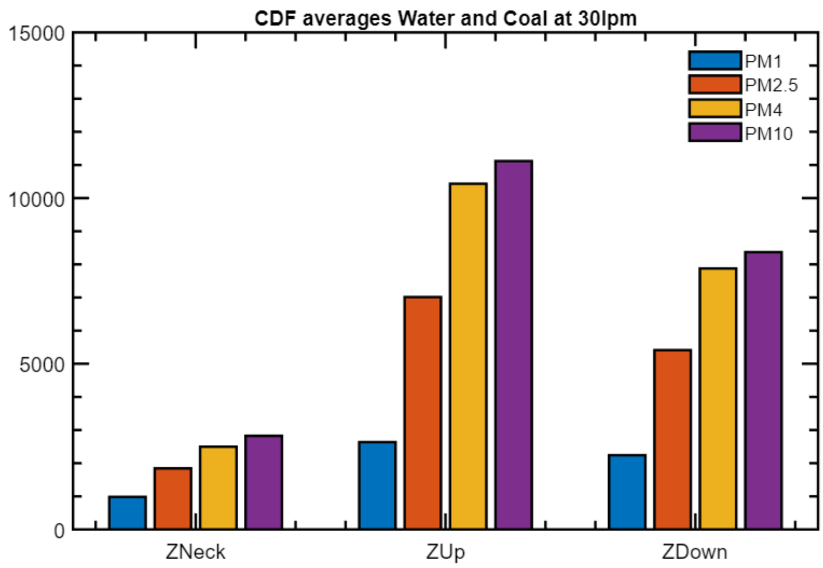

Figure 11: The CDF of normal coal operation (averaged) using the wet scrubber for respirable coal and 30lpm

It is noticeable that the Downstream particles counts are much higher than the Neck position.

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Normal 30 lpm				
	PM1	PM2.5	PM4	PM10
Up	2635	7012	10433	11117
Down	2241	5413	7875	8368
Beta	1.176	1.295	1.325	1.329
Eta	15.0%	22.8%	24.5%	24.7%

Table 5: Eta values more accurately determined for standard operation with variable flow rate

It is apparent that this is low performance of the wet scrubber for these respirable dust particles.

3.2 *PEGSIL performance and varying flow rate*

3.2.1 *Normal flow rate of 30lpm*

The results of the PEGSIL doped material was now calculated and expressed in terms of Beta and Eta. The most interesting result was that flow rate had a large impact on the performance of the PEGSIL in the wet scrubber in its interaction with float coal. This is indicating far greater wettability and droplet size dependance on the interaction of the PEGSIL doped water and coal. The normal performance of wet scrubber declines as a function of water flow rate.

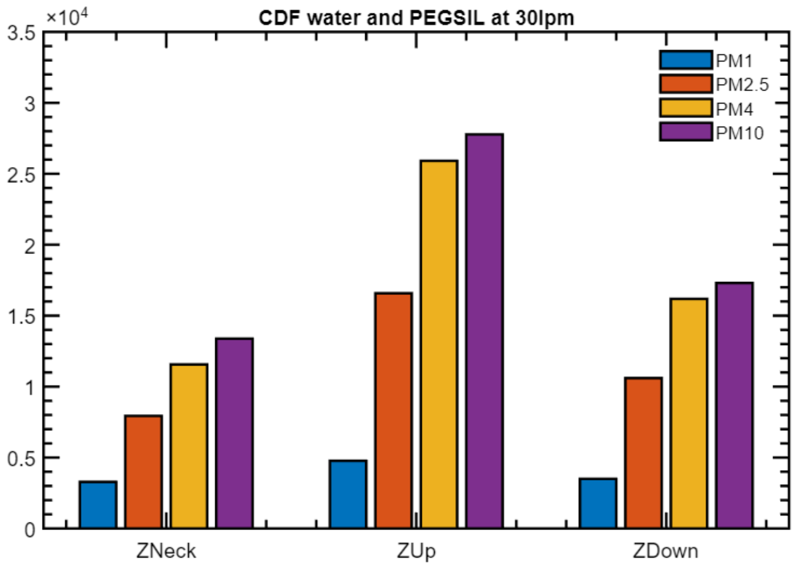

Figure 12: The CDF plot of PEGSIL operation at 30lpm

The scrubber is performing better with the addition of PEGSIL. There is also a notable decrease in the down-stream counts when compared to the normal operation of the scrubber.

PEGSIL at 30 lpm				
	PM1	PM2.5	PM4	PM10
Up	4774	16578	25910	27776
Down	3502	10602	16184	17301
Beta	1.363	1.564	1.601	1.605
Eta	26.6%	36.0%	37.5%	37.7%

Table 6: Wet scrubbing efficiency using PEGSIL as dopant

The addition of PEGSIL has improved the efficiency by 50% at this flow rate of 30lpm.

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3.2.2 *Reduced flow rate of 15lpm*

The reduction of flow rate was tested to determine if PEGSIL could offer water savings potential in the operation of a wet scrubber.

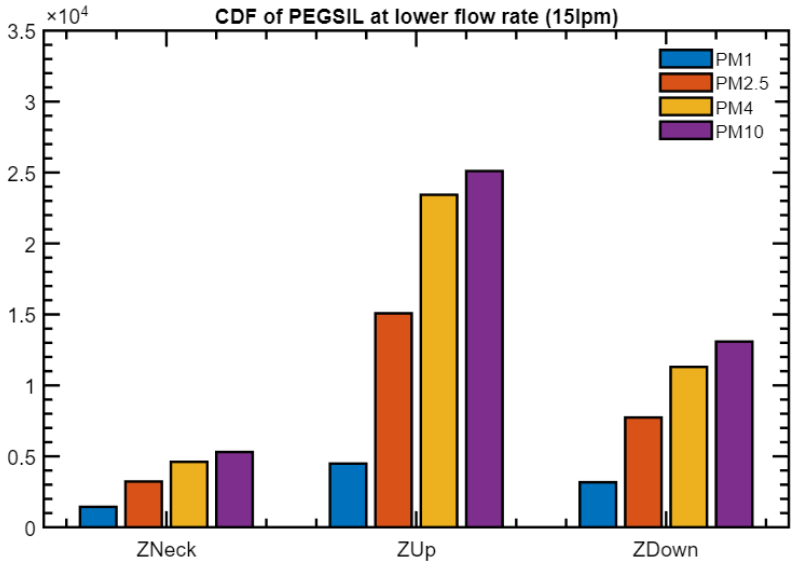

Figure 13: The CDF of PEGSIL at lower flow rate of operation.

PEGSIL at 15 lpm				
	PM1	**PM2.5**	**PM4**	**PM10**
Up	4490	15076	23434	25106
Down	3170	7735	11301	13088
Beta	1.416	1.949	2.074	1.918
Eta	29.4%	48.7%	51.8%	47.9%

Table 7: Wet scrubbing efficiency using PEGSIL as dopant and reduced water flow

These increases in Eta performance were substantial and have been repeated in further comparisons with other dust materials (PEGSIL has superior interaction with not just coal but other dust generating materials).

PEGSIL offered 50% water rate reduction and a 100% increase in scrubbing efficiency eta η compared to normal operation. The impact of flow rate and efficiency of PEGSIL are now being completely studied with more advanced flow rate and parameter control of the test rig.

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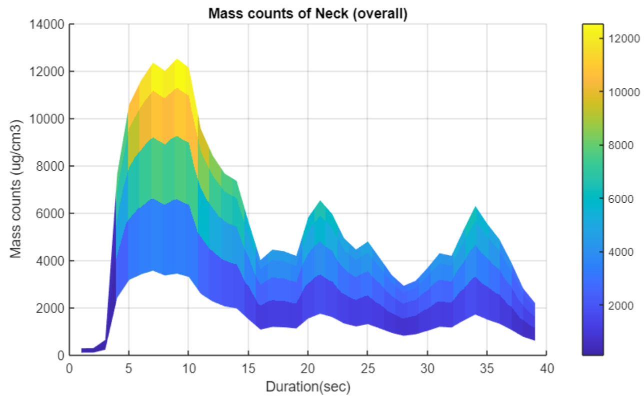
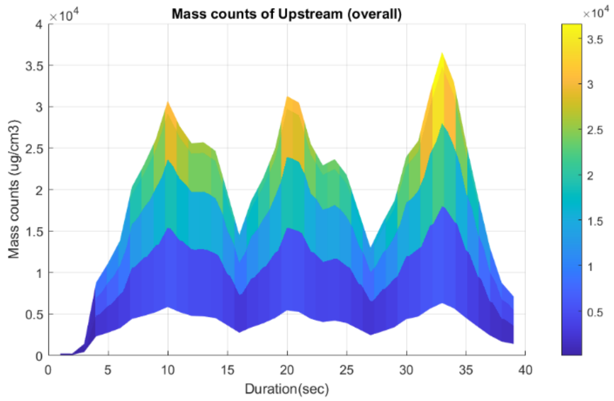
3.3 *When to measure is important*

3.3.1 *Pulses of coal entering the wet scrubber*



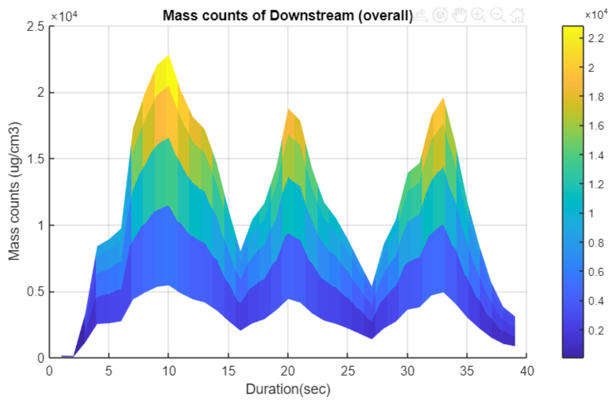
Note the three successive coal inputs for these measurements of PEGSIL and coal at reduced flow rate (15lpm)

Figure 14: The pulses of coal entering the scrubber are detected by the Neck sensor.



Note how the upstream counts do not directly correlate to the input peaks and the upstream counts are the highest for the last peak entering the system. This is evidence of complex particle size changes in the system.

Figure 15: The Upstream sensor detects these pulses but the mass flow counts are not directly the same as the Neck.



The downstream counts are highest and follow the trend of the Neck with first peak being highest and last peak being lowest.

Figure 16: The Downstream sensor follows the trend of the Neck sensor in mass counts.

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Consider the first peak and then the third peak. The CDF of the particle sensors will be different depending on where it is analyzed. This will then yield different Beta and Eta efficiency values.

In the case of the three events as depicted in Figures X=X we get a range of efficiency as shown it the table below.

	PM1	PM2.5	PM4	PM10
All peaks	1.2515	1.7033	1.8128	1.679
Peak 1	1.0932	1.4105	1.4873	1.3762
Peak 3	1.3504	1.9367	2.083	1.9335

Table 8: The Beta and Eta efficiency can be affected by where the measurement is taken for a sequence of pulses of dust

This will have ramifications in the actual efficiency of a dynamic system of dust pulses entering the wet scrubber as well as comparing the efficiency at a single point in time. This is an implication that the scrubber is influenced by previous scrubbing performances or events this will be relevant in scrubber performance during real usage where the coal supply is not continuous or stable.

This could also be indication that a mesh/demister could be exacerbating the coal deagglomeration and dependent on design constraints the introduction of PEGSIL wet scrubbing in series could outperform a meshed/demisted operation. In our calculations the interaction of just the PEGSIL when the mesh was not present was more of an impact in scrubbing performance than the increase that the Mesh/demister screen was contributing to the system. This will form some of the topics future design/development the company will undertake in optimizing wet scrubbers going forward.

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4 DISCUSSION

The performance of PEGSIL was superior to that of normal wet scrubbing at same flow rate. Some increase in the performance was possible when the flow rate was reduced – this is an interesting phenomenon and is related to the speed of wetting of the coal (and likely droplet size effects which are dominated by water flow rate).

This performance increase was seen as **an increase of efficiency η from 50 to 100%.**

A further implication is the lower water flow rate (and indeed dependance on flow rate of PEGSIL performance) offers a significant opportunity to improve respirable dust collection while offering a water savings to normal mining operation. More optimization of the dopant can now continue for any further potential advantages.

The company has gained some important knowledge that can guide further optimization development going forward.

The use of PEGSIL as a dopant for wet scrubbing operations has been patented and the product is now available.

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