Alpha Foundation for the Improvement of Mine Safety and Health

Final Technical Report

AFC215 – 15 Improved Face Ventilation for Extended-Cut Continuous Mining Using a Wing Regulator and Scrubber Control System

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University of Kentucky Department of Mining Engineering

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EXECUTIVE SUMMARY

Mining operations spend millions of dollars to provide fresh air to the miners and machines developing the underground workings. In an underground room-and-pillar coal mine section, the fresh air is intended to sweep the front of the continuous mining machine to dilute pollutants, such as methane and dust that are produced as a consequence of excavation. Many of these mines employ a blowing face ventilation scheme where a line curtain, placed on the opposite side of continuous miner's scrubber discharge, is used to direct the fresh air to the face. This scheme is very popular in mines with methane-rich coal seams because it is more effective at diluting dust and methane at the face than a similarly configured exhausting ventilation system. However, even the blower scheme faces difficulty when ventilating an extended (deep) cut section where the continuous miner advances the face up to 40 feet beyond the last row of permanent supports. The fresh air having insufficient velocity does not reach the face and instead takes a low resistance path to the return portion of the airway. As a result, during deep cuts the methane and dust concentrations could build up at the face, causing significant health and safety related issues in the mine.

Numerous efforts have been made to bring the fresh intake air close to the coal face to dilute the pollutants generated by the continuous miner, but none of them has been very effective or widely adopted. This project investigates the efficacy of a novel device, the Wing Regulator, for dust and methane dilution. The Wing Regulator is a vertical air foil that increases the air velocity and directs the air in a stream along the rib, encouraging the air to flow closer to the miner head with an insignificant increase in resistance.

During the course of this project several different Wing Regulators were fabricated. One was constructed by Schauenburg Flexadux with its tubing material. These different designs were used and experimented with in both active mines and in the Dust Gallery (discussed below). Finally, an ergonomical and effective prototype was constructed in-house by using a strong, but lightweight, fabric and metal frame.

The intent of this project was to gauge the influence of the Wing Regulator on blowing ventilation systems. This influence is not limited to the movement of the air, but also includes the commonly found control devices, such as water sprays and flooded bed scrubbers. The project was divided into multiple objectives and tasks. The researchers first performed a series of Computational Fluid Dynamics (CFD) models to simulate a single room of a typical size mine. A 1:12 model of a single room was constructed, and a variety of techniques was used to examine the airflow characteristics and to match the airflow observed in the mines. In the 1:12 model, particle image velocimetry (PIV) was employed, which is difficult to do in full scale. A 1:1 model of the same was constructed

underground in a limestone mine, called the Dust Gallery. In the full scale facility, we are able to use tools that would not be available for use in underground coal mines. A full-scale continuous miner model was designed and built with a functioning wet head, body sprays, and a flooded bed scrubber. A variety of experiments and measurements were performed under controlled conditions, which are discussed in this report. These experiments were not confined only to the full cut, but also include the incremental portions of the cut.

This report is primarily concerned with the full-scale Dust Gallery design considerations and testing results as these are the most relevant to operators and regulators. Collected data is available in the appendix, and the analysis of the data is contained in this report. Three mine ventilation consultants were heavily utilized in the performance of this project. Drs. Wala and Petrov are the inventors of the Wing Regulator and contributed greatly to the work performed in the lab, the active mines, and the dust gallery. Furthermore, Ventilation Innovation was utilized for a peer-review, and its report is contained in the Appendix.

It is researchers' collective conclusion, that the Wing Regulator performs its intended task with little added work for mine workers and essentially no impact on the power requirements of the mine's ventilation system. Usage of the regulator does not impede the efficacy of other gas and dust control systems already present in coal mines. Importantly, at the minimum statutory required airflow to the face of a coal mine, the Wing Regulator has the most visible impact. Operators using the blowing system, who are concerned with gas levels, should consider the Wing Regulator a viable tool for remedy.

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1. PROBLEM STATEMENT AND OBJECTIVE

This project is in the Foundation's focus area: Health and Safety Interventions, with the topic area: Dust Control. The intervention is an engineering control preventing dust exposure to the worker.

During deep cut mining of coal with a continuous miner, the ventilation system has difficulty delivering fresh air to the region inby cutting drum when using curtains. Whether a blowing or exhausting curtain is used, the total amount of fresh air in the intake does not reach the face. Research has shown that approximately 20% of the fresh air behind the curtain reaches the face. For blowing systems, this phenomenon can be described as early airflow separation from the rib. This leaves a region close to the face with elevated concentrations of methane and dust. This dusty air presents a health hazard for miners operating the continuous miner and shuttle car operators as it rolls back over them, in the form of elevated risk of coal worker's pneumoconiosis. Elevated methane concentrations increase the potential for ignition in the same area with the freshly created coal dust and no rock dust. Various controls have been used to address this problem, including a machine mounted scrubber and sprays. This has introduced problems such as recirculation, increased maintenance requirements, noise, and water usage, but fails to address the root of the problem. Additional fresh air needs to be brought closer to the face to dilute the dust and methane.

1.1 Specific Aims

The root cause of the difficulties encountered with high dust and methane levels is lack of air reaching the immediate face. The solution is to bring additional fresh air to the face to dilute those hazards. The wing regulator technology addresses this specific need. It has shown in pilot testing to cut those levels in half, with no further changes to the face ventilation system. Changes to the other ventilation controls could lead to greater improvements in dilution efficiency.

The overarching goal of the project is to determine how the wing regulator can be best combined with the other ventilation controls present at the face. This is best accomplished in a controlled environment which necessitates the need for the construction of new dust gallery. With this optimization conducted, the improvements made with the wing regulator will greatly improve the working conditions in underground coal mines. It will help improve the health and safety of workers. It will assist mining companies to maintain compliance with the new dust standards and possibly safeguard their investment from a potential fire. Finally, it will significantly contribute to the community's ability to perform this type of research in the future.

1.2 Research Objectives

The following objectives were met during course of the research project.

Objective 1 – Design and construction of an improved prototype wing regulator using materials typical of rigid ventilation ducting

Task 1.1 Identify specific solutions to improve usability

The wing regulator is a proven concept that has been shared with the mining community at the SME Annual Conference. There are shortcomings to the prototype with regards to usability. The design could be improved to aid setup and movement of the wing regulator in the section.

Task 1.2 Wing regulator construction

This step includes the construction of two wing regulators including the identified usability improvements from Task 1.1. The wing regulators were constructed with materials and methods consistent with rigid fiberglass ventilation ducting.

Objective 2 – Prediction the impact of the wing regulator on dust and methane levels at the face

Task 2.1 Reduced scale physical model testing

Reduced scale physical modeling is a tool that has been in use at the University of Kentucky for more than ten years. Thanks to the advances in 3D printing, an improved model of the continuous miner (CM) with a functional scrubber was produced. CM data from Joy Global has already been secured to make the model as representative as possible. Particle image velocimetry is the primary means to obtain data from the model. This revealed velocity vectors within the model that indicate what quantity of air being delivered to the face.

Task 2.2 CFD modeling

CFD modeling was completed at the same time as the reduced scale physical modeling. CFD studies, when proper inputs are chosen, allows one to gain greater understanding of the phenomenon happening at the face. Scenarios can be rapidly developed prior to development of the full scale physical model. The aim of CFD modeling exercises was to identify any strong cross coupling effects between the different ventilation controls at the face. This assisted with the design of the fractional factorial experimental design in Task 3.1.

Task 2.3 Dust gallery construction

The aim of Task 2.3 was to build a full-scale dust gallery for testing face ventilation scenarios. This construction effort would take place in an operating, underground limestone mine near Georgetown, Kentucky. It currently houses a colleague's explosive testing laboratory and is well suited for mine ventilation research. This included the construction of a 1:1 scale physical mockup of a continuous miner, with working scrubber, rotating drum, and spray arrangement. A PLC control system was implemented to control the operation of the various ventilation controls in place. The gallery is approximately 20 feet wide by 50 feet long by 7 feet tall.

Task 2.4 Full scale physical model testing

This task included the activities required to commission the dust gallery constructed in Task 2.3. Result from Tasks 2.1 and 2.2 was used to determine an appropriate scenario for testing. The performance criteria for each of the ventilation controls was verified, including but not limited to:

- Gallery air quantity
- Scrubber air quantity
- Spray direction, flowrate, and pressure
- Dust seeding at the face
- Gas injection at the face

With the performance of the ventilation controls verified to an acceptable standard, sampling methods for dust and gas levels were evaluated.

Objective 3 – Determination of the optimal arrangement of ventilation controls at the face

Task 3.1 Develop experimental design

Ventilation conditions at the face are influenced by several factors, such as cut sequence, curtain arrangement, machine mounted scrubber settings, and spray configurations. This is further influenced by the presence of the wing regulator on the discharge side of a blowing curtain. Based upon the experience of the research team, a review of face ventilation plans currently in practice, and the results of the modeling exercises completed in Objective 2, these factors were incorporated into an experimental design to determine the impact of each of these factors on miner dust exposure levels and methane concentration at the face. Due to the number of factors involved, the experimental design took the form of a fractional factorial design applying the response surface methodology to determine the optimum response.

Task 3.2 Conduct experimental design

The aim of this task was to execute the experimental design developed earlier. The statistical analysis was completed and the response surface generated. Best practices when using the wing

regulator was identified based upon the test results and compared to the currently recommended best practices in the absence of a wing regulator.

Task 3.3 Control algorithm development

Upon completion of the experimental design in Task 3.2, the influence of the individual ventilation controls was understood. Pilot testing and CFD modeling have both indicated that the efficacy of the face ventilation scheme is dependent upon the quantity of air delivered by the curtain and the scrubber setting. Measurements of velocity behind the curtain would provide the feedback to the scrubber fan controller, forming a closed loop control system. The aim of this task was to identify two control methods. The first would minimize an operator's dust exposure level, while maintaining acceptable methane levels. The second would minimize methane levels, while limiting dust exposure to acceptable levels.

Objective 4 – To validate the modeling efforts with testing at mine sites

The following tasks within objective 4 were completed at each mine site where wing regulator testing took place. The minimum number of mines to visit, in order to complete the milestone, was no less than three.

Task 4.1 Dust and methane characterization without wing regulator

Dust and methane levels were characterized at the mine using the existing ventilation system. This includes dust exposure levels for the miner operator and the shuttle car operators, via a personal dust monitor with data logging. Methane levels were also evaluated at the same time using a handheld MX6 gas detector with data logging. Researchers logged activities occurring at the face to further corroborate the measurements taken with the instruments.

Task 4.2 Dust and methane characterization with wing regulator

After completing the testing for Task 4.1, the same steps were repeated with the wing regulator in place to determine its effectiveness. Where allowed by MSHA, further changes to the face ventilation scheme will be implemented to match the recommendations determined in Objective 3.

Task 4.3 Summary report from each specific mine site

The final task of this objective was to prepare a summary report for the activities at each specific mine where testing occurs. Once mine surveys were completed, at three different mine sites, these summary reports were compiled into this report for objective 4.

Objective 5 – To document the results

Task 5.1 Wing regulator usage guide

A usage guide for mine operators was prepared. This document was developed with miners in mind, in order to provide a simple, but well-illustrated guide to using the wing regulator in a section. Guidance for used under different cut scenarios was developed based upon the results from the CFD and physical modeling.

Task 5.2 Publication of results

The project team has disseminated their findings as widely as possible. Manuscripts targeting journals that serve the mining industry such as SME Magazine and SME Transactions. Conference papers and presentations were prepared to serve that audience, which included the SME Annual Conference and Expo and the North American Mine Ventilation Symposium.

Task 5.3 Final Report

This report including all the findings was prepared for the Alpha Foundation.

2. RESEARCH APPROACH

The facilities to achieve the research goal of the project, to quantify the effect of the wing regulator under controlled and repeatable conditions, were constructed in the course of the project. There were several major construction tasks, which are discussed in this chapter. These construction tasks were completed in order to implement the experimental design that is discussed in this chapter.

2.1 Dust Gallery Design Consideration

A single room full scale lab for repeatable face ventilation measurements was designed and constructed, commonly called the Dust Galley. The facility has the ability to produce flow patterns typical for the line-brattice face ventilation systems common in room and pillar coal mines. The lab primarily simulated blowing line curtain face ventilation system, however, it can also be configured to simulate exhaust line curtain setup. Details of the dimensions are in the Dust Gallery Setup section of this document.

The lab was constructed inside a limestone mine near Georgetown, KY. The view of the lab in the room and pillar mine space is shown in Figure 1, a photo of the building in Figure 2. Light frames, plastic panels, and ventilation curtains were used to create the internal room of the lab. The test gallery is 85 feet long and 35.5 feet wide. The gallery cross-cut width and the entry width is 20 feet. The test gallery is equipped with an axial flow fan with 40 hp motor, and a variable frequency drive (VFD).

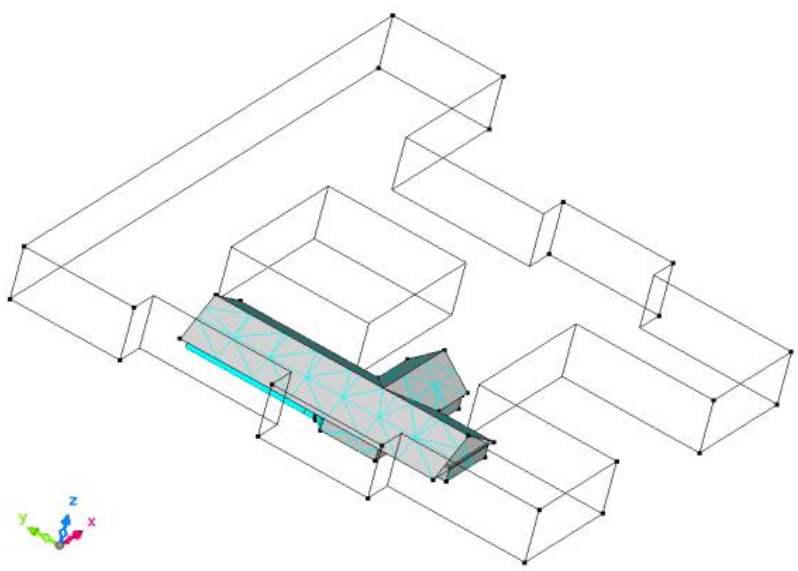


Figure 1 Dust gallery building shell in the underground space

Figure 2 Outside view of the Dust Gallery

It is established Luxner (1969). Voronina (1962), Sullivan and Heerder (1993), Moloney et al.(1997), Moloney et al. (1999), Gillies (1982), Volkwein et al. (1985), Volkwein et al. (1989), Taylor et al. (1996), Goodman et al. (1995), Goodman et al. (2000), Goodman et al. (2006), Reed and Taylor (2010), Taylor and Karacan (2010), Organiscak and Beck (2010), Schultz et al.(2010), Wala et al. (2000-2004), Turner et al.(2002), Petrov et al.(2010-2014) that the line-brattice face ventilation systems developed specific flow patterns in the equipment free scenarios. Computational fluid dynamics (CFD) simulation of the flow patterns for a typical blowing curtain face ventilation layout, using validated CFD code (Petrov, 2014), is shown in Figure 3.

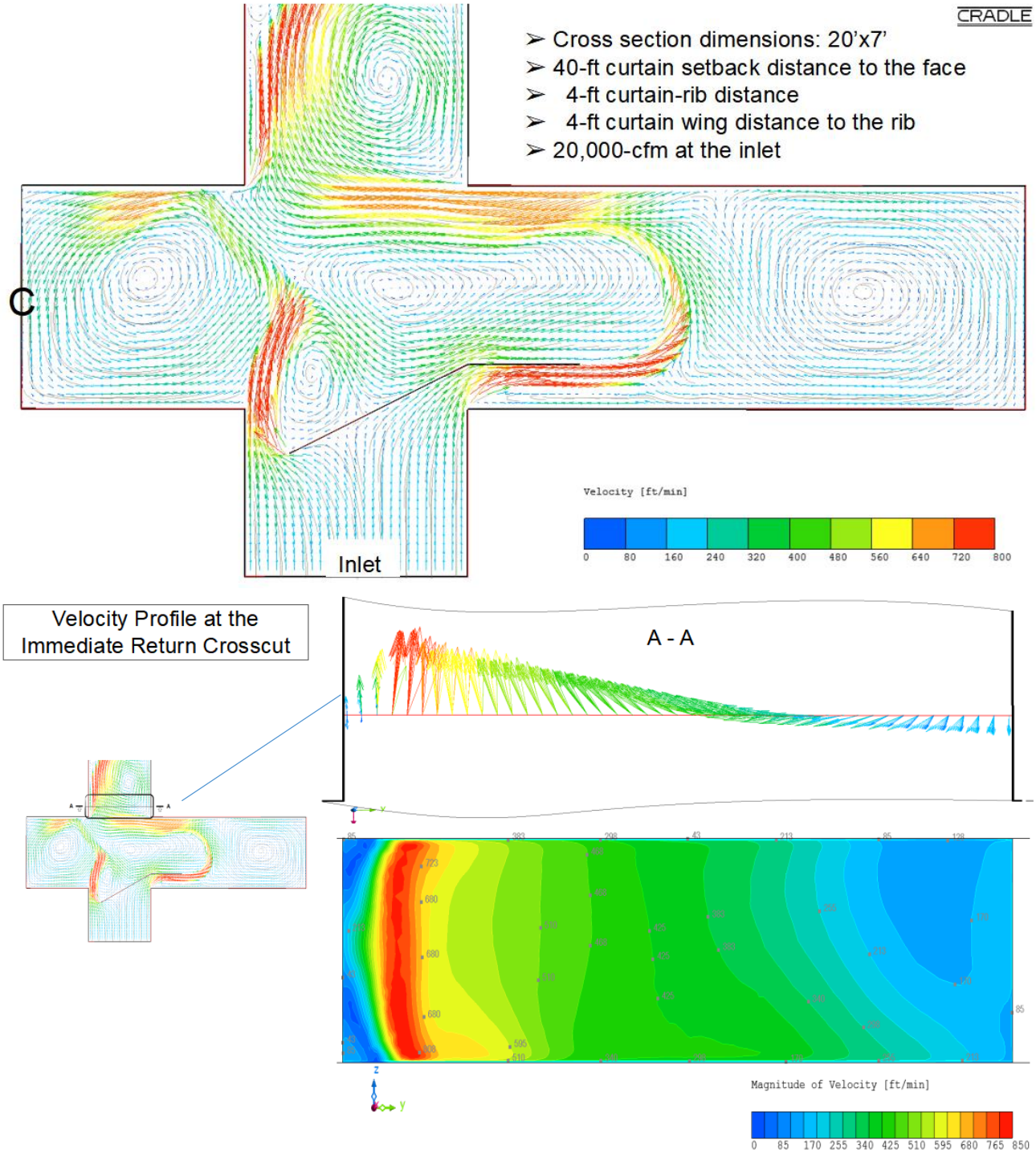


Figure 3 CFD Simulation of flow patterns for a typical blowing curtain face ventilation layout

With the original construction, observed mining conditions and the flow patterns were not generated in the dust gallery. This required several changes be made to the lab interior.

A return flow regulator curtain was designed to control the return airflow patterns. Without this regulator the return stream followed a shortcut to the fan with flow patterns atypical for the mine. The return flow stream pattern at the exhaust crosscut is an important factor which impacts the distribution of gas and dust concentrations into the entry. The impact zone of the return flow patterns spreads from the check-curtain to the shuttle car and continuous miner operators and partially to the immediate face zone. The widespread effect is due to the recirculation patterns caused by the flow separation and the machine mounted scrubber and sprays.

Wall roughness has been added to the curtain side rib using two inches wave shaped roof plates. The research shows that the intake turbulence and the roughness of the curtain-side wall are both control factors to trigger the flow separation phenomena for the open entry 20-ft wide scenarios.

Airflow in a mine is almost always turbulent in the main airways with Reynold's number of the order of hundreds of thousands. Turbulence parameters, especially, intensity is an important parameter that defines the airflow in addition to the volumetric flow rate. Turbulence intensities usually lie in the 5-15% range in typical mine airways; in-mine testing for this research also confirms this. An intake deflector acting as a turbulence intensifier was designed to produce the typical turbulence at the last open crosscut. This was crucial since air was brought into the experimental gallery from a huge adjacent chamber associated with insignificant intensity. The deflector insures fully developed turbulent flow behind the curtain with turbulence intensity in range of 8% to 12% measured by TSI Velocicalc instrument.

A series of CFD simulations have been performed to analyze the effect of inlet turbulent intensity (Tu) on flow separation at the gallery. For the gallery, the analysis covers three case scenarios for inlet boundary conditions, including turbulent intake flow; intake flow with Tu=8%; and intake flow with Tu=12%. The result for turbulent flow boundary conditions and those for Tu=8% have shown transition of the blowing curtain stream to flow penetration to the face. For the scenario with Tu=8% it takes longer time for the transition to complete and the flow patterns to build quasi-stable shape penetration to the face. The results for inlet turbulent intensity Tu=12% showed more stable flow behavior keeping flow separation patterns (Figure 4 and Figure 5). The values for Tu, used in the simulations, correspond to the data of in-mine measurements for turbulent intensities (Appendix C).

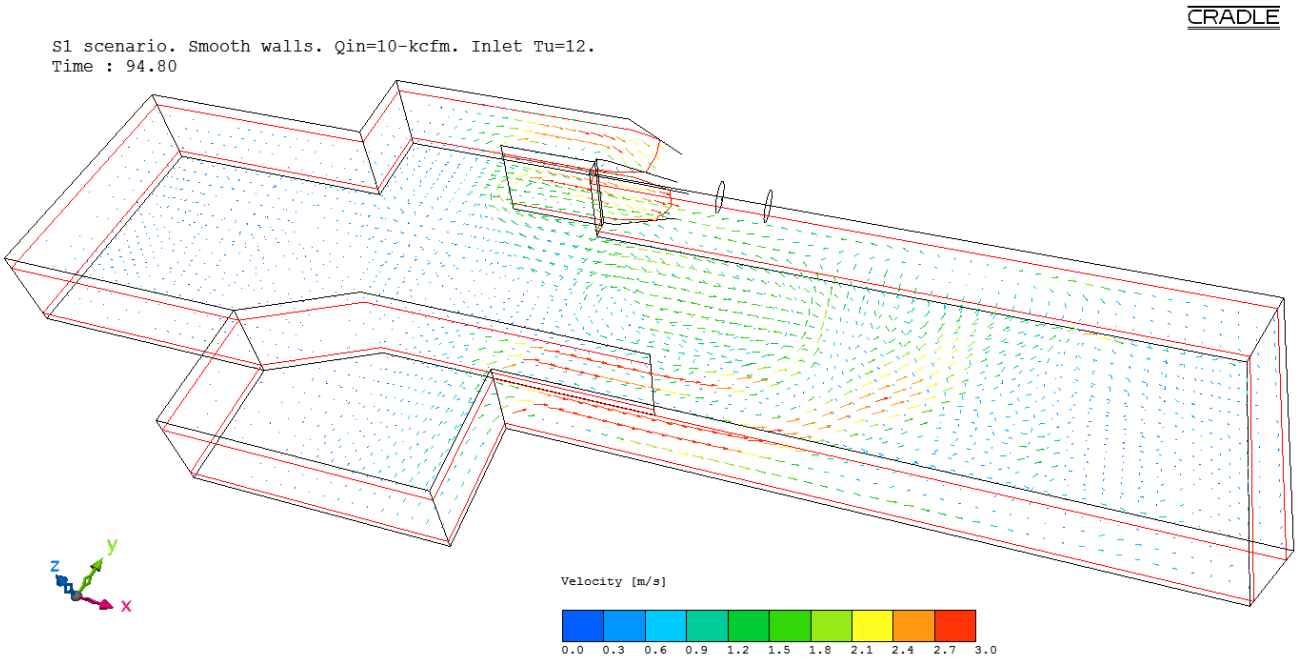


Figure 4 Flow patterns in scenario Tu12: QFan=10,000-cfm; Intake turbulent intensity Tu=12%; smooth walls

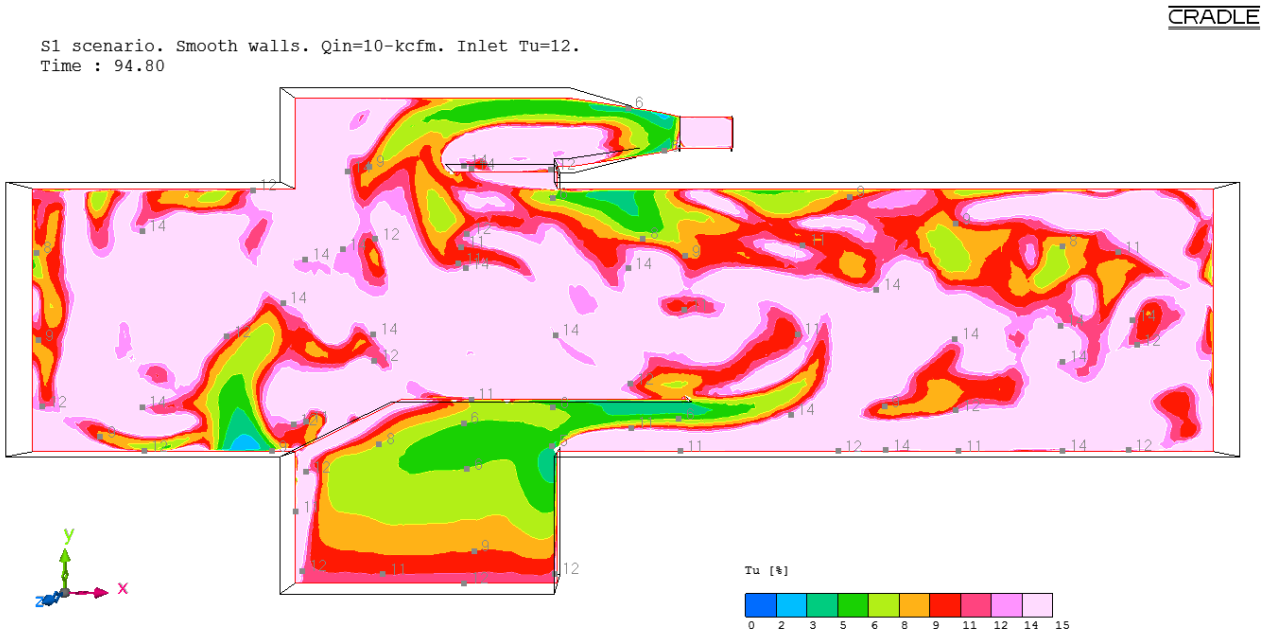


Figure 5 Turbulent intensity contour map in scenario Tu12: QFan=10,000-cfm; Intake turbulent intensity Tu=12%; smooth walls

Alternative constructions were considered, information regarding the other scenarios is available in Appendix C. Combination of turbulence intensifiers, VFD controls, and artificially created surface roughness enabled the research team to mimic the airflow rates and associated turbulence parameters observed in underground room and pillar coal mining operations. The scenario, Georgetown_Test_Oct_12_2017, is the direct similarity with the in-mine conditions and especially the roughness at the curtain side, where the WR will act.

Laser enhanced images of early tests for flow visualization is shown in Figure 6. Shortly after this image was taken, the wall roughness was added to complete the lab design. Without the roughness the separation will occur momentarily and unpredictably, with the roughness the separation is reliable and constant.

Figure 6 Laser enhanced image of the flow separation phenomenon in the Face Ventilation Lab facility. Configuration for 40-ft setback with slab, smooth walls

CFD analysis was performed to explore the possibilities for recirculation of tracer gas around the lab facility. This was a particular concern for tracer gas concentration used during testing. The results show that the recirculation around the pillars is possible and can be minimized by keeping the outlet of the exhaust tube parallel to the lab body, as shown in Figure 7, instead of using 45º elbow, see Figure 8.

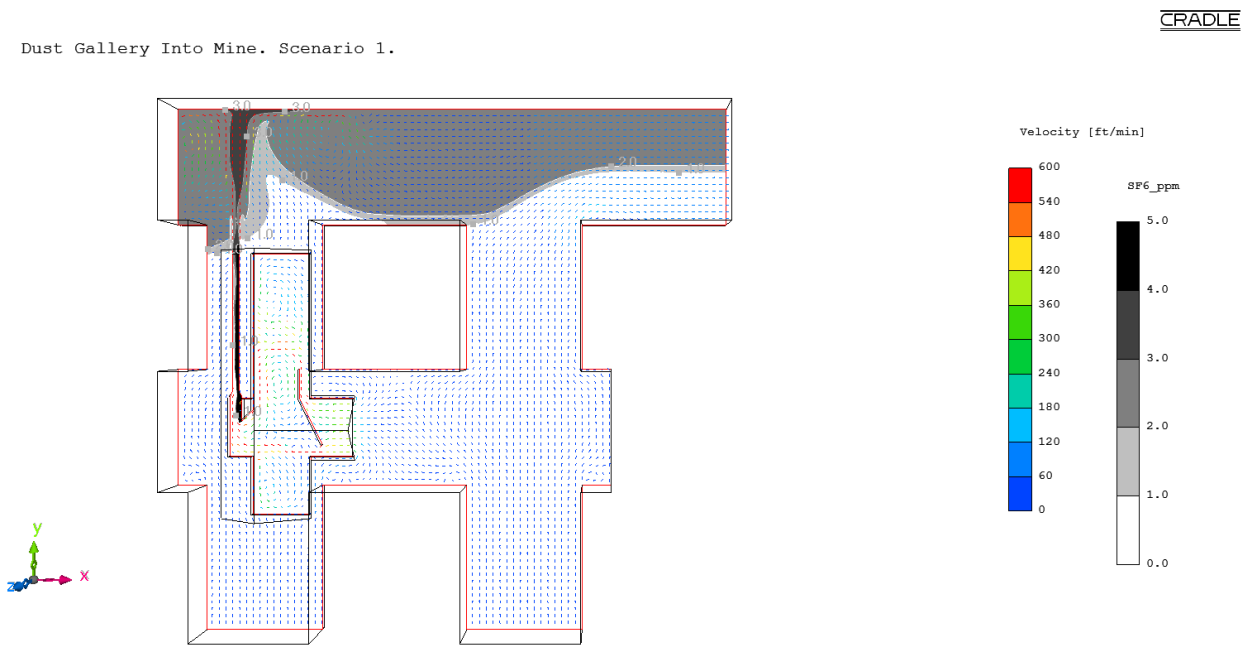


Figure 7 Recirculation analysis outside of Dust Gallery with straight exhaust

Figure 8 Recirculation analysis outside of dust gallery with 45º bend exhaust

2.2 Continuous Miner Model

Another unique feature of the dust gallery construction is the inclusion of a functional 1:1 continuous miner model. The full-scale continuous miner was divided into seven parts, as shown in Figure 9. The work was carried out in two stages: first, a metal frame structure (skeleton) of each part was built and then the metal frames were covered with skin made of wood and plastic.

Figure 10 through Figure 12 present the five constructed parts that were painted before they were assembled.

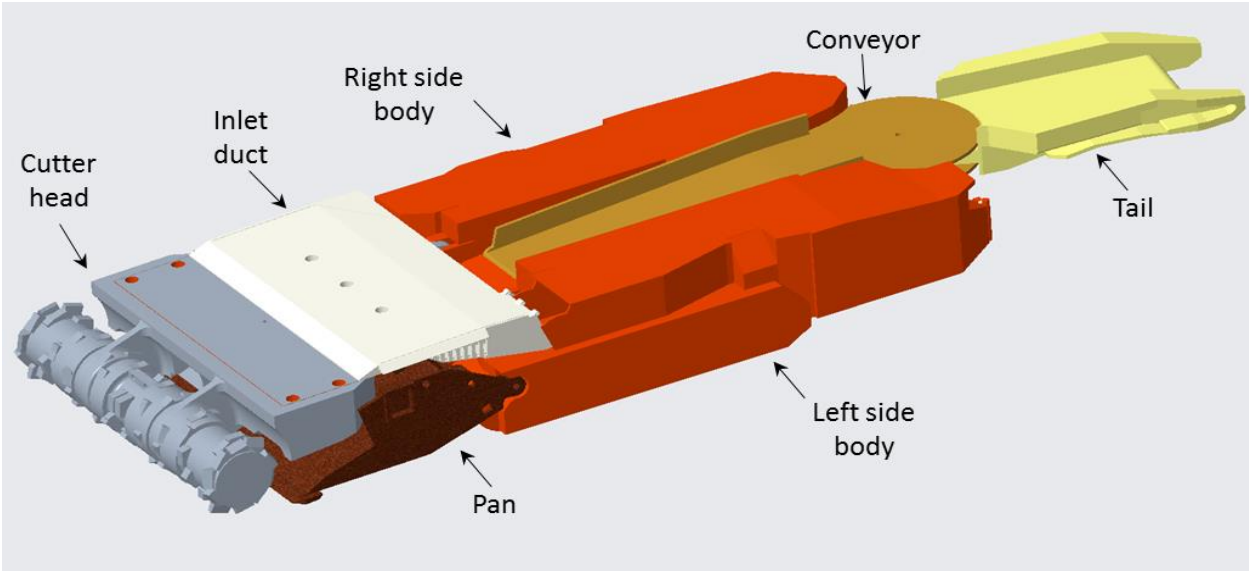


Figure 9 Representative 3-D drawing of a continuous miner showing its different components

Figure 10 Continuous miner model Head assembly, actuation works

Figure 11 Fabricated right-side-body component of the continuous miner

Figure 12 Fabricated continuous miner Pan

The miner head articulates and contains three dozen spray nozzles, behind 3D printed miner bits, that operate while the head is spinning. There are 4 body sprays simulating dust controls on miners at the partner mine locations. The miner hood has a 3 port scrubber head that feeds into a flooded bed scrubber including a demister and fan capable of air quantities typical of Joy miners. The assembled miner body underground is shown in Figure 13.

Figure 13 Continuous Miner Model after Body Assembly in place underground during final assembly

2.3 Dust Gallery testing

The continuous miner prototype was installed in the room and pillar mine test facility built in the limestone mine in Georgetown, KY. The test gallery is 85 feet long and 35.5 feet wide. It resembles a portion of an active room-and-pillar face where a continuous miner is in operation, as shown in Figure 14. The roof of the test gallery was fixed at a height of seven feet, representing average height of underground coal mines in Central Appalachian region.

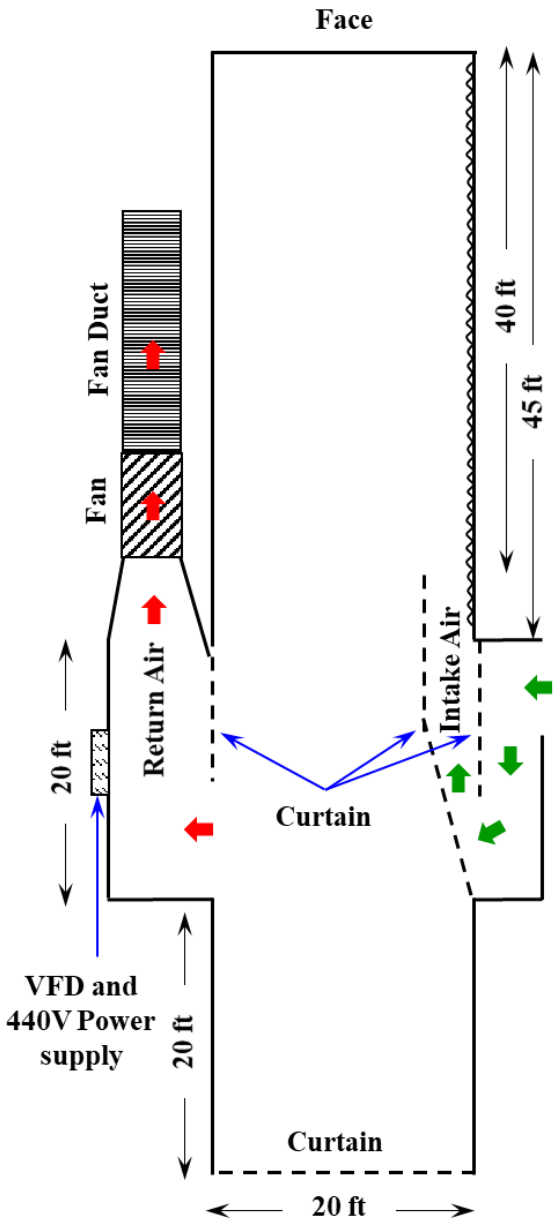


Figure 14 A cross-sectional view of test gallery in the underground limestone mine in Georgetown, KY

The simulated face is 20 feet wide and it is located at a depth of 45 feet from the crosscut. The gallery cross-cut width is the same as the entry width (20 feet). In Figure 14, solid lines show the boundaries of the test gallery, whereas dashed lines represent check curtain hanged from the ceiling. The test gallery is equipped with an axial fan powered by a 440V, three phase, 40 horsepower motor. The fan induces airflow in gallery and it is capable supplying a maximum of 18,000 cfm air at 60 Hz. Please see Table 1 for the fan specifications. Airflow in the gallery was

controlled using a variable frequency drive (VFD). Both, VFD and the 440V power supply were mounted on the wall of the test gallery, as shown in Figure 14.

Table 1 Main fan specifications

Manufacturer	Spendrup Fan Company
Model no.	090-040-1800-A-3-D
Serial no.	7333
RPM	1,800
Horsepower	40
Volts	460

2.3.1 DUST INJECTION

The use of coal dust in the underground limestone mine in Georgetown, KY was prohibited by the operator. Limestone rock dust of specific gravity 2.35 g/cc was used to introduce dust. Results of a laboratory test on a dust sample using the CILAS Particle Size analyzer is presented in Figure 15. The D_{10}, D_{50}, and D_{90} of the dust particles were found to be 1.21 µm, 5.76 µm, and 21.30 µm, respectively.

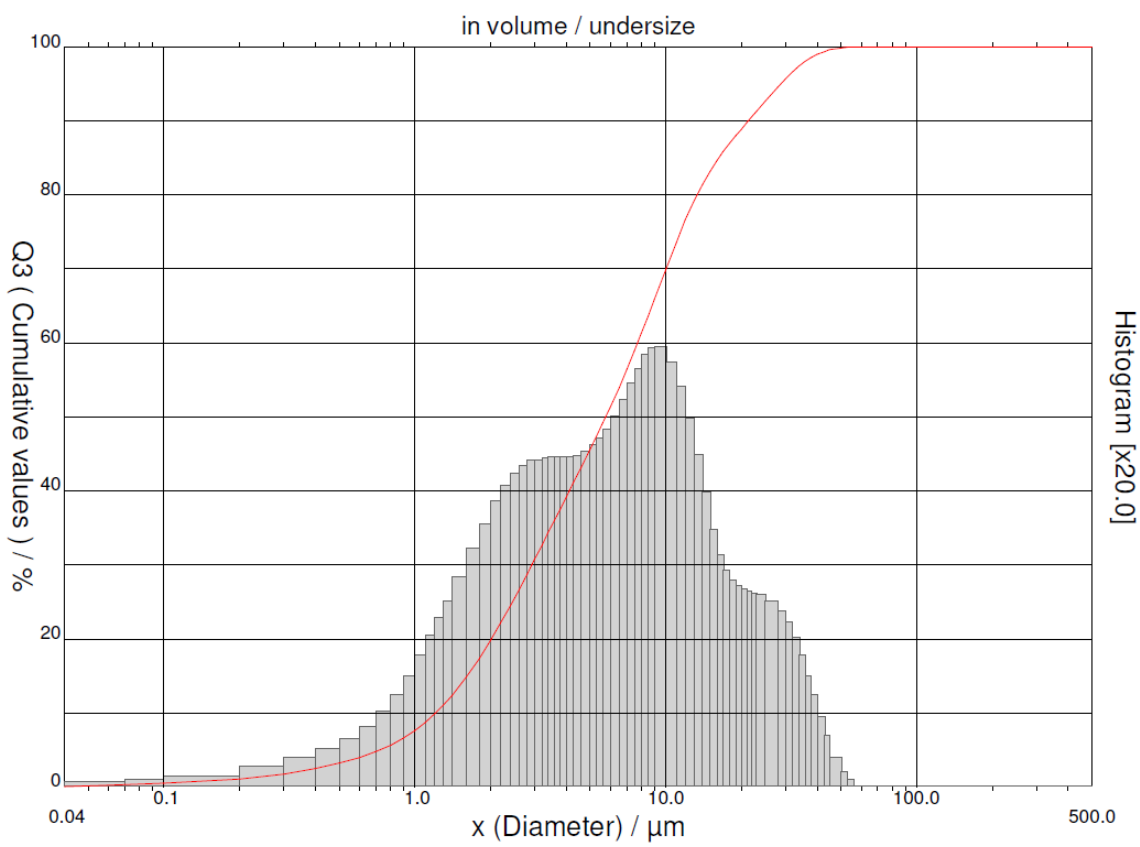


Figure 15 Particle size distribution of rock dust used in the Georgetown test gallery

Dust was introduced into the test gallery through a 10 ft. long, 4.0 in. diameter PVC pipe clamped to the front wall (face) of the gallery at a height of 6.5 feet from the floor. One end of the PVC pipe was plugged (sealed) while the other end was connected to a 1.5 in diameter flexible hose which was further connected to a rock dust feeder placed outside the test gallery, as shown in Figure 16. The PVC pipe had nine equally spaced, one-inch diameter holes with axis of the holes directed outby perpendicular to the face. The location of the PVC pipe varied along the face for different cut sequences in order to keep the pipe always in front of drum of the continuous miner to simulate dust generation due to cutting action of the continuous miner.

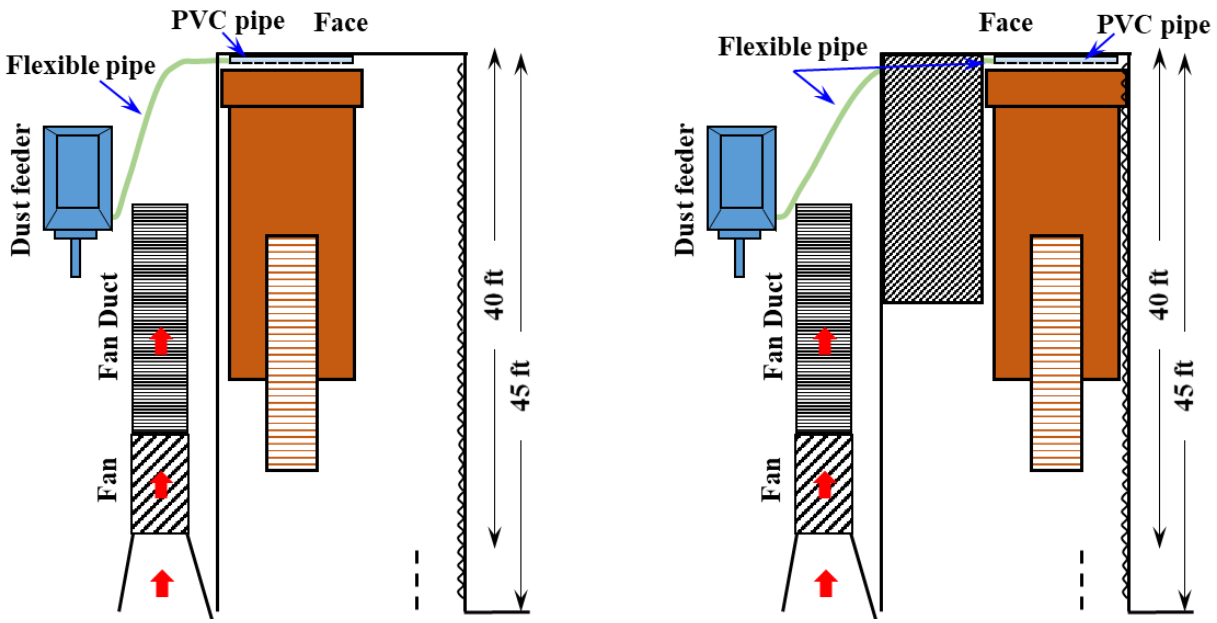


Figure 16. Dust injection system for different cut sequences.

No flow settings exist on the rock dust feeder which works by using a vibrating plate to feed into a venturi pump which introduces the dust into a stream of compressed air. At many points in the system, the fine dust has the ability to clog in several points inside the machine and in the delivery tube. Clogging is made worse in the presence of water and high humidity. At points in this report where dust is discussed, any measurements should be read as relative to the measurement made nearest the dust delivery pipe and not compared in absolute values between tests. As discussed in the next section, measurements were taken at set locations and in consistent times, only the concentration of dust delivered into the dust gallery was inconsistent.

2.3.2 DUST SAMPLING LOCATIONS

Dust concentration was measured at different sampling points located along the boundaries of the test gallery. The sampling points were placed at height of 60 inches from the floor and at a distance

of 12 inches from the boundary walls. Figure 17 shows the locations of the dust sampling point for two different cut sequences. All the measurements were taken from outside of the gallery. A 0.25-inch diameter, 2.5 feet long clear tube of was used at each sampling location with one end positioned inside the gallery and other outside. Dust sampling device was connected to the outside end of the tube and sample was collected.

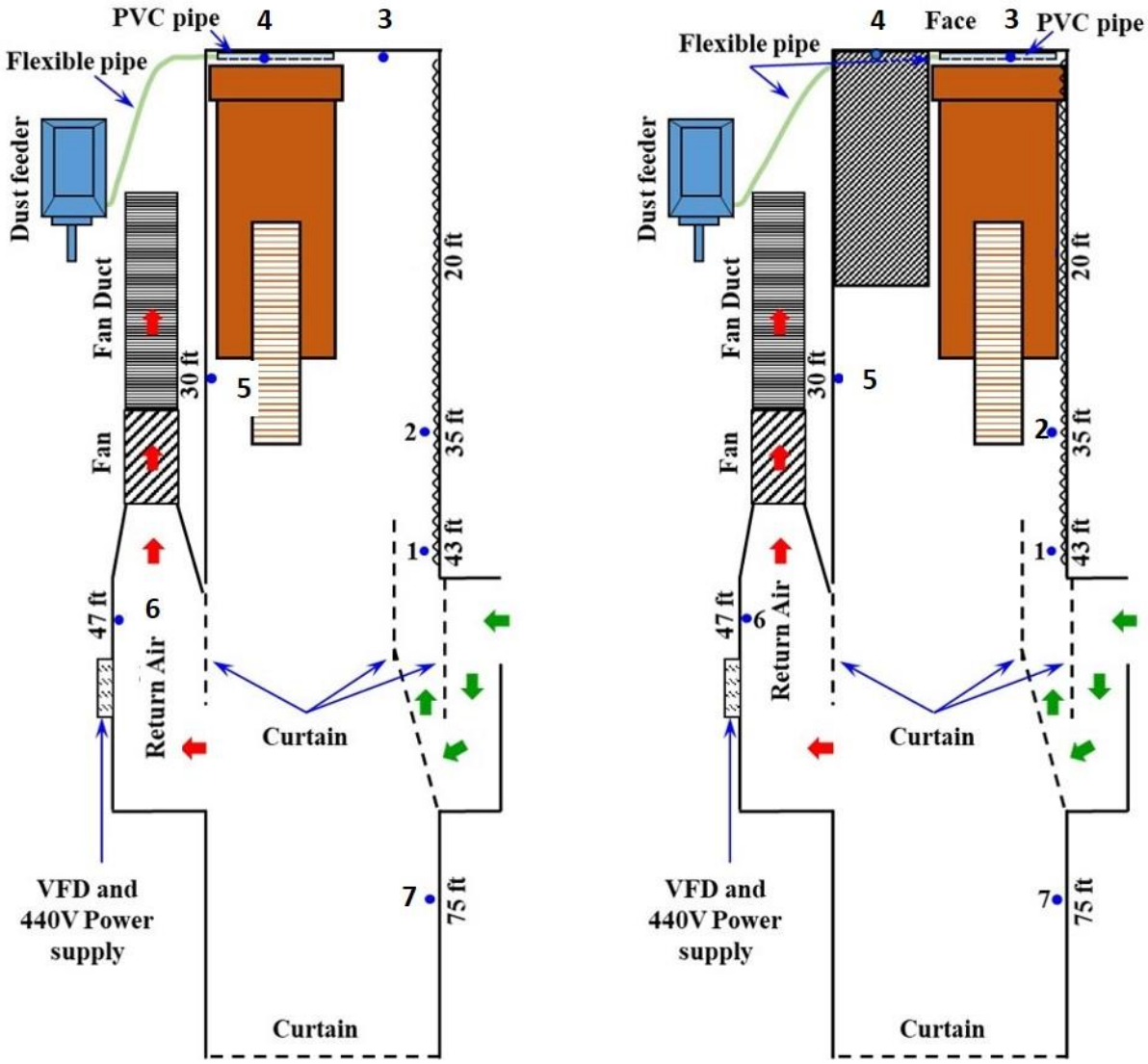


Figure 17 Dust sampling locations in the test gallery for different cut sequence.

2.3.3 DUST SAMPLING DEVICES

One of the main goals of this research was to minimize an operator's dust exposure level as well dust concentration in the return. Two different dust-sampling instruments were used to measure dust concentration at the dust sampling locations - personal dust monitor (PDM) and DustTrak. Personal dust monitors were used to measure dust concentration at the sampling location where

the operator is most likely to stand, DustTrak was used at rest of the sampling points. MX6 gas monitor was used to measure and report CO_2 gas concentrations.

PERSONAL DUST MONITOR

Thermo Scientific Personal Dust Monitors (PDMs) 3700 was used to measure dust concentration at the operator's location in the dust gallery. A PDM is a real-time particulate monitor developed by NIOSH and approved by MSHA for its use in underground coal mines' respirable dust concentration measurement. It meets MSHA intrinsic safety requirements and performs mass measurement with an accuracy of ±25% with 95% confidence, as compared to gravimetric reference samplers using similar cyclones, in the range of 0.2 mg/m^3 and greater.

Mass measurement is achieved through a filter-based direct mass monitoring instrument using a tapered-element oscillating microbalance (TEOM) and momentum compensation technology. The TEOM uses a Teflon coated fiberglass filter mounted on one end of a vibrating hollow tube, vibrating with a known frequency. The dust sample enters the system through the clip (PDM 3700) sample inlet and is carried through a cyclone. The air is then drawn into a heated tube and is made to flow through the TOEM vibrating hollow tube, resulting in deposition of dust particles on the fiberglass filter. Subsequently, the air is directed to the air-temperature and relative-humidity sensor and then exits the system through a pump.

The deposition of dust particles on the TOEM fiberglass filter changes its vibration frequency. This change in frequency is related to the mass of respirable dust that accumulates on the filter and hence, measures the respirable dust concentration. The dust measurements are displayed on the PDM screen and also stored in its memory.

Figure 18. ThermoFisher PDM 3700

Over the course of the testing done in this project the PDM was placed in the same location to approximate a single position for the miner operator. The data collected and displayed on the

device was used by the research team to approximate what dust levels would be communicated to the miner operator. This device measures both slowly and inaccurately as well as using a completely different technology from the DustTrak (described below). In order to avoid mixing two incompatible dust measuring technologies the data collect from this device is not presented in this report but is archived.

DUSTTRAK

DustTrak 8530 is a data logging, light-scattering laser photometer that provides real-time aerosol mass readings of dust, smoke, fumes, and mists. The machine measures aerosol concentrations corresponding to PM1, PM 2.5 and respirable PM10 or size fractions.

Figure 19. TSI DustTrak 8530

2.4 Experimental design

The experiment was designed to determine the effects of different factors on dust and CO_2 concentrations in the simulated room-and-pillar mine test gallery. A two-level, four-factors, full-factorial (2^4) design was preferred considering available resources, time, and cost of the experiments. The four factors included the cut sequence, the blowing curtain location, the scrubber quantity, and the wing regulator, discussed below. The associated low level and high level of these factors are listed in Table 2.

Table 2 Factors and levels for the experiment.

Factor	Label	Low (-1)	High (+1)
Cut sequence	A	Box cut	Slab cut
Blowing curtain location	B	25’	40’
Scrubber quantity	C	0 cfm	7,000 cfm
Wing regulator	D	Removed	Included

2.4.1 Cut Sequence

Figure 20 shows the four cut sequences that are employed at an extended-cut room and pillar mine section. Cut sequences 3 and 4, which are considered as the worst-case scenarios for the face ventilation purpose, were selected as low level and high level for the cut sequence factor, respectively.

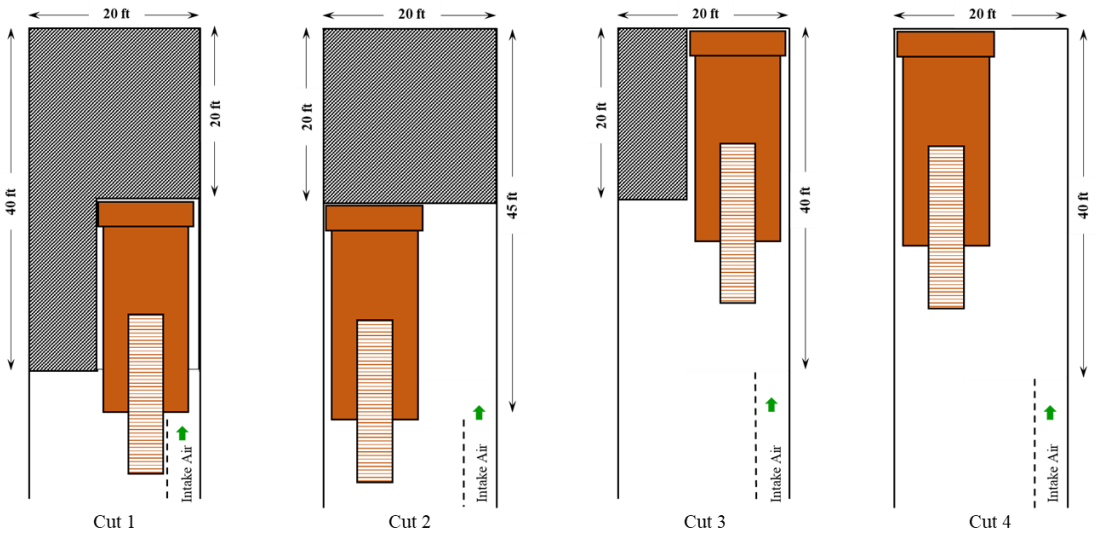


Figure 20. Cut sequence for an extended-cut room-and-pillar mine section.

2.4.2 BLOWING CURTAIN LOCATION

The distance of blowing curtain from the coal face varies for different cut sequences, as shown in Figure 20. In the cut sequences 1 and 2, the blowing curtain is placed 25 ft. outby from the face, whereas in cut sequence 3 and 4, the blowing curtain is 40 ft. outby from the face. The 25 ft. and 40 ft. curtain distances were considered as low level and high level for the blowing curtain factor, respectively.

2.4.3 SCRUBBER QUANTITY

Scrubber quantity is the amount of air drawn by the scrubber fan through the flooded-bed scrubber system. The variation in the scrubber quantity was achieved through a VFD control that allowed the scrubber's axial fan to induce 7,000 cfm airflow (high level) at 45% at rated voltage. The VFD used for the scrubber is separate from the one used for the main fan. The amount of air moving through scrubber system was determined through the multi-point traverse method. Multi-point traverse was performed at 25 different points on a cross-section 15 in. upwind of the center line of

the screen using a pitot-tube (Figure 21). The measured velocities were averaged, and then multiplied with the duct cross-sectional area to calculate the average airflow through the duct. During the velocity measurement, the scrubber spray was kept ON and its flow was maintained at 6.5 gallons per minute (gpm).

Table 3. Scrubber fan specifications

Manufacture	Spendrup Fan Company
Model no.	055-042-3600-A-2-D
Serial no.	7332
RPM	3,600
Horse power	30
Volts	460

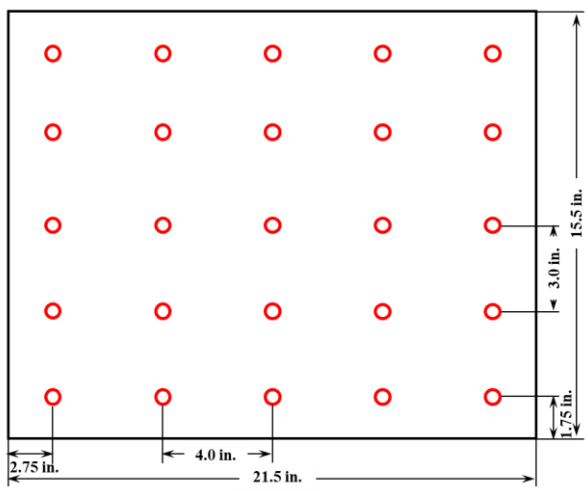


Figure 21. Location of measurement points at the cross-section upwind the flooded-bed screen

2.4.4 WING REGULATOR

The influence of wing regulator on dust and CO_2 concentrations in the test gallery was determined by presence or absence of the wing regulator on the discharge side of a blowing curtain, as shown in Figure 22. It was expected that placement the regulator would direct intake air to the face, and therefore, it will help reduce both flow separation and flow recirculation inby the end of the curtain and at the face, respectively. Markings were made on the floor and ceiling to ensure that the regulator was always in the same location and orientation, only one regulator was used in recorded testing. However, prototypes were substituted to test their design against the base line.

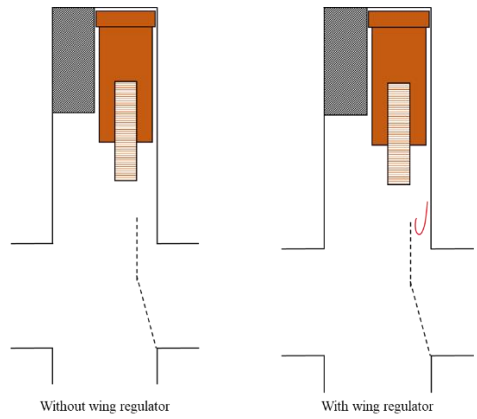


Figure 22. Experimental setting with and without wing regulator for the cut sequence 3

The full factorial experimental design for four factors at two levels resulted in a total of sixteen (2^4 = 16) experiments (treatments), as shown in Table 4. Each experiment was repeated three times, resulting a total sum of 48 (16 x 3) experiments (observations). The results (output responses) of each experiment, which were the respective dust and methane concentrations, are recorded and available in the Appendix. Analysis of the results is in the Research Findings chapter.

Table 4. Experimental design for four factors at two levels

Test Scenario	Cut sequence	Blowing curtain location (ft.)	Wing regulator	Scrubber quantity (cfm)
A1	Box-cut	25	-	0
A2	Box-cut	25	Included	0
A3	Box-cut	25	-	7,000
A4	Box-cut	25	Included	7,000
A5	Box-cut	40	-	0
A6	Box-cut	40	Included	0
A7	Box-cut	40	-	7,000
A8	Box-cut	40	Included	7,000
B1	Slab-cut	25	-	0
B2	Slab-cut	25	Included	0
B3	Slab-cut	25	-	7,000
B4	Slab-cut	25	Included	7,000
B5	Slab-cut	40	-	0
B6	Slab-cut	40	Included	0
B7	Slab-cut	40	-	7,000
B8	Slab-cut	40	Included	7,000

3. RESEARCH FINDINGS

The main goal of this research was to analyze the feasibility of the WR and its effect on face ventilation gas dilution ability and control of the respirable dust. The WR performance has been tested in full scale in equipment free entry and with the continuous miner (CM) in place. The test program was designed to provide information about the effect of the face ventilation control parameters, such as the curtain airflow quantity, scrubber flow rate and water sprays on the gas dilution and dust removal efficiency of the system. In order to determine the variability of each parameter, the effect of any of the control parameters was tested separately.

A series of scenarios for 8,000-cfm and 15,000-cfm curtain flow, denoted as "Low flow" and "High flow" in the data sheets, were tested. These flow amounts were the typical amounts that are part of the ventilation plans in the test site mines. This is also typical of the ventilation plans known to the consultants used on this project, even though this is a higher flow than the minimum required by regulation.

This series of tests included scenarios for 25-ft and 40-ft curtain setback distance to the face with conventional setup (blowing curtain, CM, machine mounted scrubber, etc.). As was described in the problem statement, it is well established that blowing ventilation works well for the 20-25-foot cut depth. The main reason to utilize the WR is to extend the airflow in the deep cut, which is limited by regulation to 40 feet total depth.

A repeatable series of tests were performed for 40-ft setback box cut and slab cut scenarios with the CM in place and the WR. This test series was performed to examine the consistency of the WR performance to improve the gas dilution and the dust control. Fixed curtain flow rate of 8,000-cfm, scrubber flow rate close to 7,000 cfm and fixed number of sprays were applied for all the tests in this series.

In the course of performing the experimental design that was presented in the previous chapter the examiners determined that many tests would yield overlapping results and did not need to be performed separately. The primary variable under test is the presence of the WR, not all combinations of the other mitigation controls was examined. Any tests with interesting or anomalous results were repeated.

A series of CFD simulations were generated to support the test results and for better understanding the process of face ventilation. These simulations were used in the design of experiments and in the dust gallery construction but also offer insight into properties that we are unable to measure, even in the dust gallery.

3.1 Equipment-free test series

This test series was a necessary starting point to learn about the lab behavior and to visualize the flow patterns with and without the WR (Figure 23 to Figure 30). On every figure the locations where the velocities were measured are noted with blue circles. Every triad of numbers denoted the velocity (ft./min), from top to bottom, measured at one foot below the roof, in the middle height, and one foot above the floor. The blue colored numbers indicated the primary stream velocities, the purple numbers are for the secondary stream velocities if flow separation takes place, and the red numbers showed the return stream velocities. Every figure presents data for both, the conventional face ventilation system and the system with a WR applied. The intake/curtain flow (Qc), the flow directions and the average flow velocity behind the curtain are shown. For the scenarios with flow separation the flow patterns are sketched and the flow separation distance from the curtain end is dimensioned.

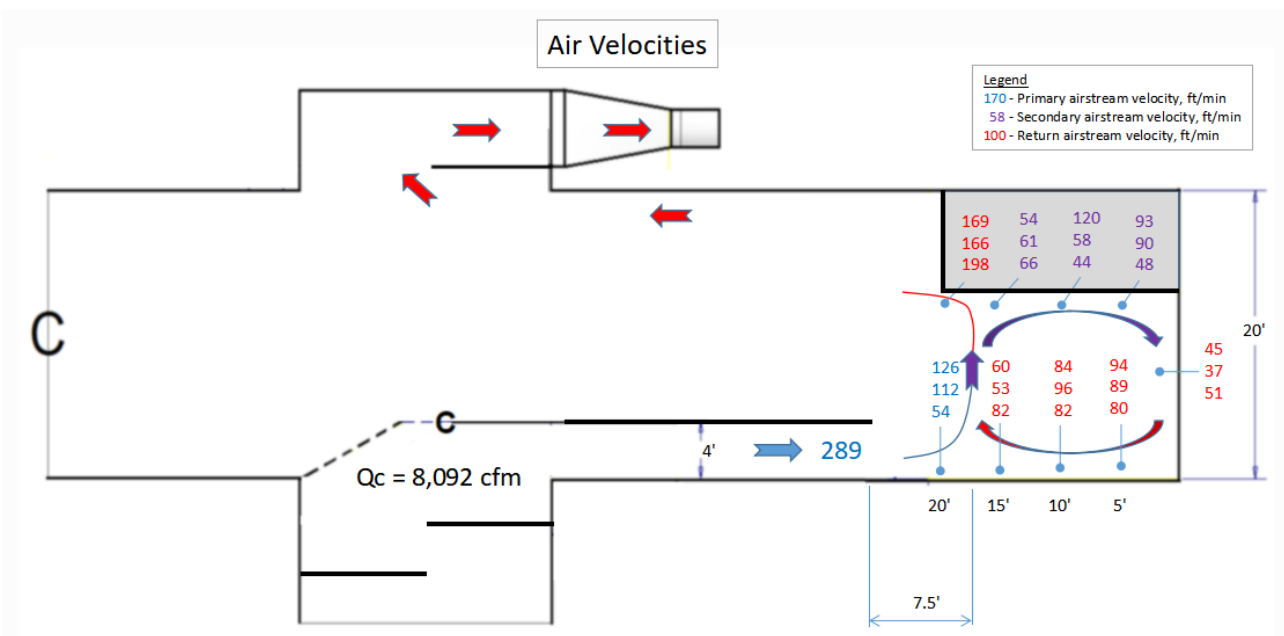


Figure 23 Lab test scenario for airflow velocity measurement, 25-ft setback with slab, conventional setup

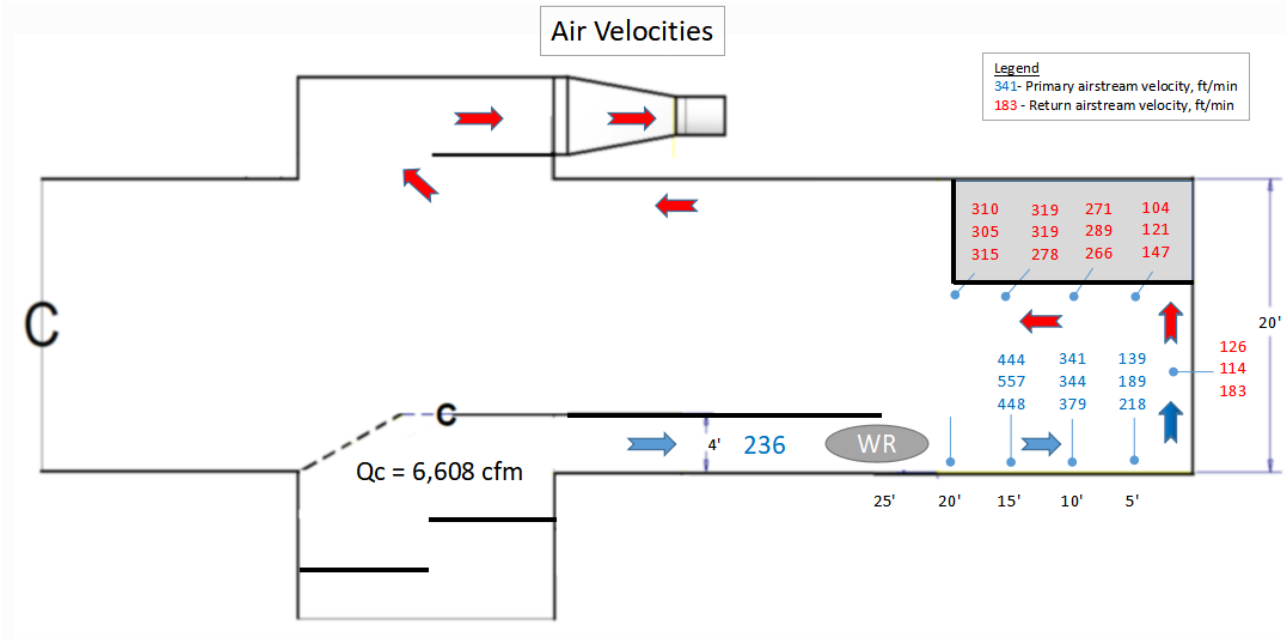


Figure 24 Lab test scenario for airflow velocity measurement, 25-ft setback with slab, WR setup

The presence of the slab causes a dead end with higher static pressure to form, which causes early separation of the intake stream. The flow separation that is shown on Figure 23 is not present in Figure 24, where the only change is the wing regulator. No adjustment of the curtain airflow rate has been made by the examiners after the conventional scenario (Figure 23). The airflow behind the curtain is lower for the WR scenario (Figure 24) because of the shock losses induced by the wing. The pressure loss caused by the wing regulator is close to 5 Pa (0.02 in H_2O).

Figure 25 shows the intake airflow separates from the rib 17.5 feet after the curtain end. When the WR is present the air is sweeping the face in much higher speed and goes to the return without flow separation, see Figure 26.

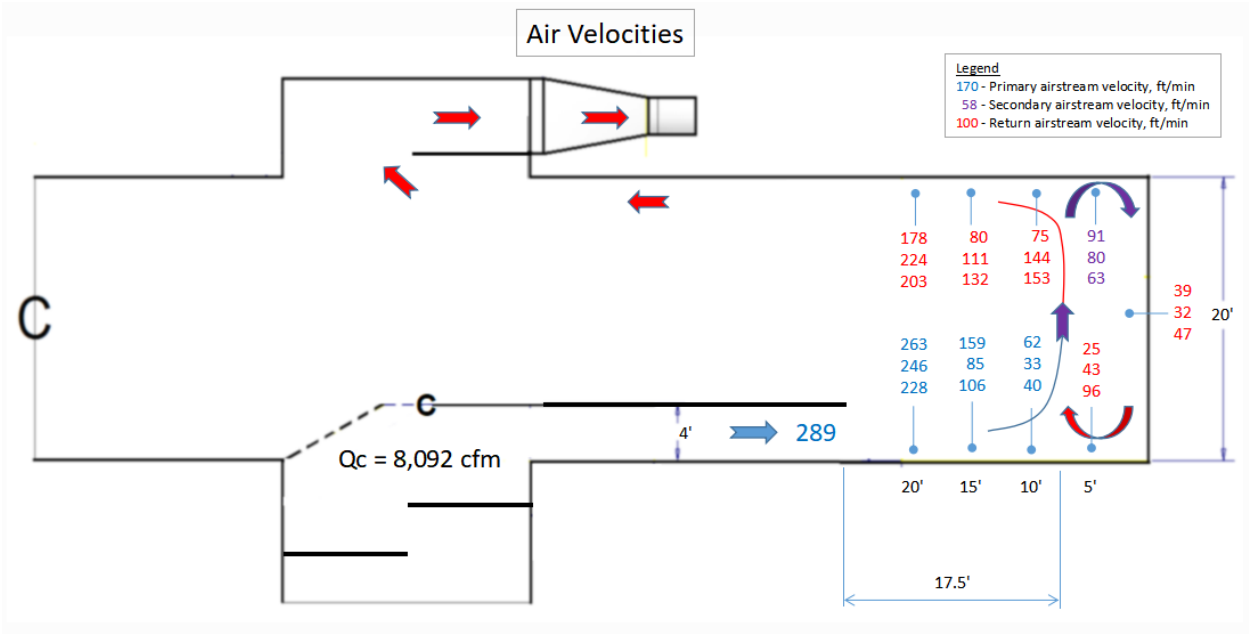


Figure 25 Lab test scenario for airflow velocity measurement, 25-ft setback, conventional setup

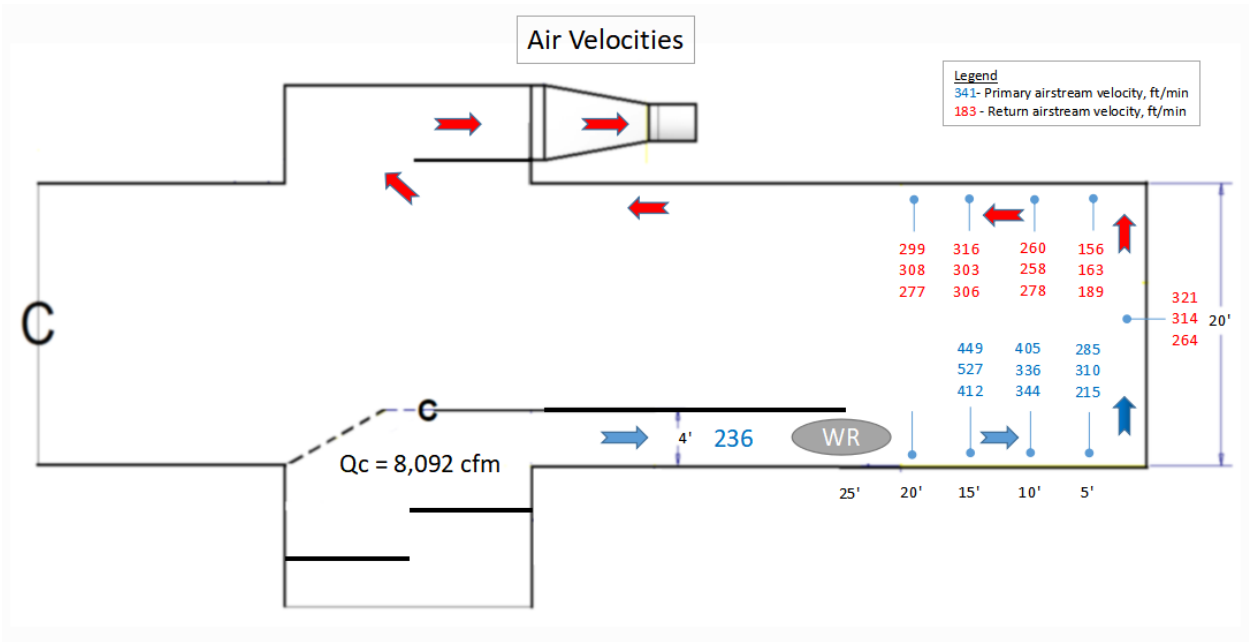


Figure 26 Lab test scenario for airflow velocity measurement, 25-ft setback, WR setup

The base case scenario involved box cut with the curtain set at 25'. The wing regulator was absent and the scrubber fan was turned off. This also corresponds to low values of all parameters on Table 5 in this document. This is the most common scenario that is presented in the literature. We consider this to be the scenario for the initial setup of the ventilation arrangement before the cut is started. The scenarios shown in Figure 27 and Figure 28 were not practical, but they were the worst

case scenario. It's is presented for comparison purposes. With conventional blowing curtain, the flow separates in 17 ft after the curtain end (Figure 27).

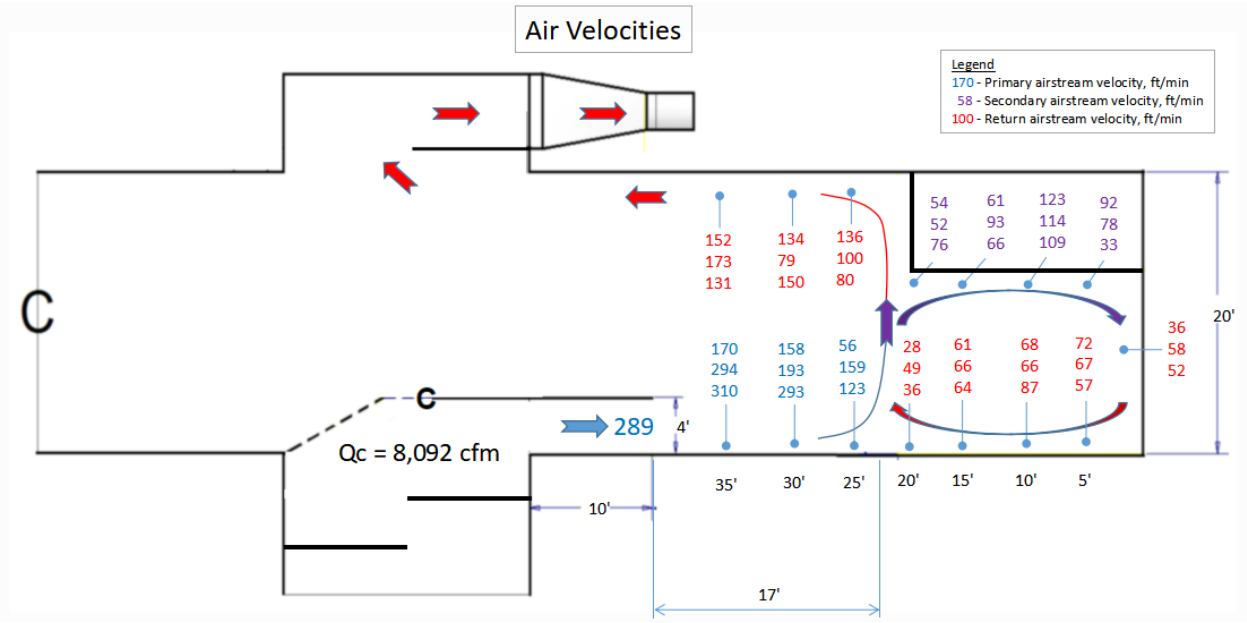


Figure 27 Lab test scenario for airflow velocity measurement, 40-ft setback with slab, conventional setup

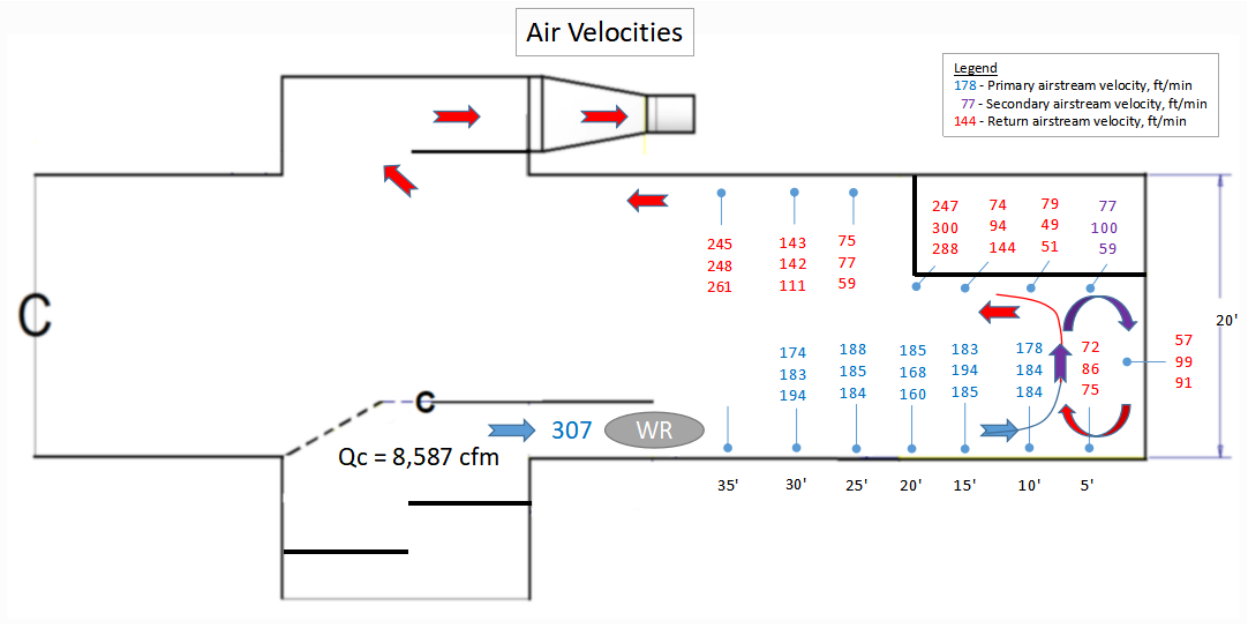


Figure 28 Lab test scenario for airflow velocity measurement, 40-ft setback with slab, WR setup

If the slab is extended to more than 20 ft., the flow will go from the end of the intake curtain to the corner of the slab, effect that was observed by the examiners. The scenario depicted on Figure 29

and Figure 30, is the typical case showing the area after the miner has completed the cut. Here again, the separation is occurring before the air is able to sweep the face. With the presence of the WR, the increased velocity allows the air to flow much further along the rib to almost five feet remaining distance to the face.

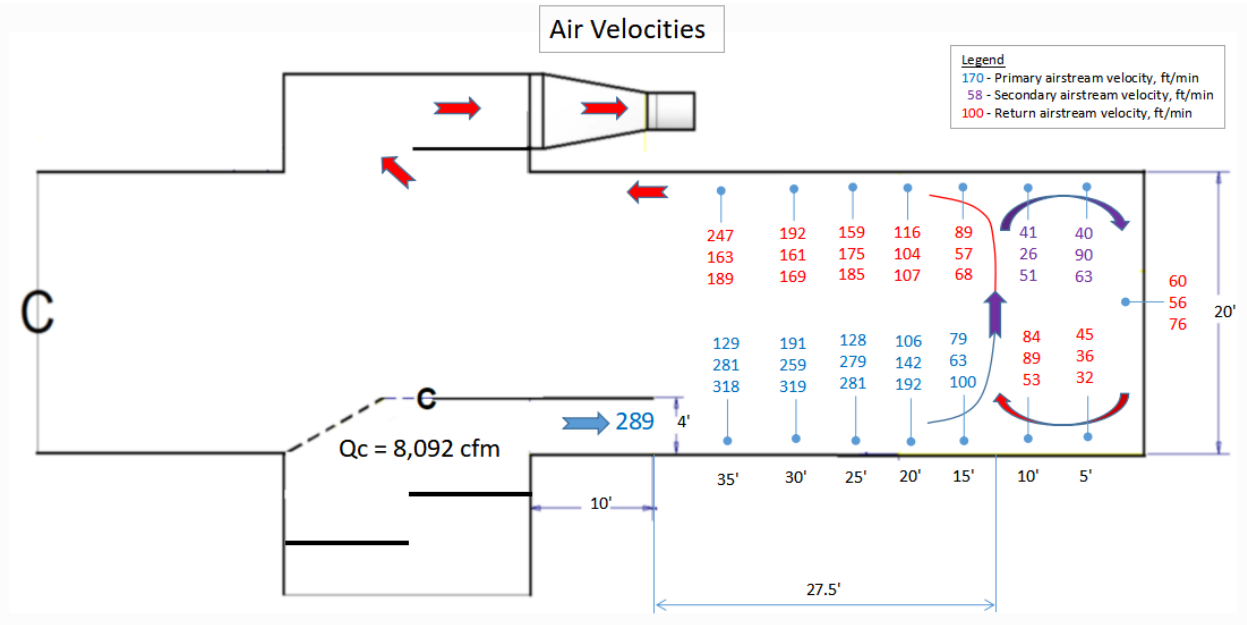


Figure 29 Lab test scenario for airflow velocity measurement, 40-ft setback, conventional setup

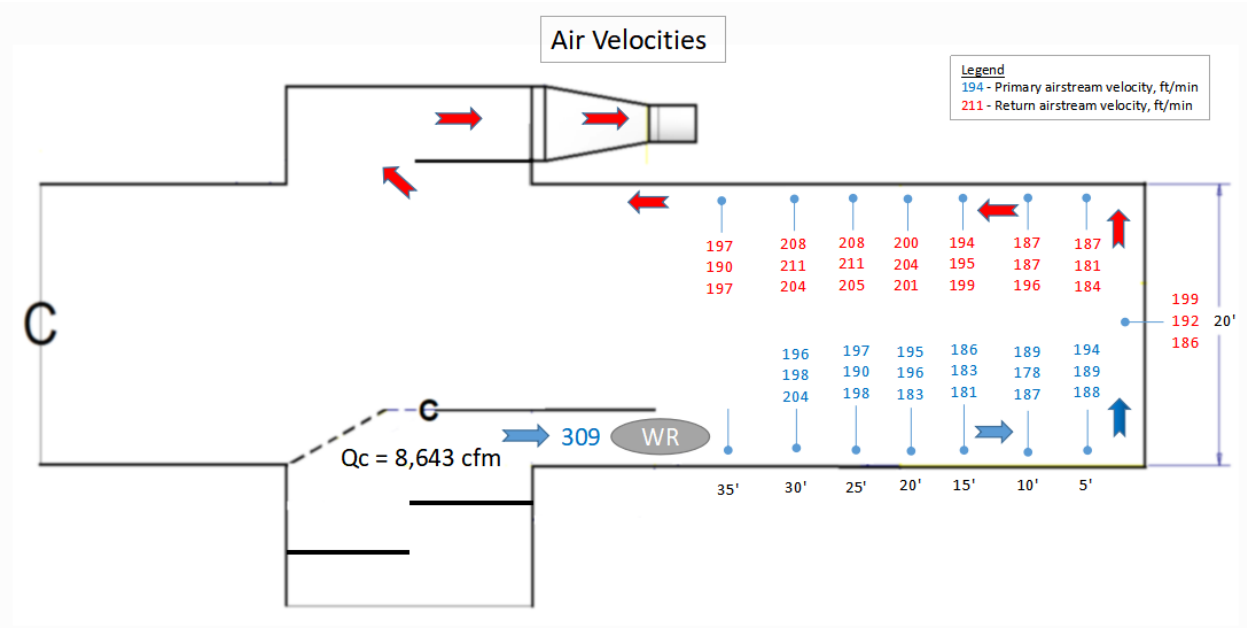


Figure 30 Lab test scenario for airflow velocity measurement, 40-ft setback, WR setup

A CFD simulation similar to the conventional scenario given on Figure 27 is shown on Figure 31.When the WR is introduced, the air is sweeping the face at a reasonable velocity. CFD simulation of the WR scenario for 40-ft setback is shown on Figure 32.

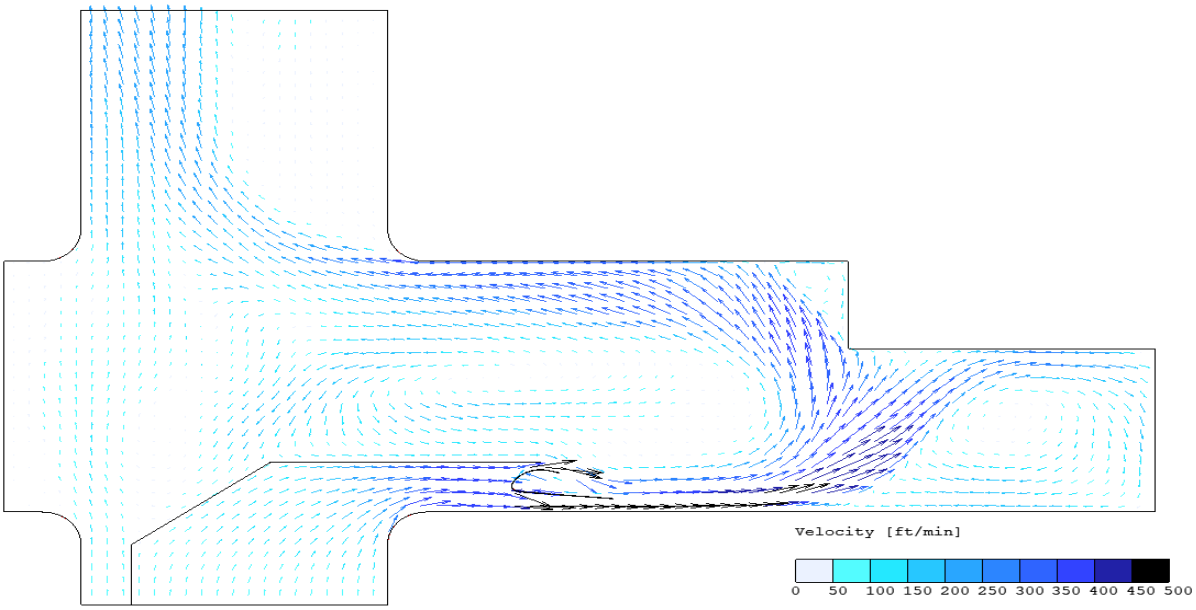


Figure 31 CFD results for equipment free entry with the WR , 40-ft setback with slab

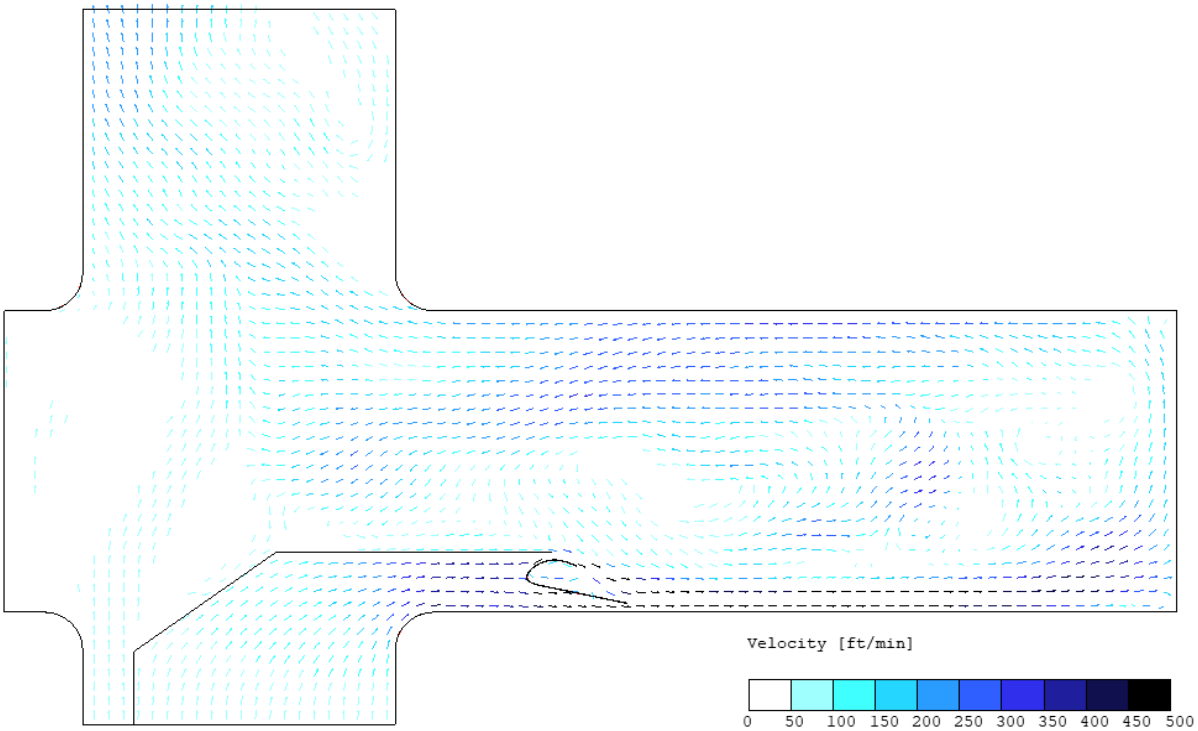


Figure 32 CFD results for equipment free entry with the WR , 40-ft setback, open entry

SUMMARY OF THE EQUIPMENT-FREE TEST RESULTS

These tests show two to three times higher velocities at the face with the WR applied. The WR effect is better for the open entry than for the scenarios with slab, where the intake flow developed by the WR penetrated to the face without separation to 40 ft. In the scenarios with slab for 40 ft. setback the WR intake flow extended the penetration distance from 17 ft. for the conventional curtain to 33 ft. with WR by increasing the air velocity at the face with 40% higher than the conventional curtain was able to achieve.

3.2 Test series with CM in place

To investigate the effect of the scrubber quantity and the WR on the face ventilation gas and dust control ability, twelve tests were performed by varying the parameters given in Table 5, one at a time. The CO_2 gas measurements are the primary means of measuring the effect of the scrubber air quantity and the WR on the face ventilation system gas dilution ability and dust reduction efficiency. Dust injection and measurements have shown volatile readings, as explained in the design of experiments. Therefore, the dust concentration data should be interpreted secondarily to the gas concentration data.

Table 5 shows the 4 parameters that are varied during this sequence of tests. The scrubber in this sequence is either on at 7,000 cfm or off. An example set of test data sheet is provided on Figure 33. Table 6 and Table 7, are the expanded set of tests with the measurements taken at the standard points for 25 ft. and 40 ft., respectively. The curtain flow rate was fixed at 8,000 cfm and no body spray was used.

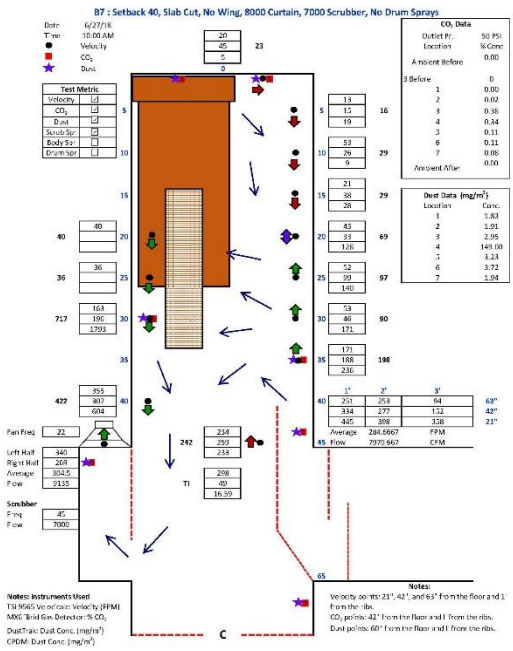
Table 5 Variable test parameters

Parameter	Low (-1)	High (+1)
Type of the cut	Box-cut	Slab-cut
Curtain setback	25’	40’
Scrubber quantity	0 cfm	7,000 cfm
Wing regulator	Removed	Included

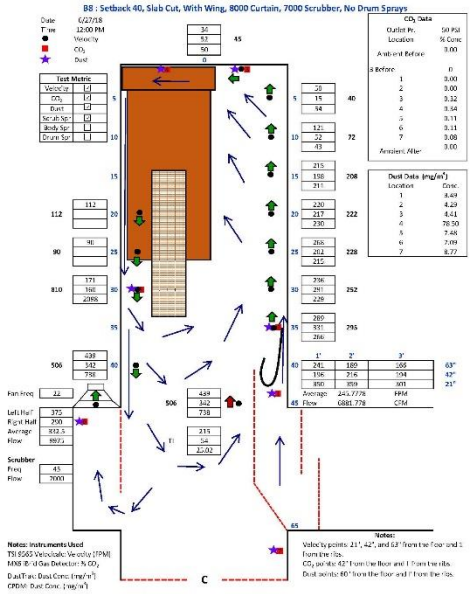
For this set of tests, gas and dust measurements were carried out at seven stations for CO_2 gas and dust respectively. *The station point locations (PT1 to PT7) are located as follows: PT1 is placed behind the curtain for the all scenarios at about 45-ft to the face; PT2 is at 35-ft to the face and falls behind the curtain for the 25-ft setback scenarios and five feet ahead of the curtain end for the 40-ft setback scenarios; PT3 and PT4 are located at the face; PT5 is located at the off-curtain rib, 30-ft from the face; PT6 is at the return stream, close by the fan inlet; and PT7 is close by the check curtain at the curtain side of the entry.* Ambient readings were also taken to account for injection of dust or gas from outside the gallery. Limestone dust could not be injected close to the continuous miner drum with consistency over the duration of testing. The difference in gas

concentrations reported by the MX6 gas monitor is the gas reduction capability of the WR and scrubber system operational in tandem. The transportation of CO_2 gas was assumed to mimic the transportation of dust clouds. It was more reliable compared to dust measurements due to consistency of gas injection and ease of measurement. Details of CO_2 gas concentrations have been achieved, a repetitive test case has been shown later in this report.

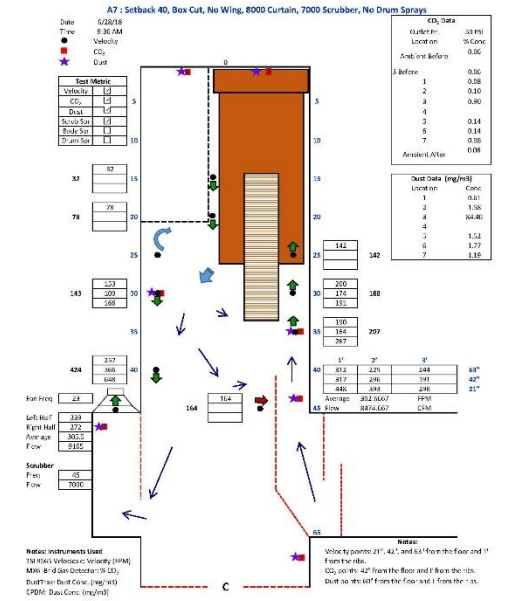
Every station represents a specific role in the data interpretation. PT1 indicates the intake concentrations, PT2 is providing data for the concentration changes at the CM's operator location, except the 25-ft setback scenarios, where it falls behind the curtain. The other points indicate the values as the air flows through the dust gallery and equipment in the gallery.



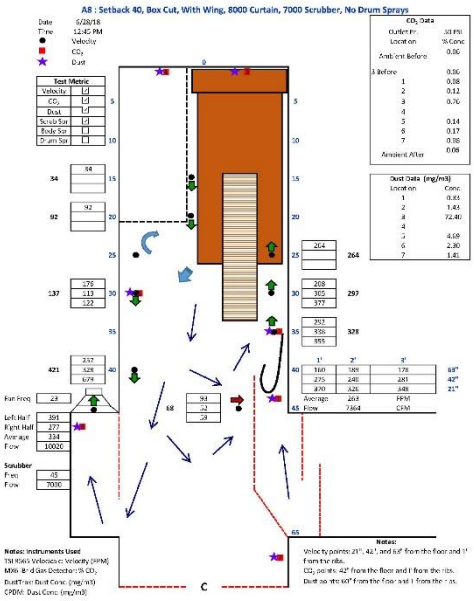
Test B7



Test B8



Test A7



Test A8

Figure 33 An example set of data sheets

PT3 and PT4 are the stations where the data for the face concentrations were collected. In the box-cut scenarios, PT4 falls behind the slab and is not applicable for data collection. PT5 data indicate

the immediate return flow concentrations, including the effect of the scrubber exhaust jet. PT6 monitors the concentrations at the return, and the PT7 readings can provide information for the magnitude of the recirculation caused by the scrubber exhaust. The same stations were used for dust and gas measurements. Ambient value of CO_2 in the underground laboratory was measured to be 0.03 % and remained unchanged for entire duration of experiments.

The tracer gas is the most measurable, repeatable and representative data, the gas data will be discussed in detail.

Table 6 Test data for the effect of the scrubber and the WR on the CO_2 concentrations for 25-ft setback curtain distance to the face

Test #	B1	B2	B3	B4	A1	A3	A4
Curtain Setback	25’	25’	25’	25’	25’	25’	25’
Type of the cut	Slab	Slab	Slab	Slab	Box	Box	Box
Scrubber flow rate [cfm]	0	0	7,000	7,000	0	7,000	7,000
Wing Regulator		WR		WR			WR
CO_2, %							
Test #	B1	B2	B3	B4	A1	A3	A4
PT1	0.17	0.17	0.14	0.17	0.06	0.06	0.06
PT2	0.22	0.17	0.17	0.19	0.06	0.06	0.06
PT3	0.47	0.19	0.33	0.22	1.78	1.11	0.53
PT4	0.64	0.42	0.44	0.36			
PT5	0.25	0.36	0.25	0.28	0.08	0.14	0.19
PT6	0.25	0.25	0.22	0.25	0.14	0.11	0.17
PT7	0.17	0.17	0.22	0.25	0.06	0.08	0.11
Ambient	0.17	0.17	0.14	0.17	0.06	0.06	0.06

Table 7 Test data for the effect of the scrubber and the WR on the CO_2 concentrations for 40-ft setback curtain distance to the face

Test #	B5	B6	B7	B8	A5	A7	A8
Curtain Setback	40’	40’	40’	40’	40’	40’	40’
Type of the cut	Slab	Slab	Slab	Slab	Box	Box	Box
Scrubber flow rate [cfm]	0	0	7,000	7,000	0	7,000	7,000
Wing Regulator		WR		WR			WR
CO_2, %							
Test #	B5	B6	B7	B8	A5	A7	A8
PT1	0.11	0.11	0	0	0.06	0.08	0.08
PT2	0.11	0.11	0.02	0	0.06	0.10	0.12
PT3	1.08	0.42	0.38	0.32	2.06	0.90	0.76
PT4	0.97	0.61	0.34	0.34			
PT5	0.19	0.19	0.11	0.11	0.31	0.14	0.14
PT6	0.19	0.19	0.11	0.11	0.14	0.14	0.17
PT7	0.14	0.14	0.08	0.08	0.06	0.08	0.08
Ambient	0.11	0.11	0	0	0.06	0.06	0.06

3.2.1 IMMEDIATE FACE AREA

The test data have shown that the scrubber alone helps to decrease the gas concentration at the face (PT3 and PT4) by approximately 30% to 38% for the 25-ft setback scenarios. The scrubber effect was stronger for the scenarios with a slab (box-cut). For the 40-ft setback box-cut scenarios, switching the scrubber on decreased the face gas concentration by 55%. With extending the curtain setback from 25 to 40 ft. the gas concentration at the face was not affected significantly (less than 2%). Although the baseline values of absolute CO_2 concentration did not show any trends with length of curtains, the experiments were run on different days. Ambient CO_2 concentration on those days were different. To account for the ambient concentrations calculations are relative to ambient concentration.

By implementing the WR with the scrubber switched on in a curtain set back distance of 25 ft, the face gas concentration dropped with another 33% to 52% for the scenarios with and without slab respectively. The WR alone, without scrubber turned on, delivered more than 60% decrease in

face gas concentration compared to the conventional curtain. No sprays have been applied during the tests.

3.2.2 RECIRCULATION INVESTIGATION

The CM scrubber exhaust creates very strong jet which, interacting with the walls of the entry develops recirculation patterns which induces flow of return air inby the face (Figure 34). This recirculation zone enables the scrubber to have multiple passes to remove dust particles from the contaminated airstream. The gas is transported back to the face by rejoining the intake airstream. The described air-curtain effect is also apparent on Figure 39 to Figure 41 later in this report.

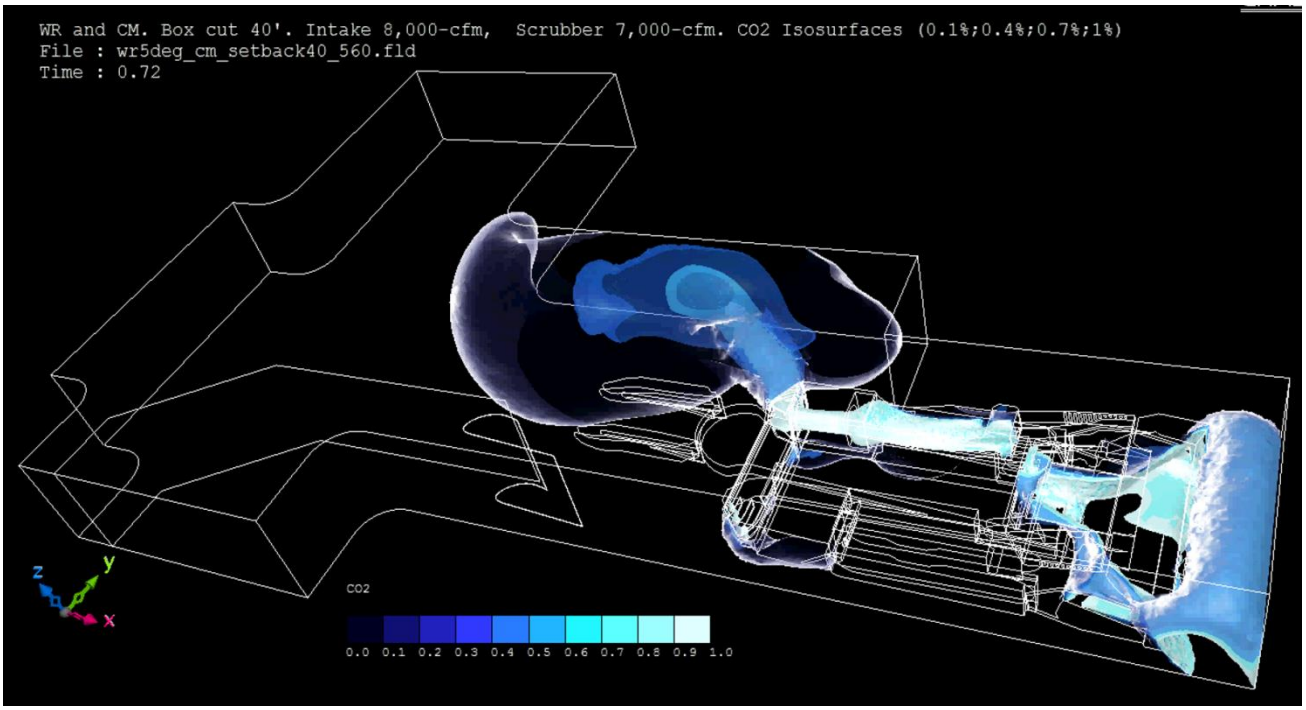


Figure 34 Visualization of the scrubber exhaust jet recirculation patterns using tracer gas concentration isosurfaces

The aforementioned recirculation patterns were observed and visualized in mine environment and in the lab using smoke and roof hanged flow markers.

3.2.3 SCRUBBER AIR QUANTITY EFFECT

To quantify the scrubber flow rate effect on the air quantity reaching the immediate face area a series of CFD simulations were performed in addition to the performed tests. For this study, a basic scenario with the scrubber switched off and curtain air quantity of 12,000 cfm was simulated to estimate the maximum, for the tests series, amount of air reaching the immediate face area. Then the scrubber flow rate was fixed at 8,000 cfm and the curtain flow rate decreased in steps from 12,000 cfm to 4,000 cfm to achieve scrubber to curtain flow ratio (Qscr/Qc) in range of 0 to 2.

Twelve simulations in total for both, open cut and box cut were performed. The scrubber to curtain flow ratio, the air quantity reaching the immediate face area, was estimated using the vector integration technique. The area where the face air quantity was estimated is depicted in Figure 35. For the box-cut scenarios the distance of the measurement area to the rib has been set to one foot.

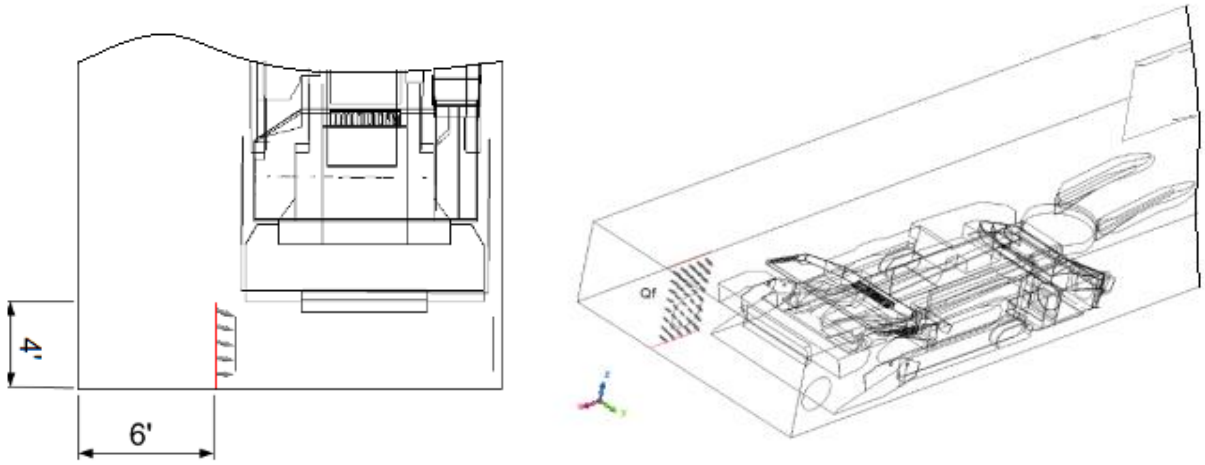


Figure 35 Immediate face zone measurement area

The data showed that the air quantity reaching the face decreases when the Qscr/Qc is increased from 0 to about 0.8 and after that becomes insensitive. This result indicates that the effective range of the face ventilation system performance can be achieved when the scrubber flow rate is lower than the curtain air quantity (Qsc/Qc <1). The results also showed that any arrangements, where the scrubber flow rate exceeds the curtain flow rate will have insignificant effect on the actual air quantity reaching the immediate face area, but will intensify the recirculation flow caused by the scrubber exhaust, thus increasing the contaminants rollback to the operator place and to the face, at the expense of more energy and noise.

The goal of this exercise was to increase the airflow towards the active face so that the methane generated at the face is swept away, immediately. This is difficult to achieve without the wing regulator. With regular ventilation controls, the gases are trapped in circulatory flow patterns close to the face. Scrubber flow assists in speeding up the airflow and traps particles from close to the active face. At the (Qscr/Qc) ratio of 0.8, the flow behind the curtain was 10,000 cfm which corresponds to an airflow of 8,000 cfm through the scrubber.

3.2.4 REPEATED TESTS FINDINGS

Design of experiments yielded sixteen tests to be carried out for four independent factors. The factors were curtain flow rate, scrubber flow rate, curtain set back, and wing regulator installation. All tests runs were repeated three times to obtain a good repeatable representative experimental data. The repeated tests have confirmed the consistency of the data readings and the stable behavior of the WR. Presence of wing regulator encouraged the ventilation airflow to reach closer to the active face. CO_2 gas concentration was alleviated due to the ventilation airflow in all the extraction configuration. As an example, the tests results for 40 ft. setback with curtain air quantity 8,000 cfm and scrubber flow rate 7,000 cfm, as the most difficult to ventilate in slab cut case scenario, are summarized in Table 8. Figure 36 shows the range and average gas concentrations with and without the wing regulator at the sampling location PT4. Data for all other sampling locations have been archived. The data showed that the presence of the wing regulator significantly decreases the gas concentration at the face compared to the conventional method of blowing face ventilation.

Table 8 Summary of the average CO_2 data presented in average CO_2 concentrations in %

Station Point #	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Conventional	0.18	0.22	0.28	1.91	0.29	0.28	0.22
WR	0.12	0.16	0.19	1.25	0.21	0.21	0.13

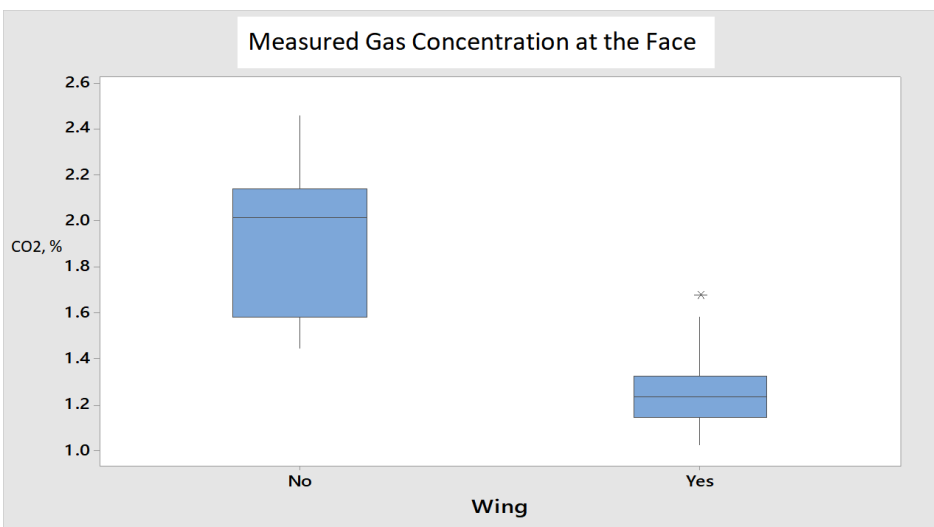


Figure 36 Statistical chart of gas concentration measurements for the box cut scenario, presenting the effect of the WR

Figure 36 illustrates the improvement of the face ventilation system to dilute gas in the presence of the WR. The data showed decrease in gas concentration at all measurement points around the continuous miner (stations 3, 4 and 5) and most significant at the face station 3 which accounts for

both slab and box cut scenarios. This decrease in gas concentration is shown in Figure 37. Figure 38 shows the same data without the outlier point 4 present in the set. The outlier point is due to the proximity of this sampling location to the gas injection.

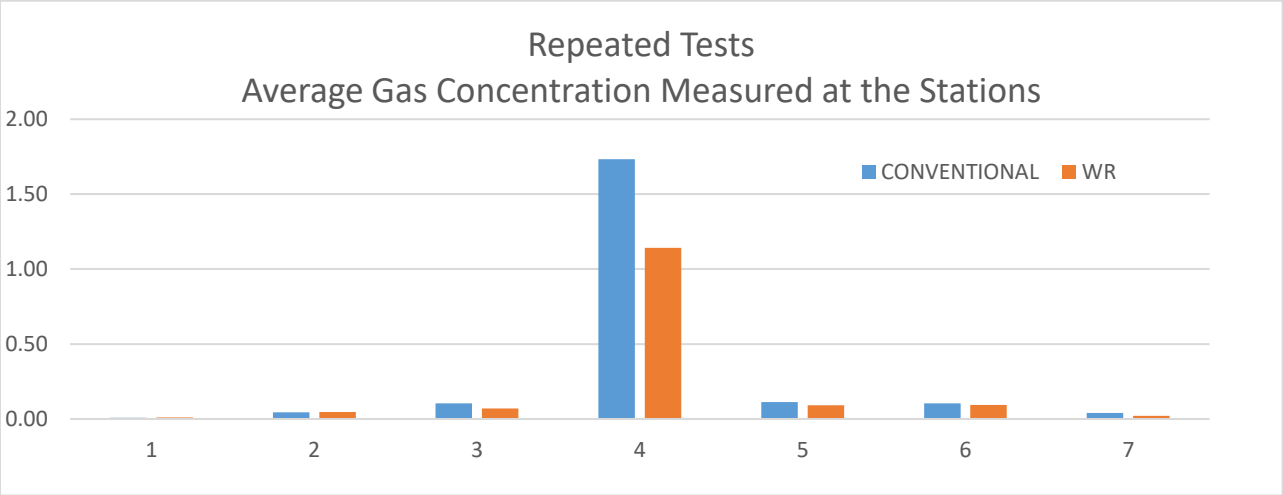


Figure 37 CO_2 concentration contour plot for 40-ft setback scenario, curtain air quantity 8,000-cfm, Scrubber flow rate 7,000-cfm, all stations depicted

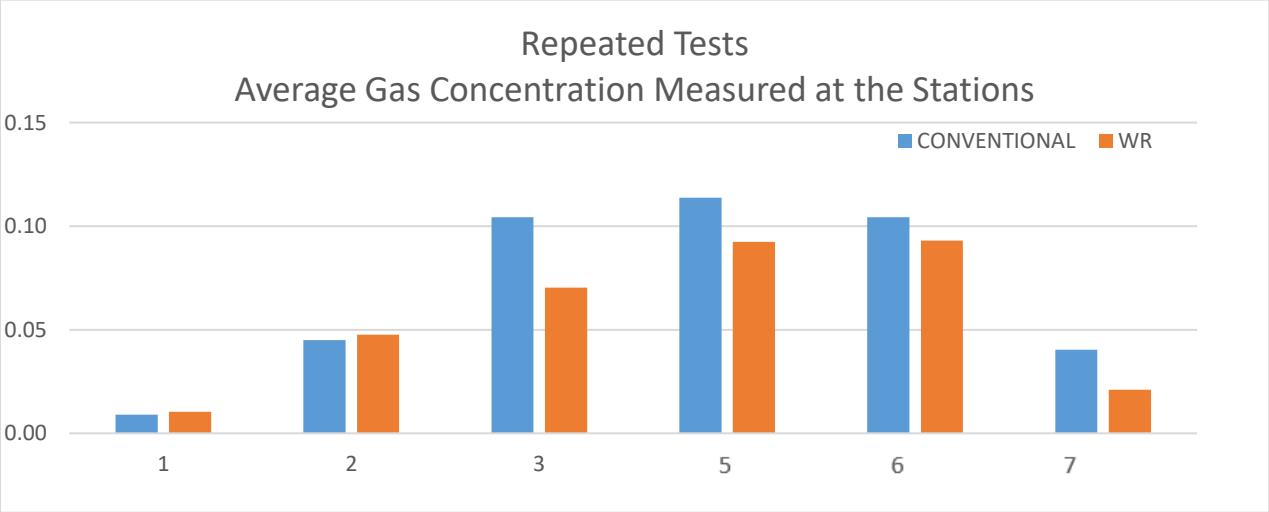


Figure 38 CO_2 concentration contour plot for 40-ft setback scenario, curtain air quantity 8,000-cfm, Scrubber flow rate 7,000-cfm, station 4 removed

To visualize the effect of the wing, a series of CFD simulations were performed following the tests scenarios conditions. Figure 39, presents CO_2 contour plot for a scenario similar to B4 test for 40 ft. curtain setback distance to the face and the WR presented. The influence of flow on airflow patterns due to presence of the scrubber is discernible when compared to conventional set up without the wing regulator.

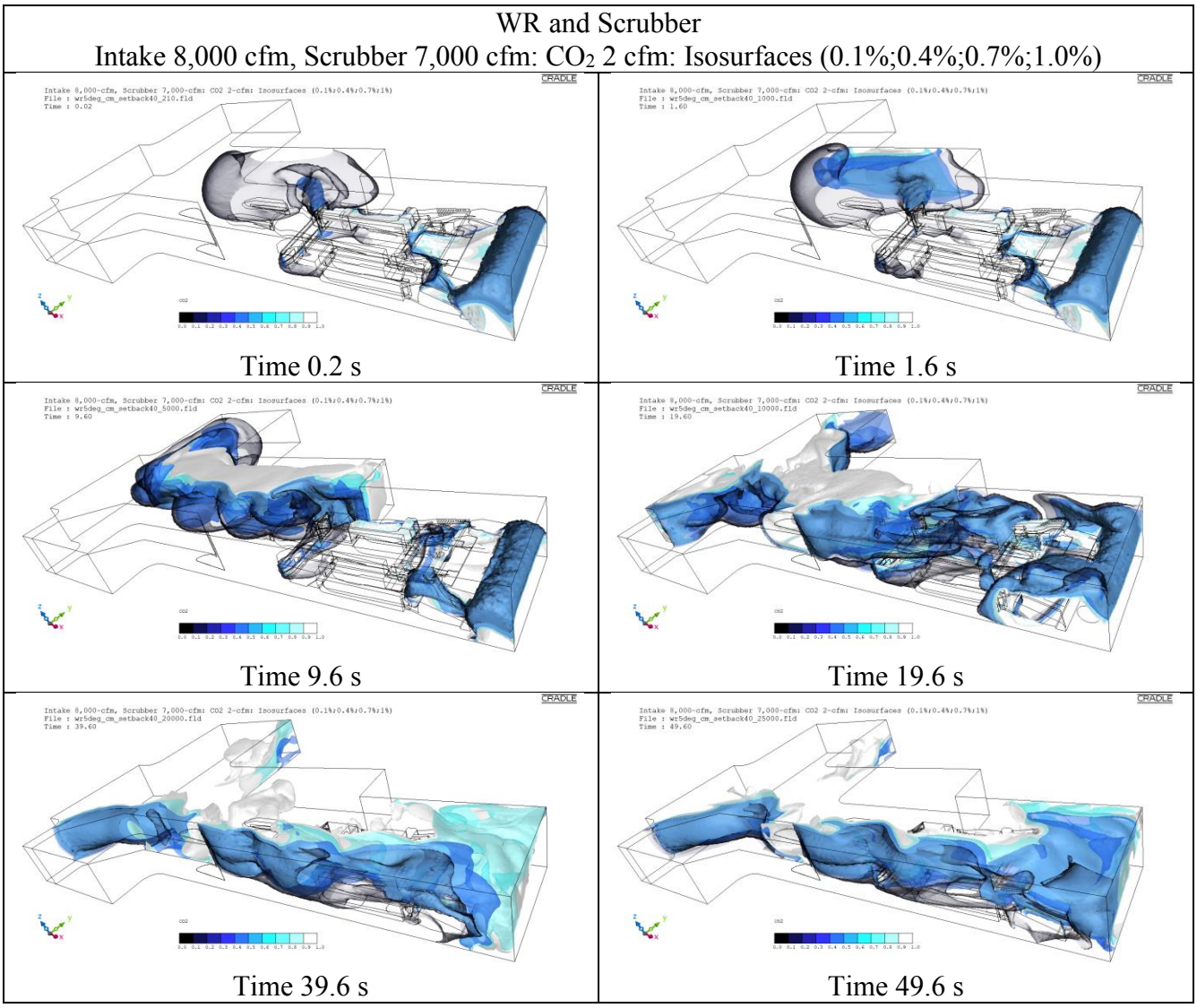


Figure 39 CFD simulation results for a face ventilation setup similar to repeated test B3 scenario

CFD models were also generated to demonstrate the influence of water spraying action due to the drum mounted nozzles on the CO_2 concentration. Water spray fine droplets with higher momentum work as powerful air movers. This effect, though local, breaks up CO_2 clouds which move towards the main exhaust fan. Effect of the sprays on the gas concentrations is illustrated on Figure 40.

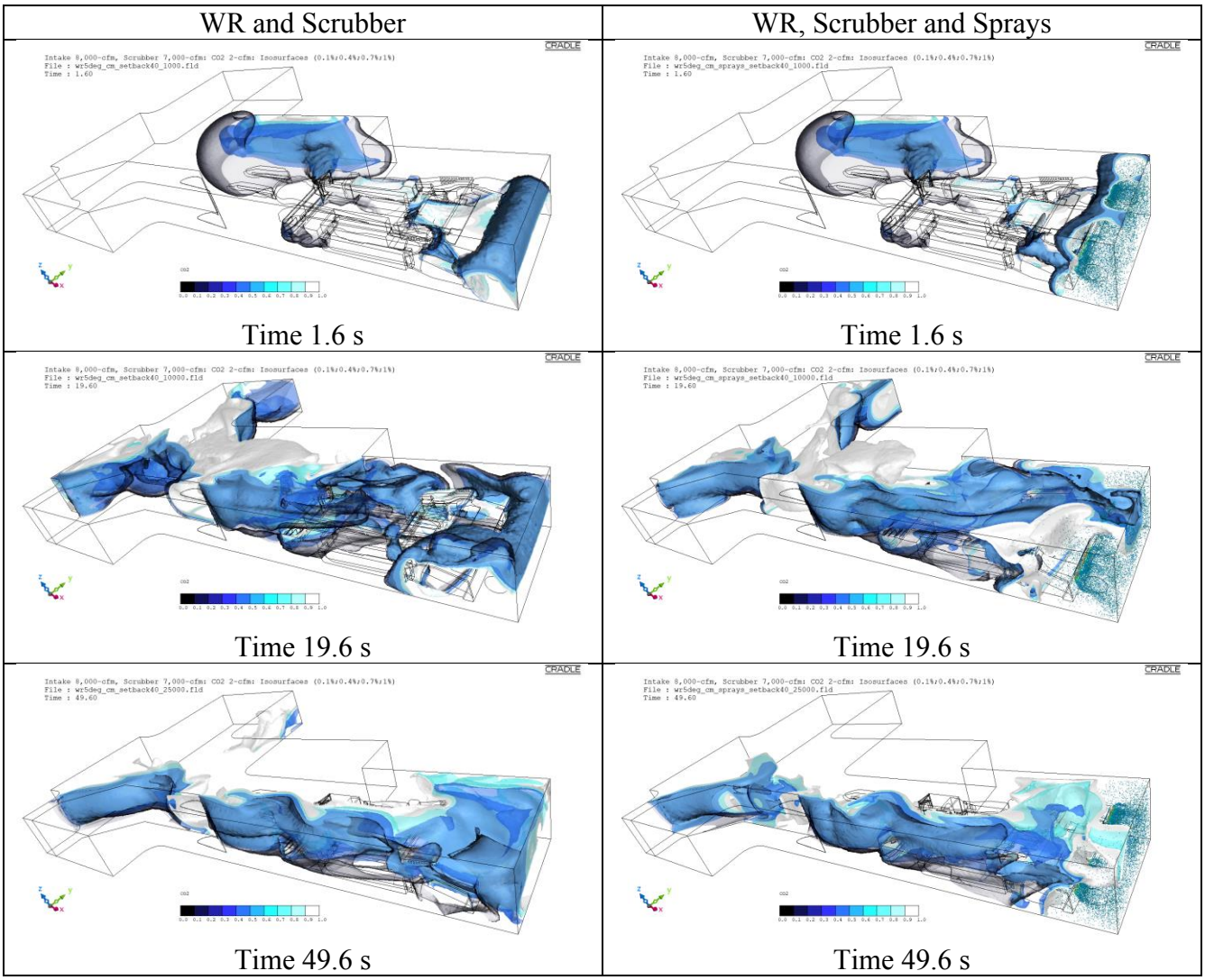


Figure 40 Effect of the sprays on the gas concentration distribution based on the B4 scenario

Figure 41 demonstrates the effect of the scrubbing performance using tracer gas as a proxy to the respirable dust. The simulated scenario is similar to B8 test. For this simulation, the scrubber removal efficiency is set to 95%. Tracer gas was used as a proxy to mimic dust particles in the CFD simulations instead of treating dust particles as solid spherical non-interacting bodies. The 'Lagrangian' or 'Eulerian' method of discrete particle requires much higher computation resources and are useful when dust particle size is crucial. Assuming dust particle cloud to behave as tracer gas (CO_2 in these CFD models) yields accurate predictions using reasonable resources.

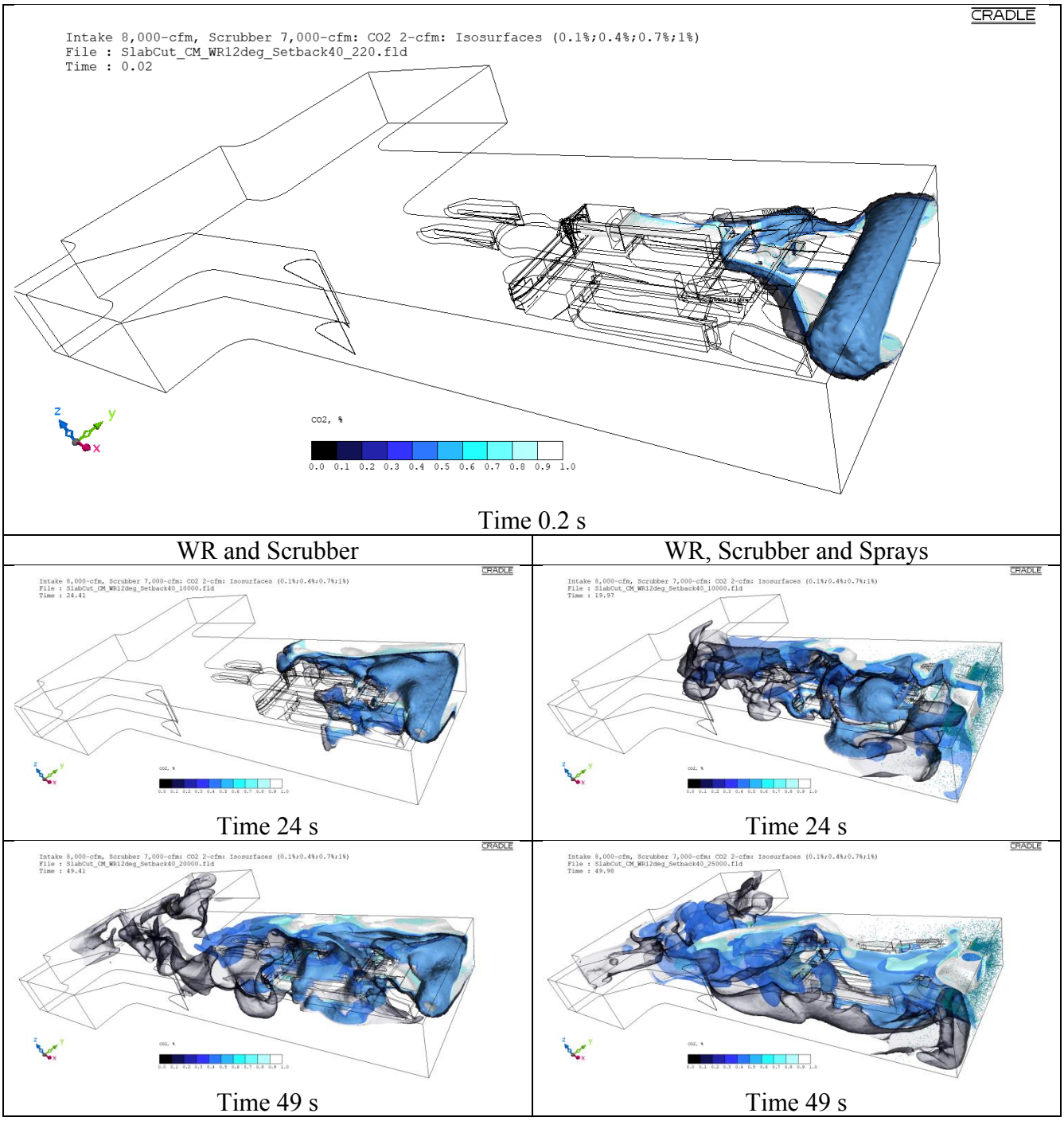


Figure 41 Simulated scrubber removal efficiency of 95% for a scenario similar to B8 test

Figure 42 and Figure 43 presents detailed contour plot of the proxy respirable dust at the end of the cutting time in the open cut scenario with a duration of 49 sec. The used modeling methodology has been tested with the industry and proved to provide results in agreement with the in-mine measurements. The numbers in red color indicate the CO_2 concentration on a plane through the center of the flow region and parallel to the coal floor. Some of the regions have a higher CO_2

concentration due to circulatory flow pattern. Colored vectors show the magnitude and direction of airflow on the same plane.

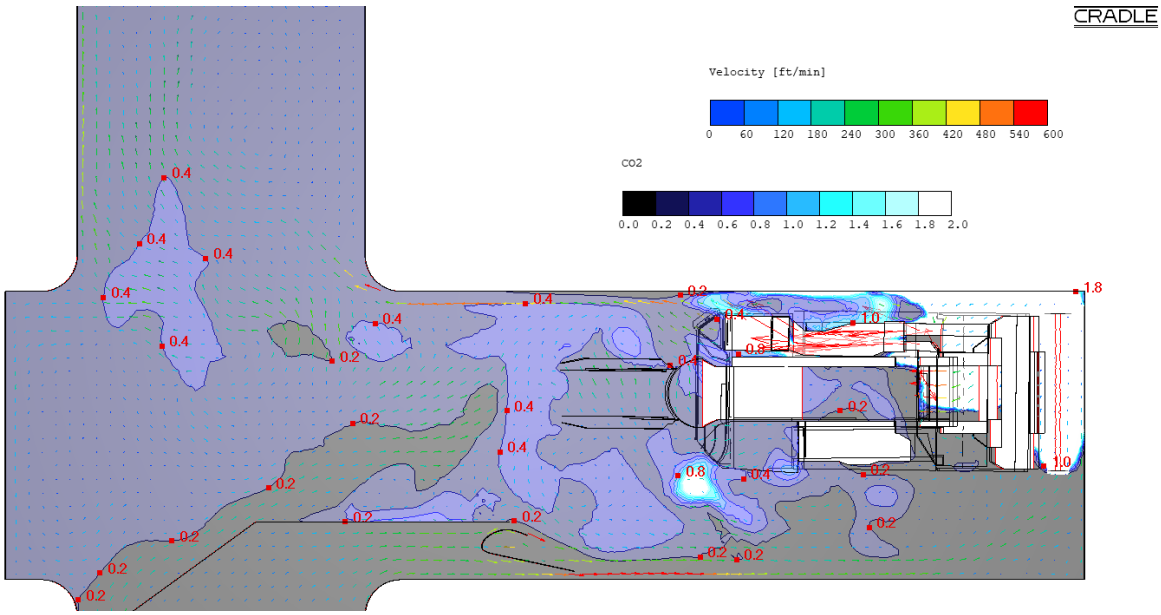


Figure 42 Air velocities and contour plot of the proxy respirable dust concentrations plotted at the middle plan of the entry for a scenario similar to B8 test, no sprays

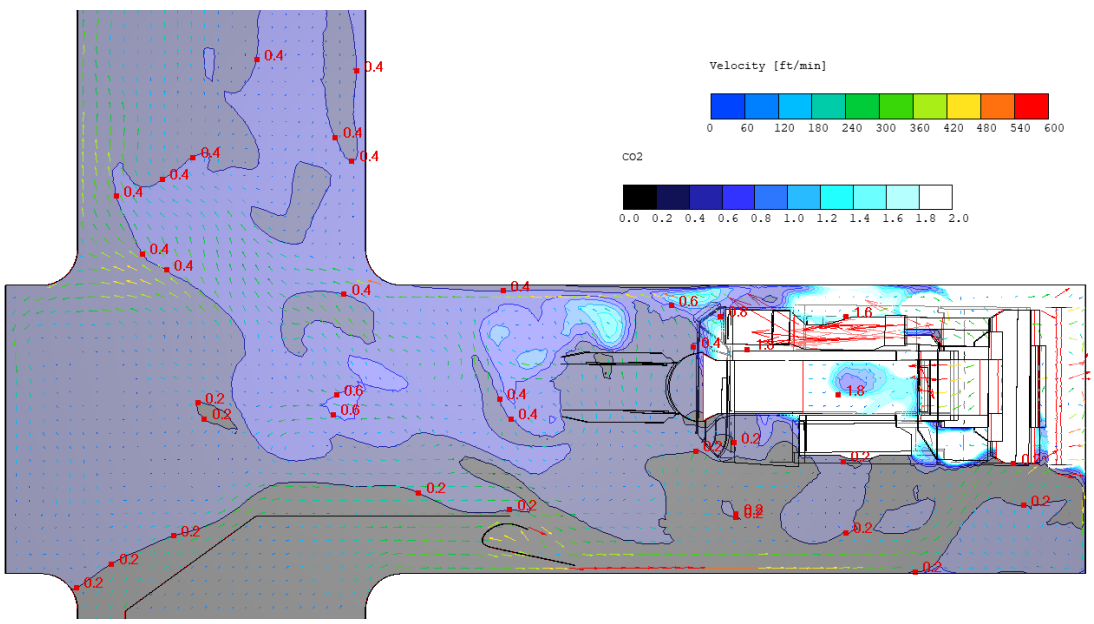


Figure 43 Air velocities and contour plot of the proxy respirable dust concentrations plotted at the middle plan of the entry for a scenario similar to B8 test, sprays active

3.3 Summary of the research findings

The research findings are presented in a qualitative manner in Table 9. The effect of the curtain flow rate, scrubber capacity, the sprays, and the WR factors on the measured face ventilation

variable has been explored using qualitative measures. Impact of curtain flow rate, scrubber capacity, sprays, and wing regulator installation are shown to influence dependent variables (column 1) including face velocity, gas concentration, and dust concentration. Three categories were accepted to qualify the role of the factors on the measured variables, as shown in Table 9.

The analysis was performed by comparing a basis scenario to scenario with changes. The basis scenario in this case is the conventional setup of the lab with 8,000-cfm curtain flow rate. The first case scenario was for the equipment free entry. The impact of the curtain flow rate variations on the face velocities were explored. Next, the CM has been introduced with scrubber turned off and the changing of the scrubber capacities on the measured variables was explored, etc.

Table 9 Summary of conventional controls interactions with WR

Factors / Measured Variables	Curtain flow rate	Scrubber capacity	Sprays	WR
Face velocity	≈	≈	+	+
Face gas concentration	≈	−	+	−
Operator dust concentration		−	−	−
Return dust Concentration		+	−	−
≈ No effect		+ Increase		− Decreased

The following listing is a summary of the findings based on actual measurements:

- As others have observed, the curtain flow rate does not significantly affect the face air velocities. This result is due to the nature of the flow separation phenomenon, in which the ventilation system develops flow patterns independent of the curtain air quantity (Section 3.1).

- When the scrubber air quantity approaches or exceeds the curtain air quantity ($Q_{scr}/Q_c>0.8$) there is little effect on the face velocity. Other technologies to move the air at the immediate face area are needed, such as water sprays and/or the WR (Section 3.2.3).

- The effective scheme for the face ventilation, particularly with blowing curtain, are those with scrubber flow ratio less than the curtain flow air quantity. Otherwise the gas concentrations around the entry can increase due to the intensification of the recirculation flow.

- The dust data for station 7 (behind the intake crosscut) showed that in an open entry scenario the recirculation zone induced by the scrubber is farther than in the box cut scenarios.

- There is an optimal layout of front sprays to maintain effective dust reduction efficiency. An excessive number of sprays spreads the dusts around the open volume which contributes to the increasing dust concentrations in zones away from the scrubber inlets, deteriorating the ventilation system dust removal efficiency.

- Recirculation patterns induced by water sprays have a secondary negative effect on the immediate face zone, impacting the gas dilution performance of the system.

- For equipment free scenarios the WR alone provides 60% dust reduction at the immediate face compared to the conventional curtain setup (Section 3.1).

- With the continuous miner in place, the scrubber alone provides 30% dust reduction at the immediate face.

- For the open cut scenarios the scrubber and WR provided 33% dust reduction at the immediate face, which indicates that the scrubber is taking in the air from the WR before it has a chance to sweep the face. This was clearly seen with smoke trace in the lab, further data on blocking inlets to the scrubber to prevent this effect is in Appendix C.

- For box cut scenarios, the scrubber alone at 25 feet cut depth, provided 33% dust reduction at the immediate face compared to the 25 foot scenario with the scrubber off. The joint impact of the scrubber and WR increase the dust reduction to 52%. The dust reduction efficiency decays with the deeper cut, at 40 feet it is 16% at the immediate face.

The WR showed good cooperation with the scrubber and benefits the face ventilation efficiency in two ways. First, delivering significantly more fresh air to the immediate face area, improving the gas dilution ability. Second, reducing the recirculation at the face area directs the air streams more uniform around the scrubber inlets, thus reducing the face dust. This effect is more noticeable with the extension of the cut and supported by the tests data for the 40-ft setback scenarios (Table 9).

4. PUBLICATION RECORD AND DISSEMINATION EFFORTS

Major data that is relevant to the industry was collected immediately before the production of this report. It is the intention of the researchers on this project to further disseminate much of the data and analysis presented in this report. We are assessing means of archiving the data collected publically so that other researchers would have access to the data for their own projects.

4.1 Publication Record

Following are categories and publications or posters that are currently accepted or pending.

4.1.1 REFEREED JOURNAL PUBLICATIONS

Kumar, A.R., K. Mayfield, S. Schafrik & T. Novak. 2018. "Large Eddy Simulations of Airflows inside a Reduced Scale Model of an Entry in a Continuous Mining Section." 2018. International Journal of Mining Science and Technology [Pending submission, Journal might be changed]

4.1.2 REFEREED CONFERENCE PUBLICATIONS

Coleman, B., Wedding, W.C., & Petrov, T. (2017), Design Considerations for the Construction of a Face Ventilation Gallery using Computational Fluid Dynamics Modeling, 16th North American Mine Ventilation Symposium

4.1.3 CONFERENCE PUBLICATIONS REFEREED BY ABSTRACT

Coleman, B., Wedding, W., & Petrov, T. (2017), A Parametric Study of the Effect of Intake Turbulence in a Full Scale Dust Gallery Using Transient CFD Models, 2018 SME Annual Conference

Mayfield, K.N. (2018). Scaled-Model Testing for the Effect of Turbulent Intensity on Continuous Miner Face Ventilation [Abstract]. SME 2018 Annual Conference and Expo, Minneapolis, MN, February 25-28.

Mayfield, K.N., Novak, T., & Schafrik, S.J. (2019) Study of Airflow Patterns during the advancement of the face in Extended-Cuts using Particle Image Velocimetry [Abstract]. SME 2019 Annual Conference and Expo, Denver, CO, February 24-27.

4.1.4 PRESENTATION OR POSTER AT PROFESSIONAL MEETINGS

Mayfield, K.N. (2017). Optimization algorithm for maximizing dust capture for a continuous-miner scrubber. Presented at the Central Appalachia Region Education Research Center Advisory Board Meeting, Lexington, KY, December 8.

Mayfield, K.N., Schafrik, S.J., & Novak, T. (2018).Analysis of face ventilation during extended cut sequence using particle image velocimetry. Poster presented at the SME 2018 Annual Conference and Expo, Minneapolis, MN, February 25-28.

Mayfield, K.N., Schafrik, S.J., Novak, T., & Sottile, J. (2018). Study for improved capture efficiency of machine-mounted dust scrubbers in coal mining applications. Poster presented at the Southeastern Regional ERC Symposium, Savannah, GA, April 3-4.

5. CONCLUSIONS AND IMPACT ASSESSMENT

The research presented in this report sought to determine the impact of the WR on the ventilation layouts found in coal mines. This project's test matrix allows estimation of not only the feasibility and the performance of the WR but also to the contribution of all the important controls of gas dilution and dust removal. The effect of variation in curtain flow rate, scrubber capacity, and water sprays on the flow patterns, gas and dust concentrations were evaluated along with the presence of the WR.

Curtain flow rate has insignificant effect on the face airflow velocities and face gas concentration. Within the nominal airflow rates encountered in modern day room and pillar coal mines, the flow separation patterns developed by the blowing line curtain has air moving at low velocity and do not reach the face. The circulatory pattern forces the air delivered via the curtain to take a less resistive path to join the return stream quickly. With the exhaust curtain layout, the situation is exacerbated, more precisely, the fresh air stream separates even closer to the curtain end, thus delivering less quantity of air for ventilating the immediate face.

Within prescribed scrubber airflow rates, when scrubber quantity approaches or exceed curtain value, little effect was observed on face airflow velocities and face gas concentration. The face dust concentration and the dust concentration measured in the return flow tend to increase with an increase in the scrubber flow rate. This is attributed to the recirculation flow patterns induced by the scrubber exhaust. The recirculation flow rolls back part of the airborne dust spread around the CM and increases its concentration at the operator place and the face. No time dependent change in gas concentration was observed since the flooded-bed dust scrubber is not equipped to remove gases from the airstream. In this case, the vacuum of the scrubber is far larger than the air available, encouraging air to be pulled from behind the miner, because in front of the scrubber inlets is solid rock.

When the scrubber flow rate is less than the curtain flow rate there is a decrease in gas and dust concentration at the face the operator place as well as at the return. In this case, the scrubber induced recirculation is reduced. The air intake in the scrubber is not pulling more air than is delivered at the curtain. This allows the vacuum of the scrubber to pull air from near the inlets, which is where the dust exists to be cleansed.

The water sprays tests, with 9 top boom sprays and 3+3 side head sprays, showed no effect on the flow at the face. The spray system has significantly reduced spray power compared to those conventionally applied in practice, where 15 to 20 top boom sprays are common and a total 40 or more are on the miner working simultaneously. The test showed that the gas concentration at the face increased when the miner model sprays were turned on, a recirculation pattern is induced by

the sprays. The data shows that the test spray system does not induce significant airflow along the face but does possess enough power to develop recirculation patterns. The positive effect of the reduced spray power is better dust capture efficiency. The optimal spray layout would need to be designed for every specific mine environment and case.

The WR data showed improvement in all monitored ventilation parameters, including the air flow velocities at the face, gas concentration at the face, dust concentration at the CM's operator zone. Both gas and dust data indicated that with the WR in place the return flow contains a higher concentration of contaminants, where at the same time reduced the recirculation.

Better performance of the face ventilation system with the WR have been demonstrated for equipment-free scenarios as well as for the scenarios with continuous miner in place and all controls turned on. The research showed that the scrubber is capable of cleansing dust from the air brought up to the face by the WR and sweeping the methane produced at the active face. Scrubber system and WR operating in tandem serve the dual purpose of combating dust and diluting methane rapidly near the extraction zone.

The data of the repeated tests have demonstrated steady behavior of the WR performance and decrease in gas concentration at the face with more than 40% of the gas concentration measured for same scenarios without the wing. The research data from the equipment free scenarios have also shown that the WR can be successfully applied during the bolting operations for improving the dust control as well as for better methane dilution.

The WR itself requires no power or water, only to be put into place at the time the curtain is being hung. For mines that are concerned about gas production and dust sampling compliance should consider adding the WR to their ventilation plan.

6. RECOMMENDATIONS FOR FUTURE WORK

The work done on this project is sufficient to show the efficacy of the wing regulator and provides an adequate basis to commercialize this device. During the course of this project a company did license the WR from the University of Kentucky Intellectual Property owners. Questions from regulators, operators and academics can be answered with the data in this report.

The dust gallery constructed in the course of this project is a unique facility. The configurable nature of the facility and the location underground allow for a flexibility that is not available elsewhere. We have tested this facility for both blowing and exhausting ventilation. The dust gallery currently is not capable for changing the mine height, but this capability could be added in the current design. We also have plans which could allow setback distances in excess of 40 feet, up to 60 feet. These modifications would also allow the cross cut and T intersections to be setup in the dust gallery.

6.1 Miner Sprays

The spray configuration that is on the miner body, behind the miner head is often used to knock down dust from the cutting process. There is also a "fan effect" from the water sprays that causes additional air circulation in the immediate vicinity of the water spray. It is common for regulators to require changes in the miner spray configuration to address dust or gas issues. There is no means of determining the proper change to address the issue, thus more sprays are added, directions are changed, but no analysis or guidance is available. The dust gallery and the miner model in the gallery is uniquely able to create a set of scenarios and measure the impact of the changes, allowing comprehensive guidance to be developed.

6.2 Miner Scrubber Filters

Similar to the miner sprays, variations in the flooded bed scrubber are often required by regulators to address perceived or measured increases in the dust production. The miner model we created in this project is easily modified from the base design. Dust can be injected in a controlled method and run through the scrubber with a variety of filter designs. Several maintenance free filters have been developed at the University of Kentucky, and these could be evaluated in the miner model. Some of these filers are drop-in replacements for the fibrous filters that are typically used, but others would require modifications to the flooded bed scrubber to be installed.

6.3 Shuttle Car Exposure

In this project a measurement point was used to be the approximation of the exposure to the shuttle car operator. Due to the work being done on other Alpha Foundation funded work, we have detailed plans for a shuttle car and a 1:1 model could be constructed to get a better understanding

of the dust exposure to the shuttle car operator and mitigation techniques, such as air curtains. This would be especially useful if paired with the modifications allowing for simulation of cross cuts, where the shuttle car operator is in a much more exposed position.

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APPENDIX A: WING REGULATOR USER GUIDE

This Appendix is a user guide that is intended to accompany the wing regulator for a mine operator with data about how to use the regulator effectively.

APPENDIX B: VENTILATION INNOVATIONS PERFORMANCE REVIEW AND VERIFICATION OF THE WING REGULATOR

This Appendix is a report carried out by an outside expert and ventilation consultant. Following is the statement of work that was requested:

> *We are investigating the impact of using a wing regulator on face ventilation for underground coal mines in the US. This ventilation control is intended to direct the air behind the curtain more efficiently to the face, reduce the recirculation and allow for less water spray and scrubber capacity to get superior dust and gas reductions. To examine this problem, the project has made CFD models of a single working place, a 1:12 scale model and a full scale dust gallery. We have completed a battery of tests, I've included preliminary measurements made from those tests, including very basic analysis.*
>
> *We are primarily concerned to get your opinion on the results that we have thus far. I think that this will require you to visit our dust gallery and witness some of the work. I would like to know what information, time and expense you need to answer the following questions:*
>
> *1. Are there circumstances where using the wing regulator is warranted and what are these circumstances?*
>
> *2. When using the wing regulator, how should other safety and ventilation controls be changed, if at all?*
>
> *3. Does the testing data and procedures employed in this project allow an expert in the field to definitively answer the proceeding questions? What level of confidence can be assigned?*

APPENDIX C: DUST GALLERY FIELD DATA AND NOTES

This appendix includes diagrams with measurements made during the test conditions described in the report. Points indicate the sampling locations, with boxes displaying the measured values and arrows to indicate the flow. Thick arrows indicate the direction of flow for measurements, while thin arrows represent the observations of flow. All measurements of dust and gas are taken from standard sampling areas, although some are not accessible because of equipment in some tests. The testing conditions are described in the title, along with a test condition reference which is used in the report.

APPENDIX D: MINE FIELD DATA AND NOTES

This appendix includes diagrams with measurements made during the field visits to partner mine locations in a diagram consistent with Appendix C. Points indicate the sampling locations, with boxes displaying the measured values and arrows to indicate the flow. Thick arrows indicate the direction of flow for measurements, while thin arrows represent the observations of flow. Measurements of dust and gas, if sampled, are indicated near the point of the sample. Conditions are described in the title.

APPENDIX A: WING REGULATOR USER GUIDE

This Appendix is a user guide that is intended to accompany the wing regulator for a mine operator with data about how to use the regulator effectively.

Wing Regulator Installation Manual

An Introduction to the Wing Regulator

Deep continuous mining cuts are difficult to ventilate because fresh air cannot be brought up to the active faces. This is because the mining faces are high resistance areas due to presence of machinery and no path for air to continue onto. Ventilating air follows the shortest path of least airway resistance out of the section. This results in a complex circulatory airflow pattern close to the face. This could lead to a poor dispersion of explosive methane gas being released from the coal face. There could also be a build-up of dust cloud close to the face leading to poor visibility for the miner operator. Flooded-bed dust scrubbers installed on the continuous miner with their inlets close to the mining face create a low-pressure region driving in some fresh air from behind the curtain. This, however, may not suffice as the cuts grow deeper and the face to curtain separation increases. Department of Mining Engineering at the University of Kentucky carried out detailed research to improve the flow of fresh air towards the active mining face.

The wing regulator developed during the research, as shown in Figure 1 is an efficient device that guides air deeper into the mining cuts. Since this is a passive device, this does not have any moving parts and uses no external power to operate. Installation and operation of wing regulator is quick and easy. This could be installed close to the curtain facing the mining face as shown in Figure 2 for the best performance.

Figure 1: Wing regular used for in-mine testing

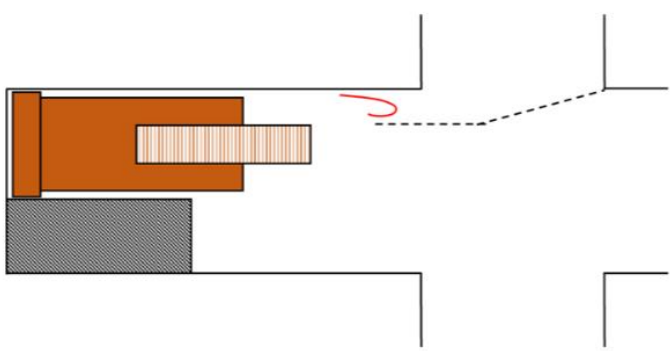

Figure 2: The wing regulator shown in red color

Operating Principle

The wing regulator has an assymetric airfloil shape which forces air to accelerate along the windward side. Due to its shape, the wing regulator efficiently directs air from behind the curtain towards the active mining face at an increased velocity. This is similar to an airfoil creating a high-pressure region on the leeward side creating a lift on aircraft. Improved face ventilation leads to faster removal of methane emancipating from the coal face. Although, not tested in detail, this will also have a favorable consequence of dust removal from the extraction region. Wing regulator performance was established using a series of tests in a full-scale room and pillar mine.

Construction

The wing regulator resembles an asymmetric airfoil shape with hollow construction. Internal support structure maintains the regulator shape which is critical to realizing a good airflow pattern on the mining cut. The mass of the wing regulator is less than 10 lbs. and could be carried in the mine with a minimal effort. The regulator could be shrunk along the vertical direction to a thickness less than 12" making it amenable to storage easily. The set-up kit consists of the airfoil and a pole with a hook that could be attached to the roof-mesh whenever available. The pole could be telescope which could enable its usage in operations with varying seam heights.

The low-pressure side of the regulator has a higher airflow speed which is used to guide air towards the blind headings of the working face. The higher pressure side has a lower airspeed and is not covered. This side, instead, has regions where the miner could stand sheltered from dust and move it easily in the mine as shown in Figure 3.

Figure 3: Moving the wing regulator

Positioning and Installation

The wing regulator should be installed in a room and pillar section with a blowing curtain ventilation system. The trailing edge of the regulator must face the mining face. The regulator should be installed at the endpoint of the curtain. This is designed to work most efficiently when it is set up about 3-4' from the rib. The wing regulator could be set up on the mine floor with the airfoil cross-section centroid marked approximately by the tip of the pole as shown in Figure 4. The wing regulator could then be extended in the vertical direction up to the mine roof to lower any leakages as shown in Figure 5. This makes the wing regulator immobile and stable in this configuration. This also ensures than the region upstream is kept pressurized forcing air at high speeds towards the face.

Figure 4: Setting up the location on the mine floor

Figure 5: Expanding the wing regulator to the mine roof

Fine-tuning for the Right Angle of Attack

Wing regulator performance is strongly influenced by the angle of attack of incident air on the windward side of the regulator. The angle of attack governs the drag and lift forces on the regulator which controls the velocity of air exiting the wingtip. This research showed that the gap between the leading edge of the regulator and the curtain needs to be about 6”. The distance between the trailing edge and the rib should not exceed 12”. This provides for a continuously decreasing cross-section area increasing air velocity. Figure 6 shows the miner rotating the wing regulator to set the angle of attack precisely. The entire installation procedure takes less than 2.0 minutes with a little training.

Figure 6: Fine-tuning to establish the required angle of attack

Using the Shelter Space

The wing regulator space close to its round edges could be used as a shelter for the miner as shown in Figure 7. This position enables the miner to have an unobstructed view of the continuous miner and the shuttle car operator. The swift air stream also carries the dust generated at the face away from the miner.

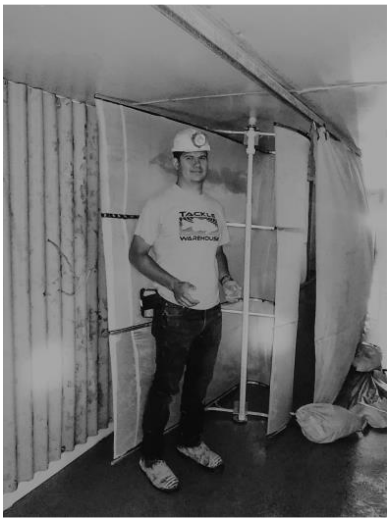

Figure 7: Miner standing in the shelter and facing the active face

Suggested Airflows for Wing Regulator Deployment

The wing regular could be deployed with an airflow rates of 5,000 – 12,000 cfm. These are the most common flow rates observed on contemporary room and pillar mining sections and were tests in the mine maintained by the University of Kentucky. The inventors do not expect any performace deterioration if the regulator is used in section with higher or lower airflows when used according to the recommendations.

Table 1 summarises the plausible curtain and scrubber flows for optimal wing regulator performance. Deviations from the tabulated airflows will not adversely affect its performance.

Table 1 : Curtain and scrubber airflows for wing regulator deployment

Curtain airflow (cfm)	Scrubber airflow (cfm)
5,000	4,000
7,000	5,600
8,000	6,400
10,000	8,000
12,000	9,600

Potential Problems while Installation/ Operations

The inventors anticipate the miners encountering following resolvable problems which might lead to sub-optimal performance from the wing regulator.

1. The wing regulator would not stay in place and tend to rotate.
2. The regular might have moved too far awar from the curtain towards the face.
3. Air might leak from top/ bottom of the wing regulator.
4. The regulator might have got dents or could be deformed while construction leading to undesireable airflow profiles.

Avoiding Improper Usage and troubleshooting

The wing regulator is a simple device to accelerate air towards the active mining face. Since this is not an active air moving system, these precautions should be taken for the best results from the regulator:

1. The wing regulator should be of the appropriate size. Since the regulator does not have any active air moving system and utilizes the change in the cross-section area to change the airspeed, it must be sized appropriately to guide the air.
2. The wing regulator surface should be made of firm fabrics/ thin metal sheets which do not deform under high airflows of pressure. This is critical to maintaining the shape and hence the airflow profile across the regulator. The wing regulator surfaces must be free from any defects including holes.
3. The wing regulator must be extended all the way to the floor for the best performance. Since the region upstream of the regulator is at a higher pressure, any leakages will move the air away from the mining face reducing its effectiveness.
4. The angle of attack should be adjusted by rotating the longer axis of the regulator so that an optimum change in airspeed is realized. This is critical since the drag and lift forces for a constant airflow speed is a function of angle of attack. While too low an angle of attack will not accelerate the air to higher speeds, a high angle of attack add drag resistance to the wing regulator system substantially.
5. Wing regulator application adds resistance to the ventilation airflow. Therefore, the angle of attack should be adjusted so that the overall resistance does not lower the airflow quantity behind the curtain. This could happen when the separation between the leading edge and the rib is less than 6”.

APPENDIX B: VENTILATION INNOVATIONS PERFORMANCE REVIEW AND VERIFICATION OF THE WING REGULATOR

This Appendix is a report carried out by an outside expert and ventilation consultant. Following is the statement of work that was requested:

> *We are investigating the impact of using a wing regulator on face ventilation for underground coal mines in the US. This ventilation control is intended to direct the air behind the curtain more efficiently to the face, reduce the recirculation and allow for less water spray and scrubber capacity to get superior dust and gas reductions. To examine this problem, the project has made CFD models of a single working place, a 1:12 scale model and a full scale dust gallery. We have completed a battery of tests, I've included preliminary measurements made from those tests, including very basic analysis.*
>
> *We are primarily concerned to get your opinion on the results that we have thus far. I think that this will require you to visit our dust gallery and witness some of the work. I would like to know what information, time and expense you need to answer the following questions:*
>
> *1. Are there circumstances where using the wing regulator is warranted and what are these circumstances?*
>
> *2. When using the wing regulator, how should other safety and ventilation controls be changed, if at all?*
>
> *3. Does the testing data and procedures employed in this project allow an expert in the field to definitively answer the proceeding questions? What level of confidence can be assigned?*

Performance Review and Verification of the Wing Regulator

Prepared for

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Lexington, KY 40506-0107

Prepared by

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on
August 13th, 2018

Summary

The Wing Regulator performance and functionality was verified through a series of tests designed to measure its performance with regard to the ventilation system of a “typical” coal mine in which it is designed for use.

These tests involved the set-up of the test bench to mimic an active face in a coal mine using a face curtain to provide ventilation across a range of ventilation flow-rates that might be encountered in an actual, operating mine. A total of four scenarios were configured, each measured with and without the Wing Regulator in place, for a total of eight test scenarios that were measured in all.

Airflows were measured at key locations throughout the system, along with fan pressure measurements (Total, Static and Velocity) at the fan, and psychrometric measurements at the facility inlet and outlet in order to establish the air density during the tests.

The review conducted indicates that the Wing Regulator functions as intended; increasing both the quantity and velocity of airflow reaching the face over the entire operating range of airflows measured. Furthermore, the review of the test bench for the experiments showed that they were constructed and carried out in such a way as to accurately represent an actual coal mine face as closely as possible.

Introduction

This letter report describes the work performed by Ventilation Innovation, LLC (VI) at the request of the University of Kentucky (UK) as part of a performance review of the Wing Regulator at the test-bench located in the Georgetown Mine. Recommendations are also made regarding the practical applications of the Wing Regulator and its potential impacts on the mine ventilation system.

This involved a visit to the Georgetown Mine during which measurements and observations were conducted in order to verify the performance and functionality of the Wing Regulator designed by the Mining Department.

The scope of work for this project included a review of the experimental testing procedure and facility at the Georgetown Mine as well as a review of the Wing Regulator performance under a range of operating conditions designed to mimic those encountered in actual underground coal mines.

The test bench for the wing regulator included a scale model (1:1) of an active coal mine face including a continuous miner and ventilated using a standard face curtain arrangement. The entry was approximately 7’ high by 18’ wide and the ventilating

curtain was located approximately 3.75' off of the rib-line. The total quantity of airflow to the face was controlled via a fan connected to the "last open cross-cut" and controlled via a Variable Frequency Drive (VFD), allowing rapid adjustment.

When utilized, the Wing Regulator was positioned in between the brattice curtain and the rib line leaving approximately six inches on either end.

Figure 1 shows the test facility looking from the end of the face curtain (approximate Wing Regulator Location) over the continuous miner and towards the face. The streamers hanging from the roof indicate the approximate direction and intensity of the airflow through the entry.

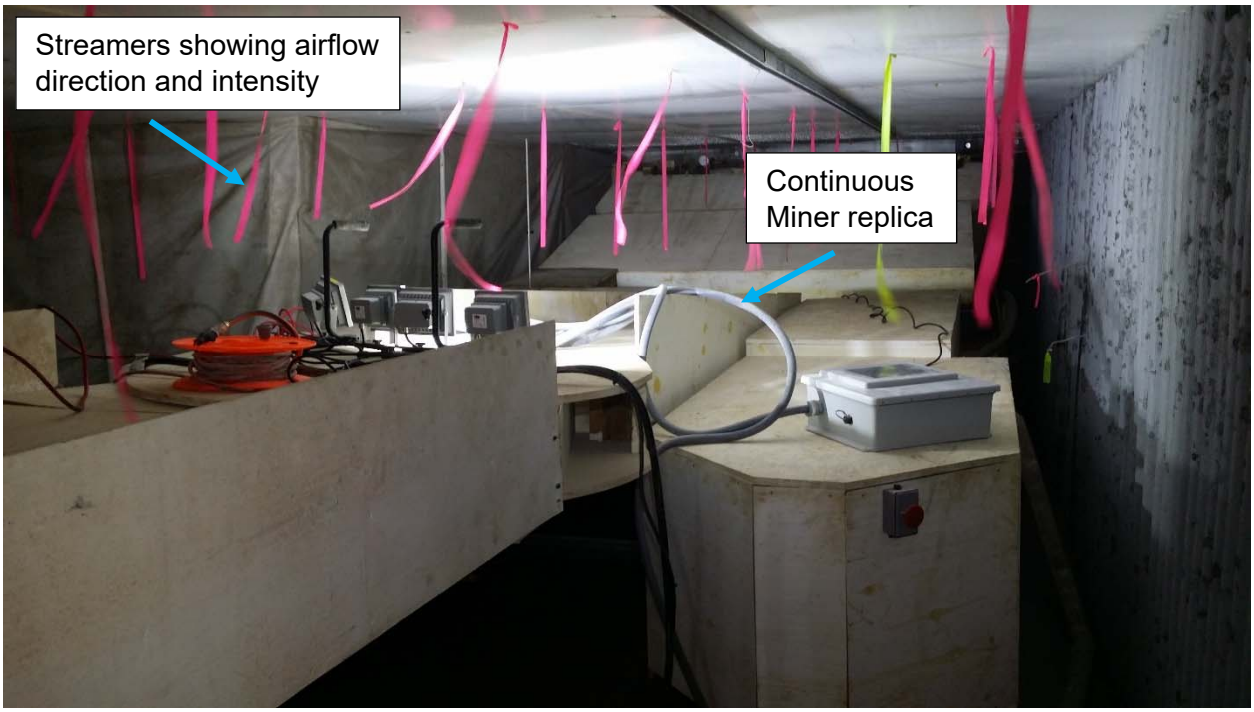

Figure 1: Wing Regulator Test Bench located in the Georgetown Mine (UK).

Performance Review

The test bench for the Wing Regulator was configured to provide a varying quantity of air that was delivered to the face via a standard brattice curtain hung approximately four feet from the right rib (looking inby). This curtain was advanced to approximately 40 feet from the face.

Airflow quantities were measured at the end of the curtain (Point 1.) and at the fan inlet (Point 2) with a vane anemometer. A Total Pressure measurement was made in the

duct on either side of the fan, with additional measurements of Static and Velocity Pressure made on the outlet side of the fan for the purpose of quantifying fan performance.

Psychrometric measurements (barometric pressure, dry-bulb temperature and relative humidity) were made at the end of the curtain line and at the fan outlet in order to determine the air density throughout the experiments.

The differential pressure across the brattice curtain just outby the location of the Wing Regulator was also made in order to determine the pressure loss across the device.

Recognizing that one of the most difficult ventilation scenarios arises when making the "Box cut" (the first insertion of the miner into a coal face, the width of the miner), the first six tests were configured to represent this condition. Measurements and observations of the airflow in the test bench were made under three different fan settings and airflow quantities both without and then with the Wing Regulator in place.

The testing was initially conducted with a total airflow of approximately 13,500 cubic feet per minute (cfm), and then repeated for airflows of 8,500 cfm and 22,500 cfm.

The final two tests were performed with the test bench configured to mimic the conditions of a "Slab cut", when the miner is used to widen the freshly-mined face to its ultimate width. These tests were conducted under a section airflow of approximately 8,500 cfm and were designed to verify that the cut type did not adversely affect the performance of the Wing Regulator under the most challenging conditions (low airflow volume).

The following figures (1 – 8) depict the approximate measured flow quantities and observed flow patterns for each test configuration.

Colored arrows are included to show the approximate direction and intensity of the airflow through the face areas as indicated by the observed streamers attached to the roof. The direction of the arrow indicates the direction of flow and the size of the arrow represents the relative intensity (velocity) of the airflow during the test.

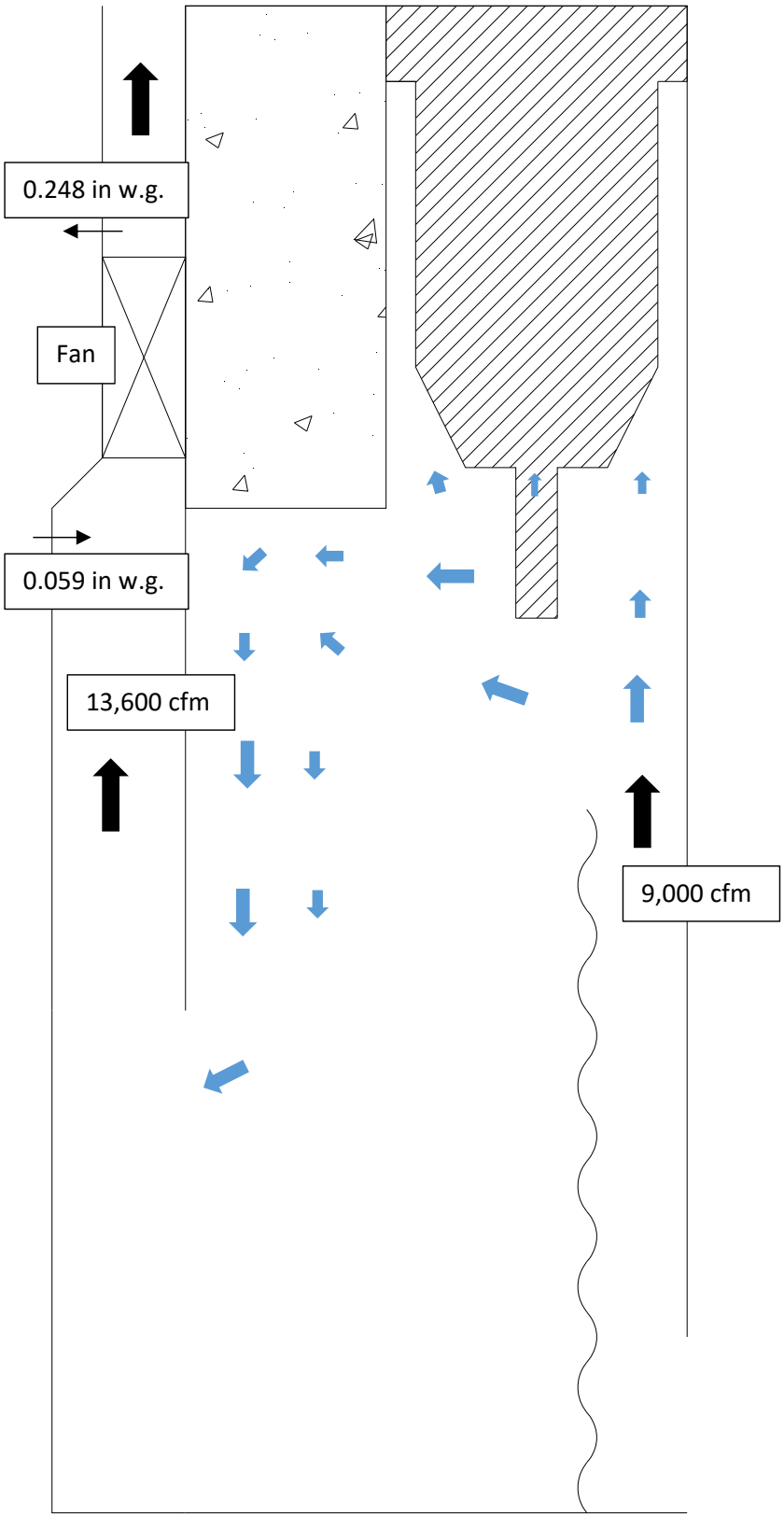

Figure 2: Box-cut flow pattern and airflow quantities without Wing Regulator (13,500 cfm).

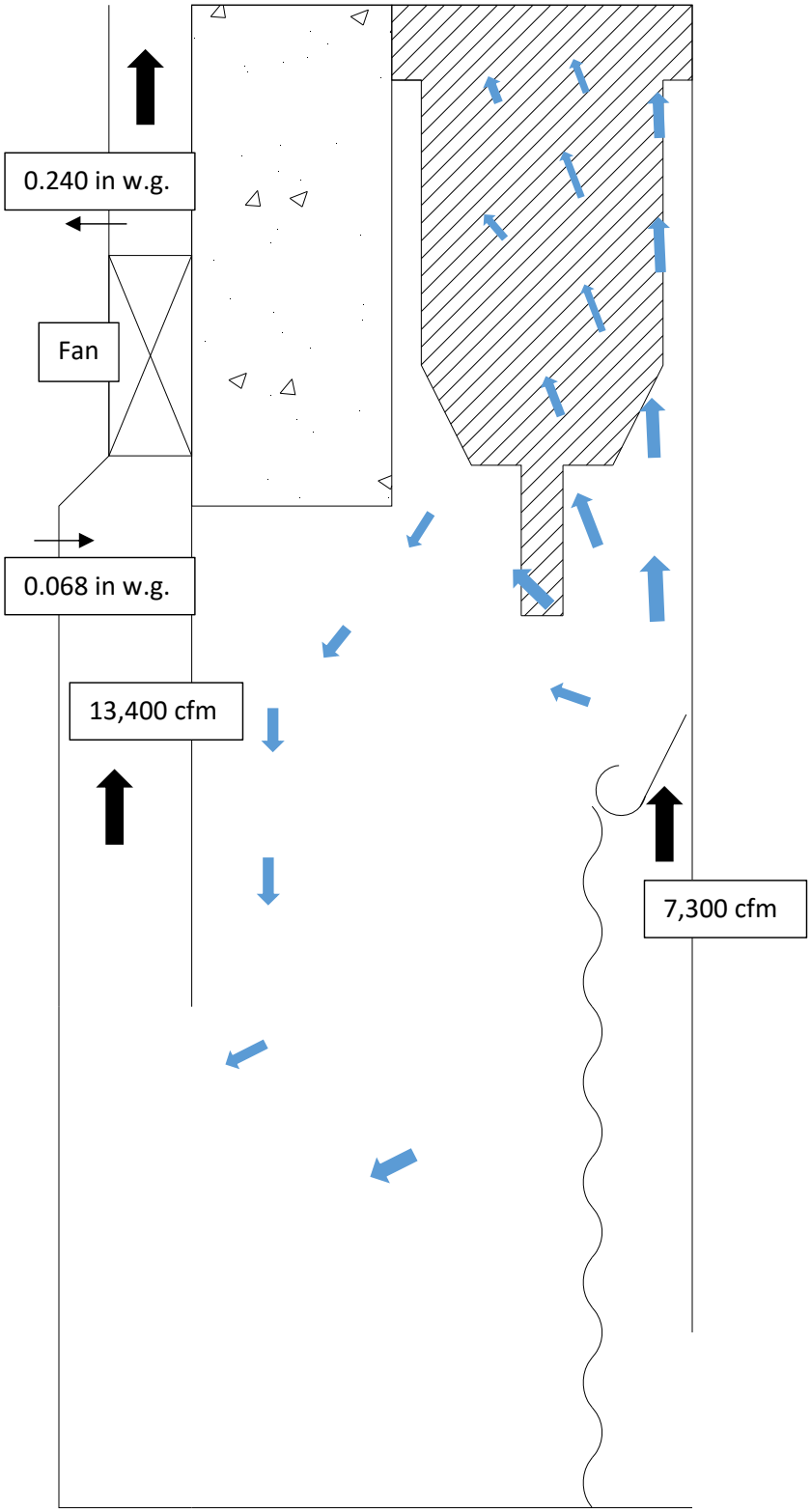

Figure 3: Box-cut flow pattern and airflow quantities with Wing Regulator (13,500 cfm).

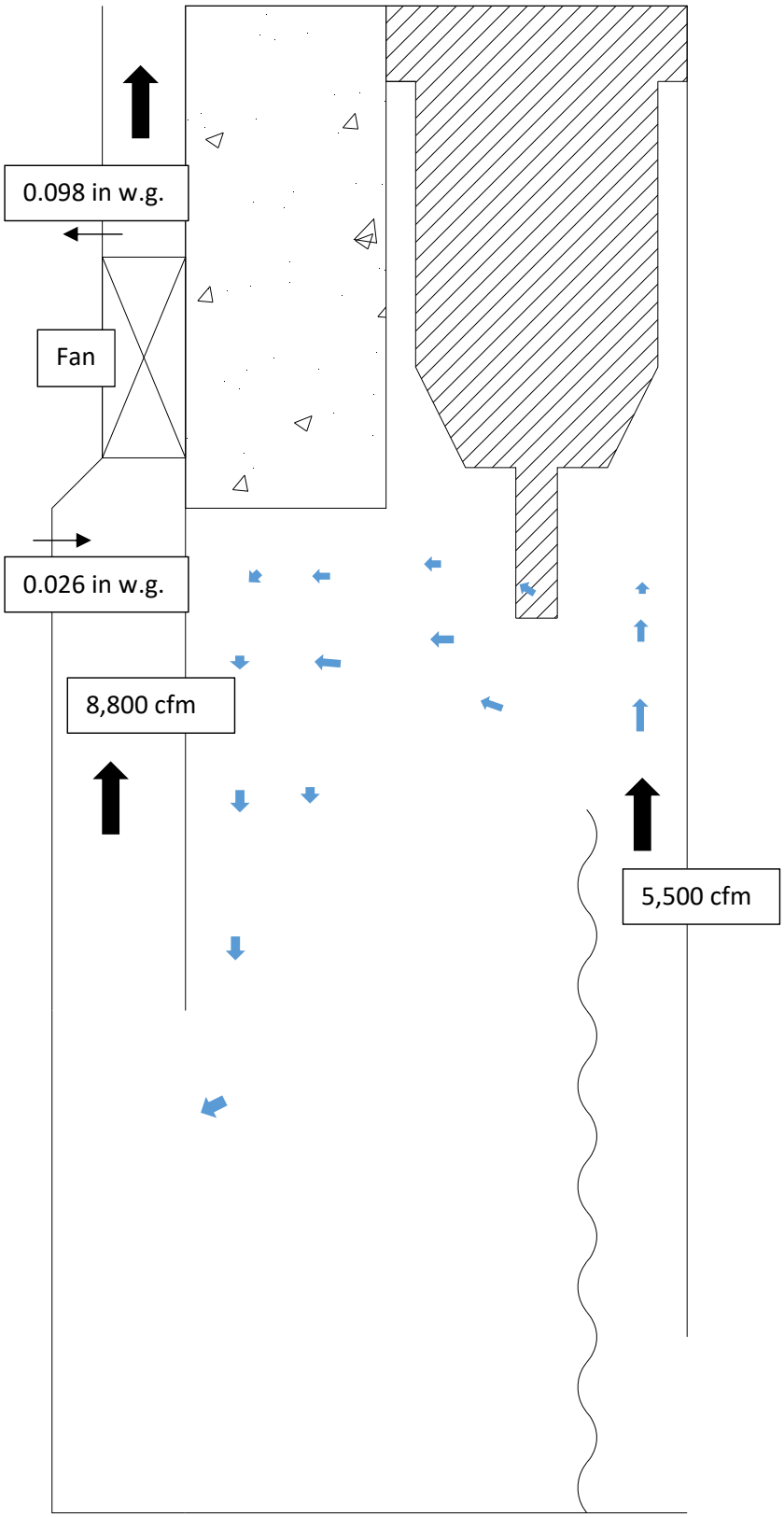

Figure 4: Box-cut flow pattern and airflow quantities without Wing Regulator (8,500 cfm).

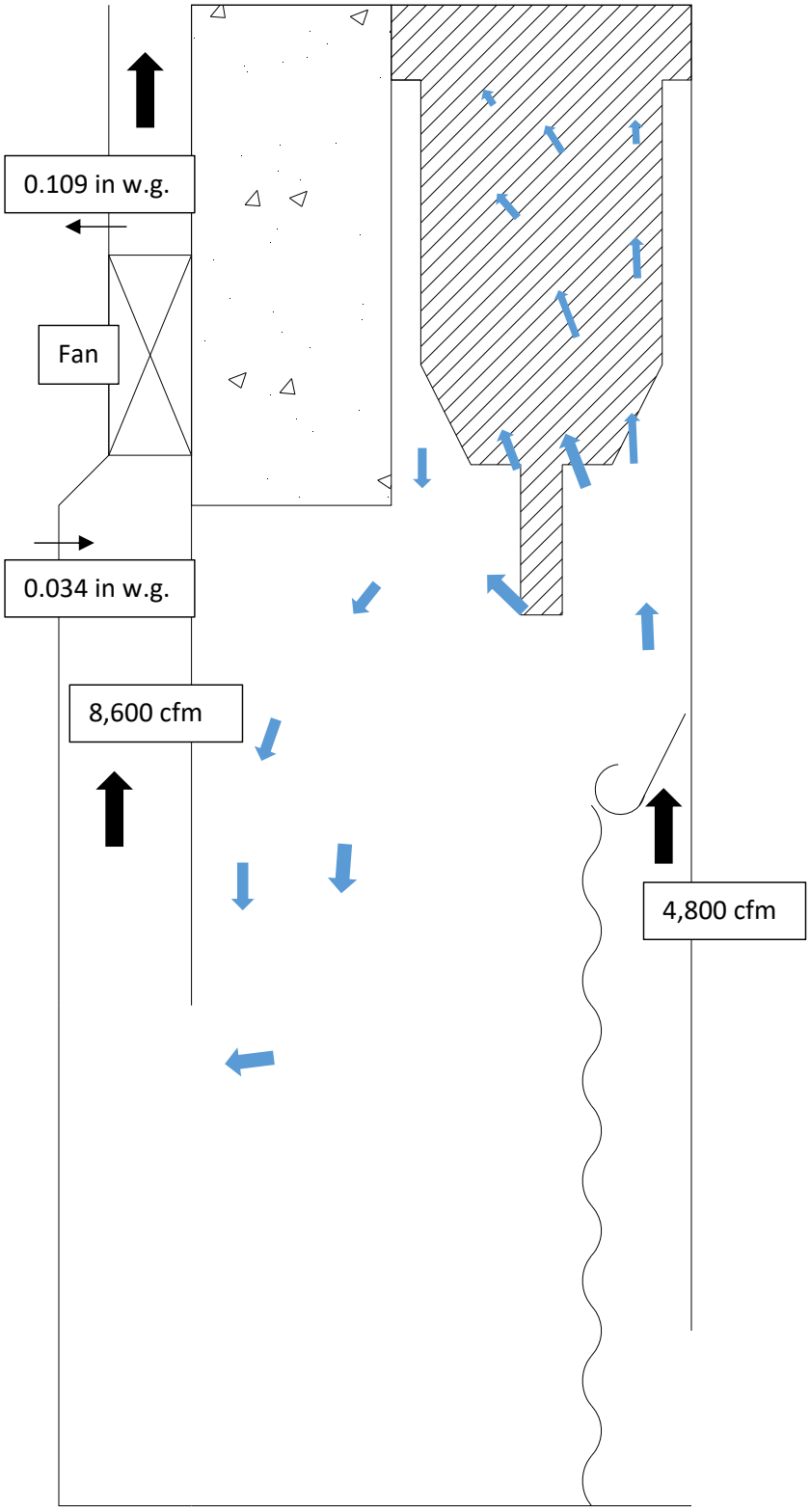

Figure 5: Box-cut flow pattern and airflow quantities with Wing Regulator (8,500 cfm).

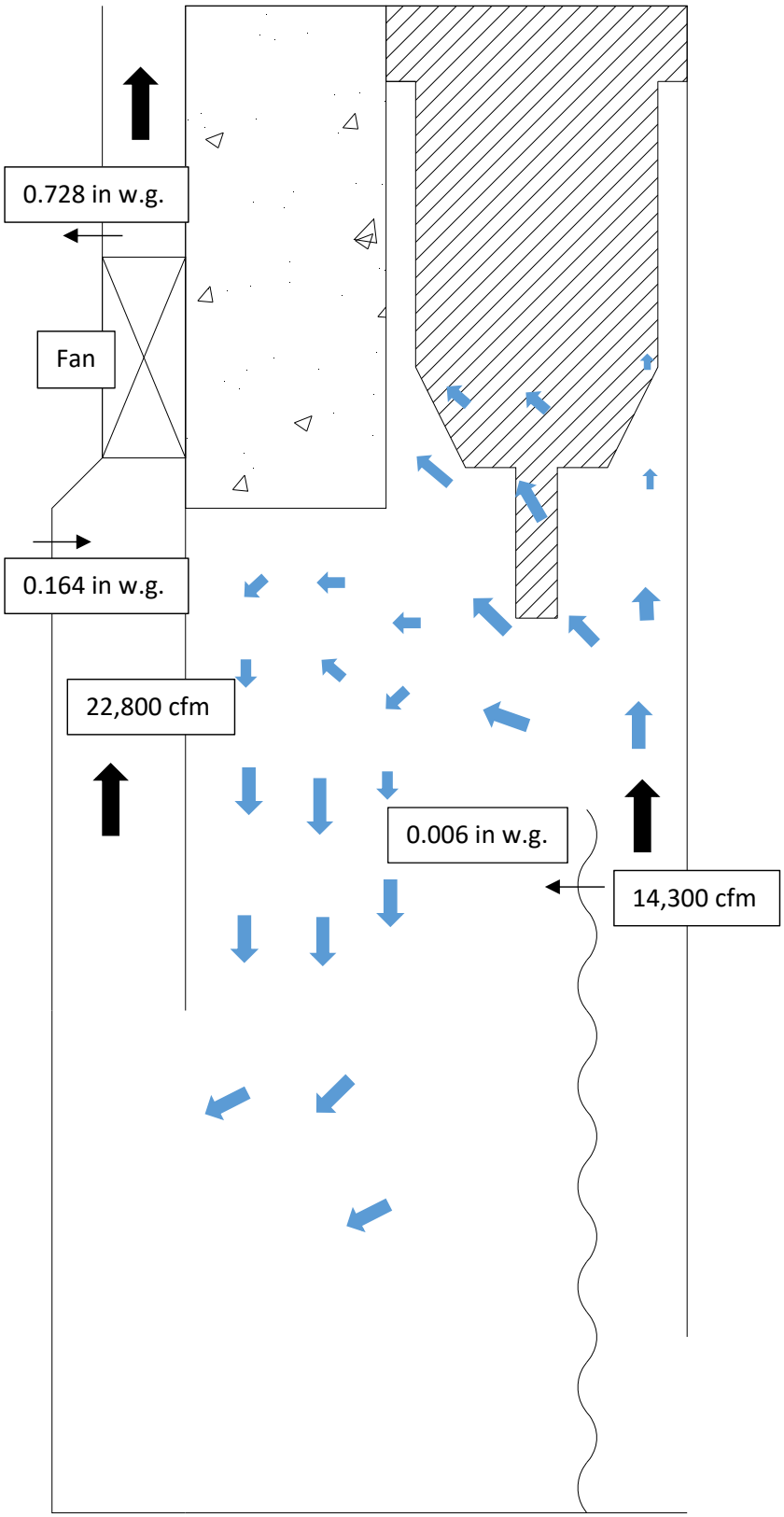

Figure 6: Box-cut flow pattern and airflow quantities without Wing Regulator (22,500 cfm).

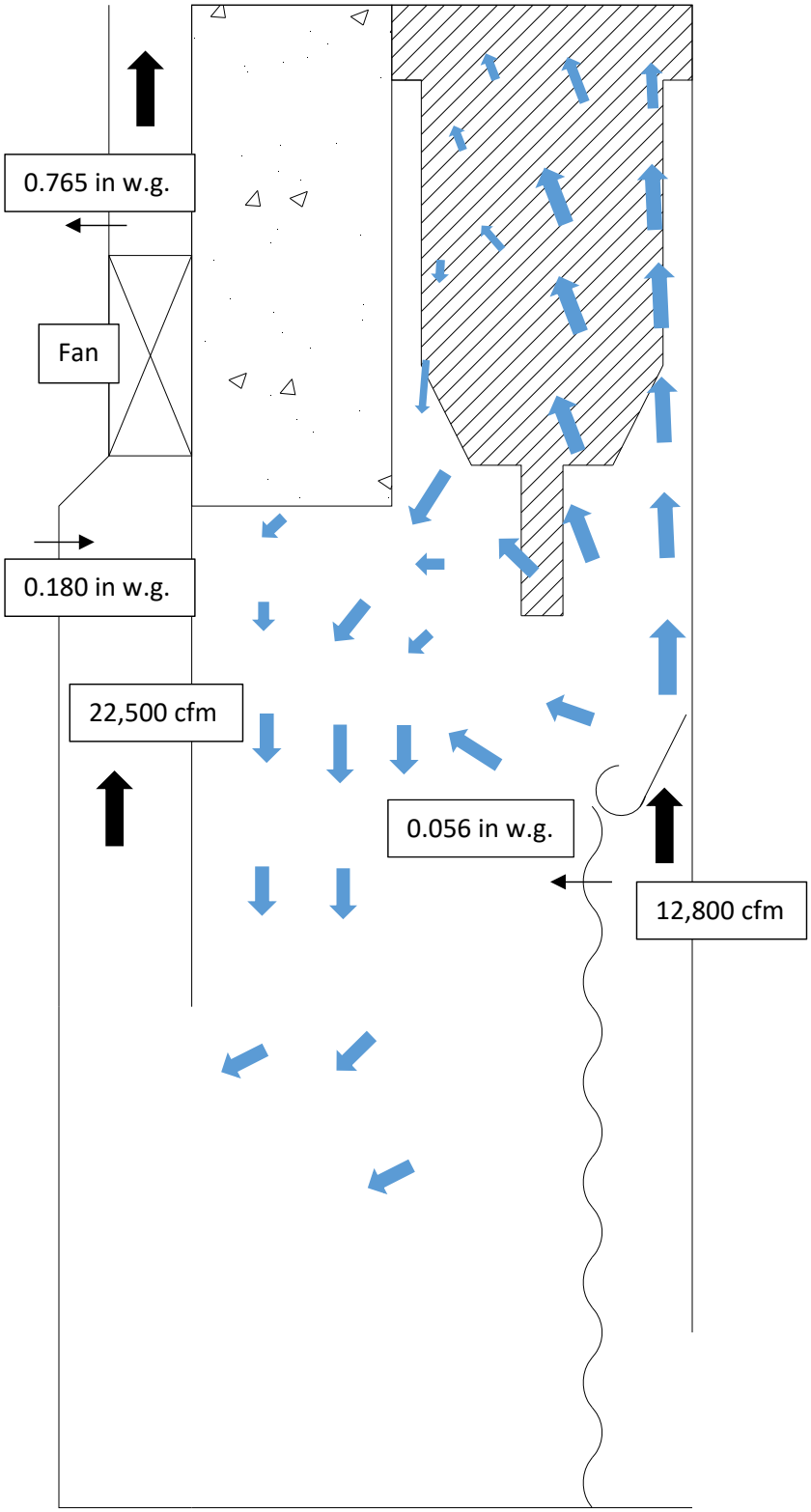

Figure 7: Box-cut flow pattern and airflow quantities with Wing Regulator (22,500 cfm).

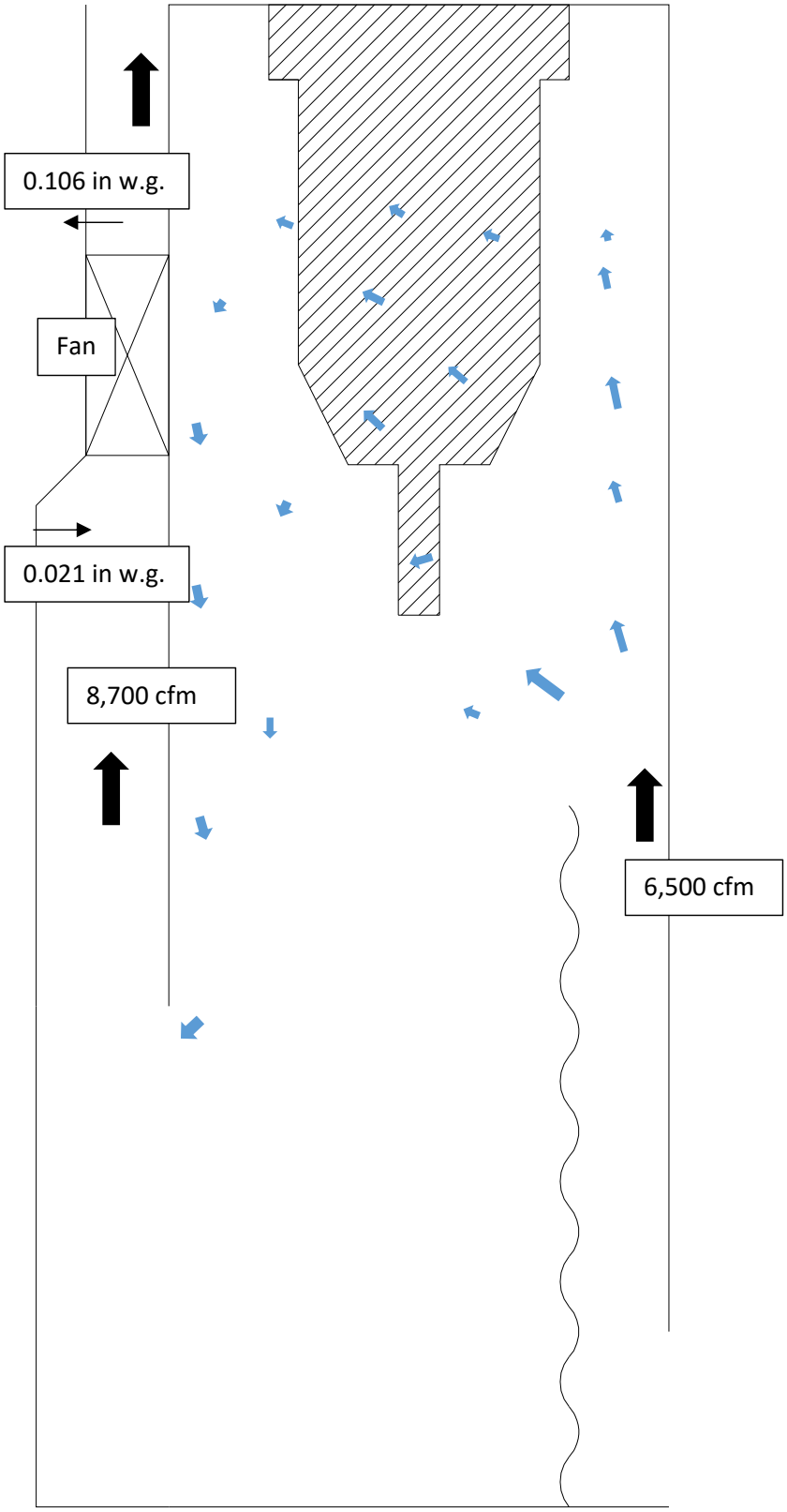

Figure 8: Slab-cut Flow pattern and selected airflow quantities without Wing Regulator (8,500 cfm).

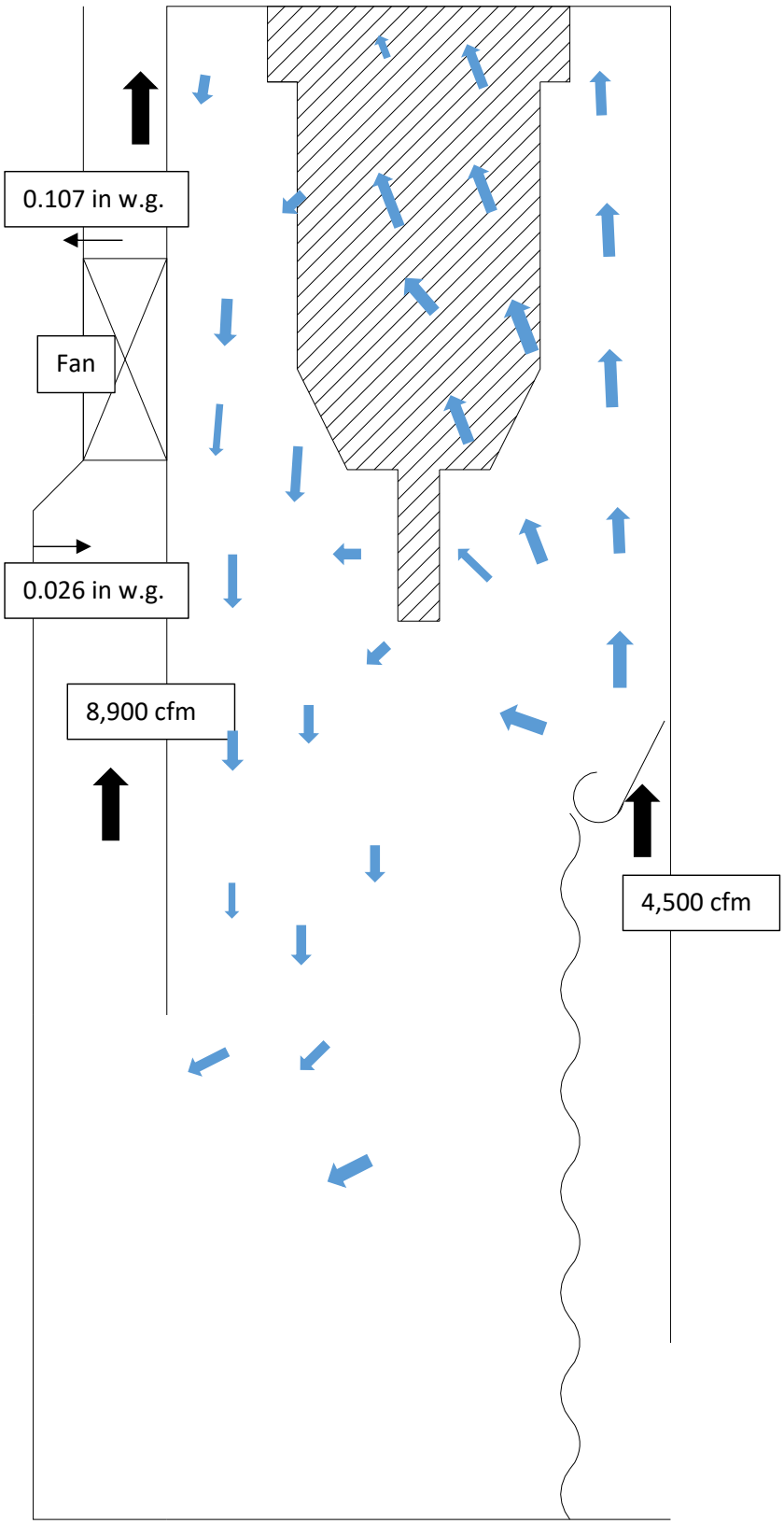

Figure 9: Slab-Cut Flow pattern and selected airflow quantities with Wing Regulator (8,500 cfm).

Conclusions and Recommendations

The test bench constructed at the Georgetown Mine provides a reasonable facsimile of an operating coal mine face, complete with miner and face ventilation. The facility is set up to test the operation of the Wing Regulator under a variety of conditions, including the operation of the miner-mounted scrubber or the presence of gas(es) and dust.

Under a range of airflows designed to test the Wing Regulator under various airflow conditions that might normally be expected in operating coal mines ventilated with face curtains, the Wing Regulator provided increased airflow quantity and velocity to the face in all scenarios.

Although the use of the Wing Regulator increases the resistance of the circuit by approximately 0.01 Practical Units (P.U.), and slightly decreases the total airflow reaching the end of the face curtain, the overall impact of this on the ventilation system was found to be negligible. In light of the demonstrable benefits of the Wing Regulator, this was not adjudged to be a problem.

The tests performed as part of this work indicate that the Wing Regulator should be used in cases where increased airflow quantity and velocity at the mining face are wanted or required. This is particularly desirable in mines that produce significant methane at the active face(s) as a result of the normal mining activities.

The use of the Wing Regulator to control the hazard of dust is less well defined, and the dust injection apparatus was not observed during this study.

Fan Ventilation Survey
Fan Measurement Sheet
Test Bench Fan - Georgetown Mine

Date:	August 2, 2018	Measurement Location	At Fan
Customer:	UK	Fan Manufacturer:	Spendrup
Duct Type:	Fiberglass	Fan	90-40-1800-A-3-D
Duct Dia. (inches):	35.5	RPM:	902
Area Duct (ft^2):	*6.874*	Rated Motor hp	771
Annulus Dia. (inches)	0	**Input Power to Motor (BHP)**	?
Area Annulus (ft^2):	*0.000*	**Motor Frequency (Hz):**	**24**
Airflow Area (ft^2):	*6.874*	**Voltage:**	N/A
ES Duct BP (kPa):	99.550	**Amperage:**	N/A
ES Duct DB (C):	15.2	**Power Factor:**	N/A
ES Duct RH (%):	99.0	**Motor Efficiency (est.):**	0.95
Density (lb/ft^3):	*0.0746*	**Electric Power Cost ($/kWhr):**	?

Measured Fan Pressures	**Fan Total Pressure (in. w.g.)**	**Fan Velocity Pressure (in. w.g.)**
Average:	**0.228**	**0.228**
Velocity (fpm):		*1,916*
Quantity (cfm):		*13,170*

Fan Description	Airflow (cfm)	Pressure (in.w.g.)	Air Horsepower	Fan Efficiency (%)	Power Cost ($/yr)
	13,170	0.228	0.47	*58%*	*#VALUE!*

Motor	volts	amps	Motor Eff.	power factor (est.)	FBHP	Mea. HP
?	460	1.0	0.95	0.80	*0.81*	?

	Point	Pv	Pt (Ave)
Fan Velocity Pressure:	1	0.228	0.228

Avg: **0.228** **0.228**

Fan Ventilation Survey
Fan Measurement Sheet
Test Bench Fan - Georgetown Mine

Date:	August 2, 2018	Measurement Location	At Fan
Customer:	UK	Fan Manufacturer:	Spendrup
Duct Type:	Fiberglass	Fan	90-40-1800-A-3-D
Duct Dia. (inches):	35.5	RPM:	902
Area Duct (ft^2):	*6.874*	Rated Motor hp	771
Annulus Dia. (inches)	0	**Input Power to Motor (BHP)**	?
Area Annulus (ft^2):	*0.000*	**Motor Frequency (Hz):**	**24**
Airflow Area (ft^2):	*6.874*	**Voltage:**	N/A
ES Duct BP (kPa):	99.590	**Amperage:**	N/A
ES Duct DB (C):	15.1	**Power Factor:**	N/A
ES Duct RH (%):	99.0	**Motor Efficiency (est.):**	0.95
Density (lb/ft^3):	*0.0747*	**Electric Power Cost ($/kWhr):**	?

Measured Fan Pressures	**Fan Total Pressure (in. w.g.)**	**Fan Velocity Pressure (in. w.g.)**
Average:	**0.222**	**0.222**
Velocity (fpm):		*1,890*
Quantity (cfm):		*12,991*

Fan Description	Airflow (cfm)	Pressure (in.w.g.)	Air Horsepower	Fan Efficiency (%)	Power Cost ($/yr)
	12,991	0.222	0.45	*56%*	*#VALUE!*

Motor	volts	amps	Motor Eff.	power factor (est.)	FBHP	Mea. HP
?	460	1.0	0.95	0.80	*0.81*	?

	Point	Pv	Pt (Ave)
Fan Velocity Pressure:	1	0.222	0.222
Avg:		**0.222**	**0.222**

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Test Bench Fan - Georgetown Mine

Date:	August 2, 2018	Measurement Location	At Fan
Customer:	UK	Fan Manufacturer:	Spendrup
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Duct Dia. (inches):	35.5	RPM:	902
Area Duct (ft^2):	*6.874*	Rated Motor hp	771
Annulus Dia. (inches)	0	**Input Power to Motor (BHP)**	?
Area Annulus (ft^2):	*0.000*	**Motor Frequency (Hz):**	**15**
Airflow Area (ft^2):	*6.874*	**Voltage:**	N/A
ES Duct BP (kPa):	99.550	**Amperage:**	N/A
ES Duct DB (C):	15.2	**Power Factor:**	N/A
ES Duct RH (%):	99.0	**Motor Efficiency (est.):**	0.95
Density (lb/ft^3):	*0.0746*	**Electric Power Cost ($/kWhr):**	?

Measured Fan Pressures	**Fan Total Pressure (in. w.g.)**	**Fan Velocity Pressure (in. w.g.)**
Average:	**0.089**	**0.089**
Velocity (fpm):		*1,197*
Quantity (cfm):		*8,228*

Fan Description	Airflow (cfm)	Pressure (in.w.g.)	Air Horsepower	Fan Efficiency (%)	Power Cost ($/yr)
	8,228	0.089	0.12	*14%*	*#VALUE!*

Motor	volts	amps	Motor Eff.	power factor (est.)	FBHP	Mea. HP
?	460	1.0	0.95	0.80	*0.81*	?

	Point	Pv	Pt (Ave)
Fan Velocity Pressure:	1	0.089	0.089
Avg:		**0.089**	**0.089**

Fan Ventilation Survey
Fan Measurement Sheet
Test Bench Fan - Georgetown Mine

Date:	August 2, 2018	Measurement Location	At Fan
Customer:	UK	Fan Manufacturer:	Spendrup
Duct Type:	Fiberglass	Fan	90-40-1800-A-3-D
Duct Dia. (inches):	35.5	RPM:	902
Area Duct (ft^2):	*6.874*	Rated Motor hp	771
Annulus Dia. (inches)	0	**Input Power to Motor (BHP)**	?
Area Annulus (ft^2):	*0.000*	**Motor Frequency (Hz):**	**15**
Airflow Area (ft^2):	*6.874*	**Voltage:**	N/A
ES Duct BP (kPa):	99.540	**Amperage:**	N/A
ES Duct DB (C):	15.2	**Power Factor:**	N/A
ES Duct RH (%):	99.0	**Motor Efficiency (est.):**	0.95
Density (lb/ft^3):	*0.0746*	**Electric Power Cost ($/kWhr):**	?

Measured Fan Pressures	**Fan Total Pressure (in. w.g.)**	**Fan Velocity Pressure (in. w.g.)**
Average:	**0.094**	**0.094**
Velocity (fpm):		*1,230*
Quantity (cfm):		*8,457*

Fan Description	Airflow (cfm)	Pressure (in.w.g.)	Air Horsepower	Fan Efficiency (%)	Power Cost ($/yr)
	8,457	0.094	0.13	*15%*	*#VALUE!*

Motor	volts	amps	Motor Eff.	power factor (est.)	FBHP	Mea. HP
?	460	1.0	0.95	0.80	*0.81*	?

	Point	Pv	Pt (Ave)
Fan Velocity Pressure:	1	0.094	0.094

Avg:	**0.094**	**0.094**

Fan Ventilation Survey
Fan Measurement Sheet
Test Bench Fan - Georgetown Mine

Date:	August 2, 2018	Measurement Location	At Fan
Customer:	UK	Fan Manufacturer:	Spendrup
Duct Type:	Fiberglass	Fan	90-40-1800-A-3-D
Duct Dia. (inches):	35.5	RPM:	902
Area Duct (ft^2):	*6.874*	Rated Motor hp	771
Annulus Dia. (inches)	0	**Input Power to Motor (BHP)**	?
Area Annulus (ft^2):	*0.000*	**Motor Frequency (Hz):**	**60**
Airflow Area (ft^2):	*6.874*	**Voltage:**	N/A
ES Duct BP (kPa):	99.510	**Amperage:**	N/A
ES Duct DB (C):	15.4	**Power Factor:**	N/A
ES Duct RH (%):	99.0	**Motor Efficiency (est.):**	0.95
Density (lb/ft^3):	*0.0745*	**Electric Power Cost ($/kWhr):**	?

Measured Fan Pressures	**Fan Total Pressure (in. w.g.)**	**Fan Velocity Pressure (in. w.g.)**
Average:	**0.658**	**0.658**
Velocity (fpm):		*3,257*
Quantity (cfm):		*22,387*

Fan Description	Airflow (cfm)	Pressure (in.w.g.)	Air Horsepower	Fan Efficiency (%)	Power Cost ($/yr)
	22,387	0.658	2.32	*286%*	*#VALUE!*

Motor	volts	amps	Motor Eff.	power factor (est.)	FBHP	Mea. HP
?	460	1.0	0.95	0.80	*0.81*	?

	Point	Pv	Pt (Ave)
Fan Velocity Pressure:	1	0.658	0.658

Avg:	**0.658**	**0.658**

Fan Ventilation Survey
Fan Measurement Sheet
Test Bench Fan - Georgetown Mine

Date:	August 2, 2018	Measurement Location	At Fan
Customer:	UK	Fan Manufacturer:	Spendrup
Duct Type:	Fiberglass	Fan	90-40-1800-A-3-D
Duct Dia. (inches):	35.5	RPM:	902
Area Duct (ft^2):	*6.874*	Rated Motor hp	771
Annulus Dia. (inches)	0	**Input Power to Motor (BHP)**	?
Area Annulus (ft^2):	*0.000*	**Motor Frequency (Hz):**	**60**
Airflow Area (ft^2):	*6.874*	**Voltage:**	N/A
ES Duct BP (kPa):	99.620	**Amperage:**	N/A
ES Duct DB (C):	15.4	**Power Factor:**	N/A
ES Duct RH (%):	99.0	**Motor Efficiency (est.):**	0.95
Density (lb/ft^3):	*0.0746*	**Electric Power Cost ($/kWhr):**	?

Measured Fan Pressures	**Fan Total Pressure (in. w.g.)**	**Fan Velocity Pressure (in. w.g.)**
Average:	**0.697**	**0.697**
Velocity (fpm):		*3,350*
Quantity (cfm):		*23,028*

Fan Description	Airflow (cfm)	Pressure (in.w.g.)	Air Horsepower	Fan Efficiency (%)	Power Cost ($/yr)
	23,028	0.697	2.53	*312%*	*#VALUE!*

Motor	volts	amps	Motor Eff.	power factor (est.)	FBHP	Mea. HP
?	460	1.0	0.95	0.80	*0.81*	?

	Point	Pv	Pt (Ave)
Fan Velocity Pressure:	1	0.697	0.697
	Avg:	**0.697**	**0.697**

Fan Ventilation Survey
Fan Measurement Sheet
Test Bench Fan - Georgetown Mine

Date:	August 2, 2018	Measurement Location	At Fan
Customer:	UK	Fan Manufacturer:	Spendrup
Duct Type:	Fiberglass	Fan	90-40-1800-A-3-D
Duct Dia. (inches):	35.5	RPM:	902
Area Duct (ft^2):	*6.874*	Rated Motor hp	771
Annulus Dia. (inches)	0	**Input Power to Motor (BHP)**	?
Area Annulus (ft^2):	*0.000*	**Motor Frequency (Hz):**	**15**
Airflow Area (ft^2):	*6.874*	**Voltage:**	N/A
ES Duct BP (kPa):	99.500	**Amperage:**	N/A
ES Duct DB (C):	15.3	**Power Factor:**	N/A
ES Duct RH (%):	99.0	**Motor Efficiency (est.):**	0.95
Density (lb/ft^3):	*0.0745*	**Electric Power Cost ($/kWhr):**	?

Measured Fan Pressures	**Fan Total Pressure (in. w.g.)**	**Fan Velocity Pressure (in. w.g.)**
Average:	**0.102**	**0.102**
Velocity (fpm):		*1,282*
Quantity (cfm):		*8,813*

Fan Description	Airflow (cfm)	Pressure (in.w.g.)	Air Horsepower	Fan Efficiency (%)	Power Cost ($/yr)
	8,813	0.102	0.14	*17%*	*#VALUE!*

Motor	volts	amps	Motor Eff.	power factor (est.)	FBHP	Mea. HP
?	460	1.0	0.95	0.80	*0.81*	?

	Point	Pv	Pt (Ave)
Fan Velocity Pressure:	1	0.102	0.102
	Avg:	**0.102**	**0.102**

Fan Ventilation Survey
Fan Measurement Sheet
Test Bench Fan - Georgetown Mine

Date:	August 2, 2018	Measurement Location	At Fan
Customer:	UK	Fan Manufacturer:	Spendrup
Duct Type:	Fiberglass	Fan	90-40-1800-A-3-D
Duct Dia. (inches):	35.5	RPM:	902
Area Duct (ft^2):	*6.874*	Rated Motor hp	771
Annulus Dia. (inches)	0	**Input Power to Motor (BHP)**	?
Area Annulus (ft^2):	*0.000*	**Motor Frequency (Hz):**	**15**
Airflow Area (ft^2):	*6.874*	**Voltage:**	N/A
ES Duct BP (kPa):	99.500	**Amperage:**	N/A
ES Duct DB (C):	15.3	**Power Factor:**	N/A
ES Duct RH (%):	99.0	**Motor Efficiency (est.):**	0.95
Density (lb/ft^3):	*0.0745*	**Electric Power Cost ($/kWhr):**	?

Measured Fan Pressures	**Fan Total Pressure (in. w.g.)**	**Fan Velocity Pressure (in. w.g.)**
Average:	**0.102**	**0.102**
Velocity (fpm):		*1,282*
Quantity (cfm):		*8,813*

Fan Description	Airflow (cfm)	Pressure (in.w.g.)	Air Horsepower	Fan Efficiency (%)	Power Cost ($/yr)
	8,813	0.102	0.14	*17%*	*#VALUE!*

Motor	volts	amps	Motor Eff.	power factor (est.)	FBHP	Mea. HP
?	460	1.0	0.95	0.80	*0.81*	?

	Point	Pv	Pt (Ave)
Fan Velocity Pressure:	1	0.102	0.102
Avg:		**0.102**	**0.102**

APPENDIX C: DUST GALLERY FIELD DATA AND NOTES

This appendix includes diagrams with measurements made during the test conditions described in the report. Points indicate the sampling locations, with boxes displaying the measured values and arrows to indicate the flow. Thick arrows indicate the direction of flow for measurements, while thin arrows represent the observations of flow. All measurements of dust and gas are taken from standard sampling areas, although some are not accessible because of equipment in some tests. The testing conditions are described in the title, along with a test condition reference which is used in the report.

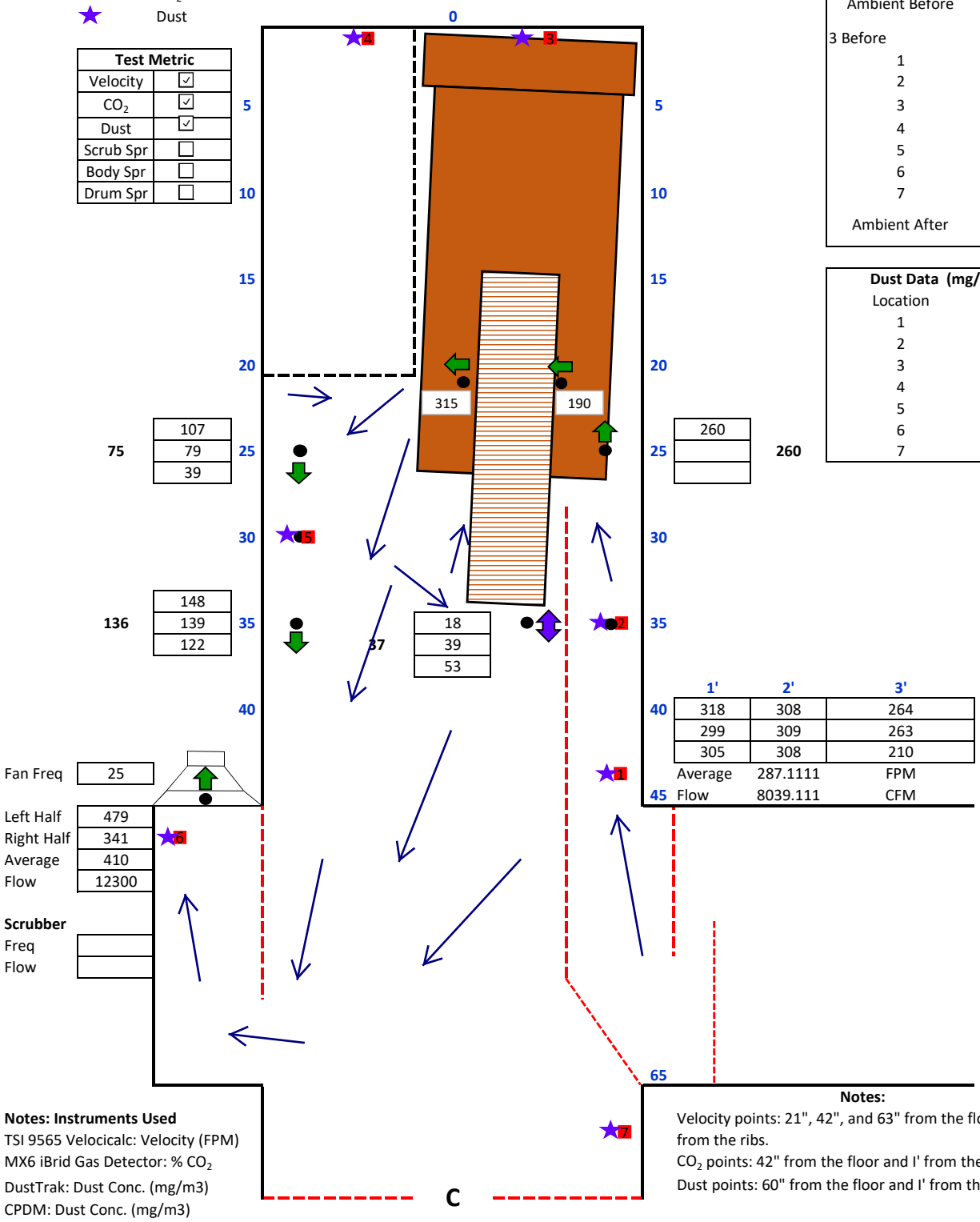
A1 : Setback 25, Box Cut, No Wing, 8000 Curtain, No Scrubber, No Drum Sprays

Date	6/28/18
Time	2:00 PM
●	Velocity
■	CO_2
★	Dust

Test Metric	
Velocity	☑
CO_2	☑
Dust	☑
Scrub Spr	☐
Body Spr	☐
Drum Spr	☐

CO_2 Data	
Outlet Pr.	50 PSI
Location	% Conc
Ambient Before	0.06
3 Before	0.06
1	0.06
2	0.06
3	1.78
4	
5	0.08
6	0.14
7	0.06
Ambient After	0.06

Dust Data (mg/m3)	
Location	Conc.
1	0.53
2	1.15
3	136.00
4	
5	17.10
6	10.10
7	2.22



Notes: Instruments Used

TSI 9565 Velocicalc: Velocity (FPM)
MX6 iBrid Gas Detector: % CO_2
DustTrak: Dust Conc. (mg/m3)
CPDM: Dust Conc. (mg/m3)

Notes:

Velocity points: 21", 42", and 63" from the floor and 1' from the ribs.
CO_2 points: 42" from the floor and I' from the ribs.
Dust points: 60" from the floor and I' from the ribs.

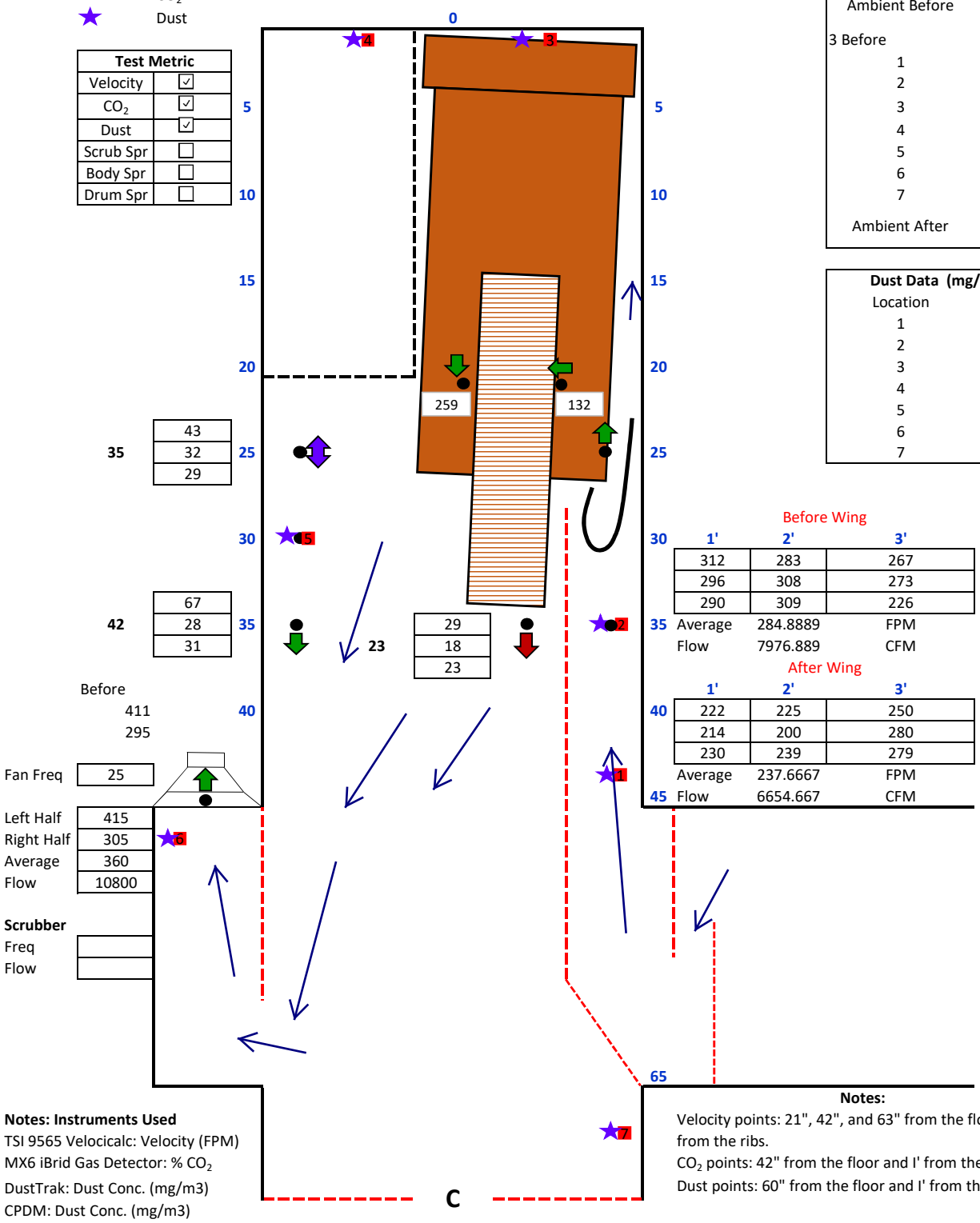
A2 : Setback 25, Box Cut, With Wing, 8000 Curtain, No Scrubber, No Drum Sprays

Date 6/29/18
Time 9:00 AM
● Velocity
■ CO_2
★ Dust

Test Metric	
Velocity	☑
CO_2	☑
Dust	☑
Scrub Spr	☐
Body Spr	☐
Drum Spr	☐

CO_2 Data	
Outlet Pr.	50 PSI
Location	% Conc
Ambient Before	0.06
3 Before	0.06
1	0.07
2	0.07
3	0.77
4	
5	0.19
6	0.14
7	0.08
Ambient After	0.06

Dust Data (mg/m3)	
Location	Conc.
1	0.59
2	3.09
3	147.00
4	
5	44.90
6	17.90
7	8.50



Before Wing

	1'	2'	3'	
	312	283	267	63"
	296	308	273	42"
	290	309	226	21"
Average		284.8889	FPM	
Flow		7976.889	CFM	

After Wing

	1'	2'	3'	
	222	225	250	63"
	214	200	280	42"
	230	239	279	21"
Average		237.6667	FPM	
Flow		6654.667	CFM	

Notes: Instruments Used
TSI 9565 Velocicalc: Velocity (FPM)
MX6 iBrid Gas Detector: % CO_2
DustTrak: Dust Conc. (mg/m3)
CPDM: Dust Conc. (mg/m3)

Notes:
Velocity points: 21", 42", and 63" from the floor and 1' from the ribs.
CO_2 points: 42" from the floor and I' from the ribs.
Dust points: 60" from the floor and I' from the ribs.

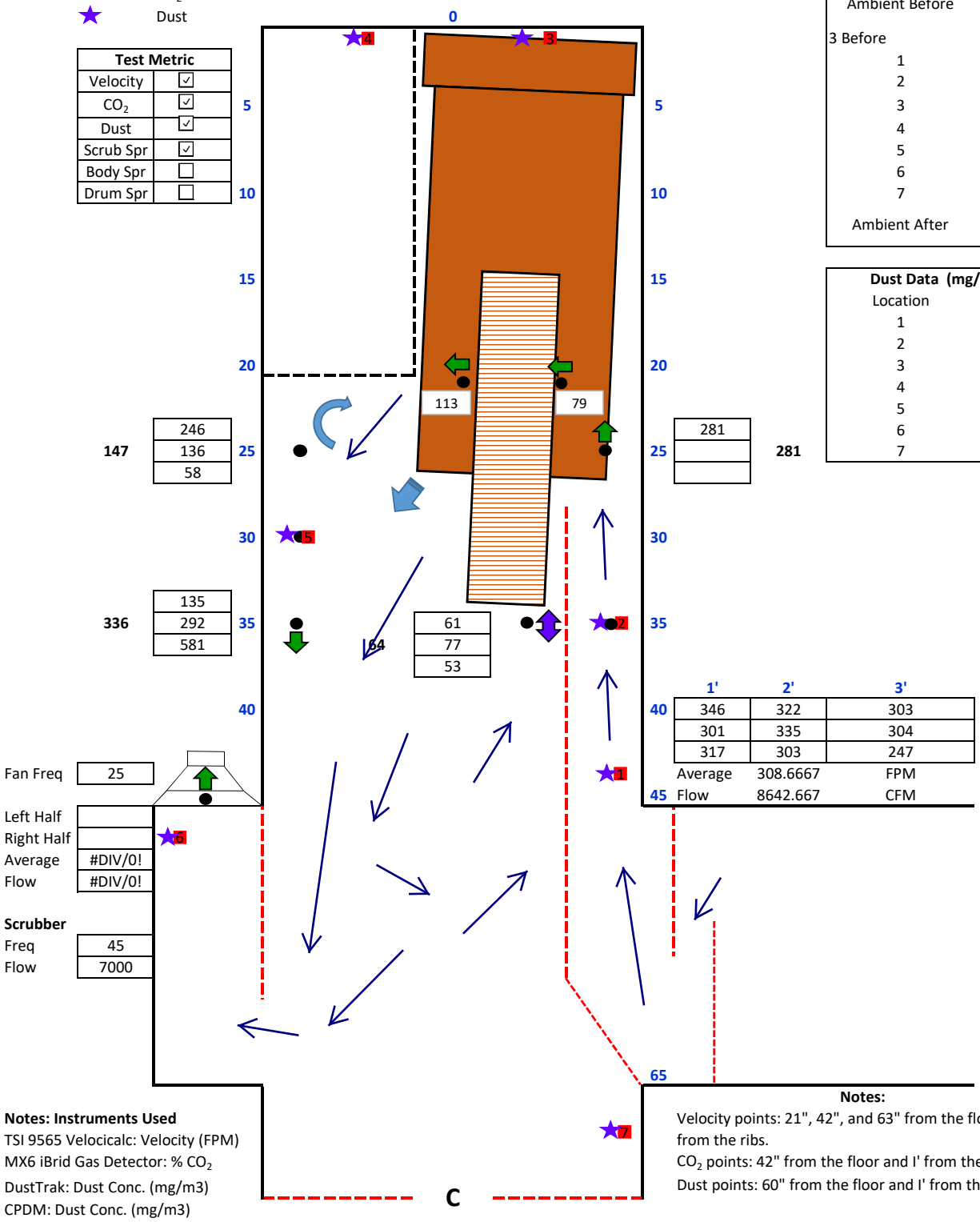
A3 : Setback 25, Box Cut, No Wing, 8000 Curtain, 7000 Scrubber, No Drum Sprays

Date	6/28/18
Time	12:45 PM
●	Velocity
■	CO_2
★	Dust

Test Metric	
Velocity	☑
CO_2	☑
Dust	☑
Scrub Spr	☑
Body Spr	☐
Drum Spr	☐

CO_2 Data	
Outlet Pr.	50 PSI
Location	% Conc
Ambient Before	0.06
3 Before	0.06
1	0.06
2	0.06
3	1.11
4	
5	0.14
6	0.11
7	0.08
Ambient After	0.06

Dust Data (mg/m3)	
Location	Conc.
1	0.96
2	0.90
3	101.00
4	
5	3.25
6	2.59
7	1.56



Notes: Instruments Used
TSI 9565 Velocicalc: Velocity (FPM)
MX6 iBrid Gas Detector: % CO_2
DustTrak: Dust Conc. (mg/m3)
CPDM: Dust Conc. (mg/m3)

Notes:
Velocity points: 21", 42", and 63" from the floor and 1' from the ribs.
CO_2 points: 42" from the floor and I' from the ribs.
Dust points: 60" from the floor and I' from the ribs.

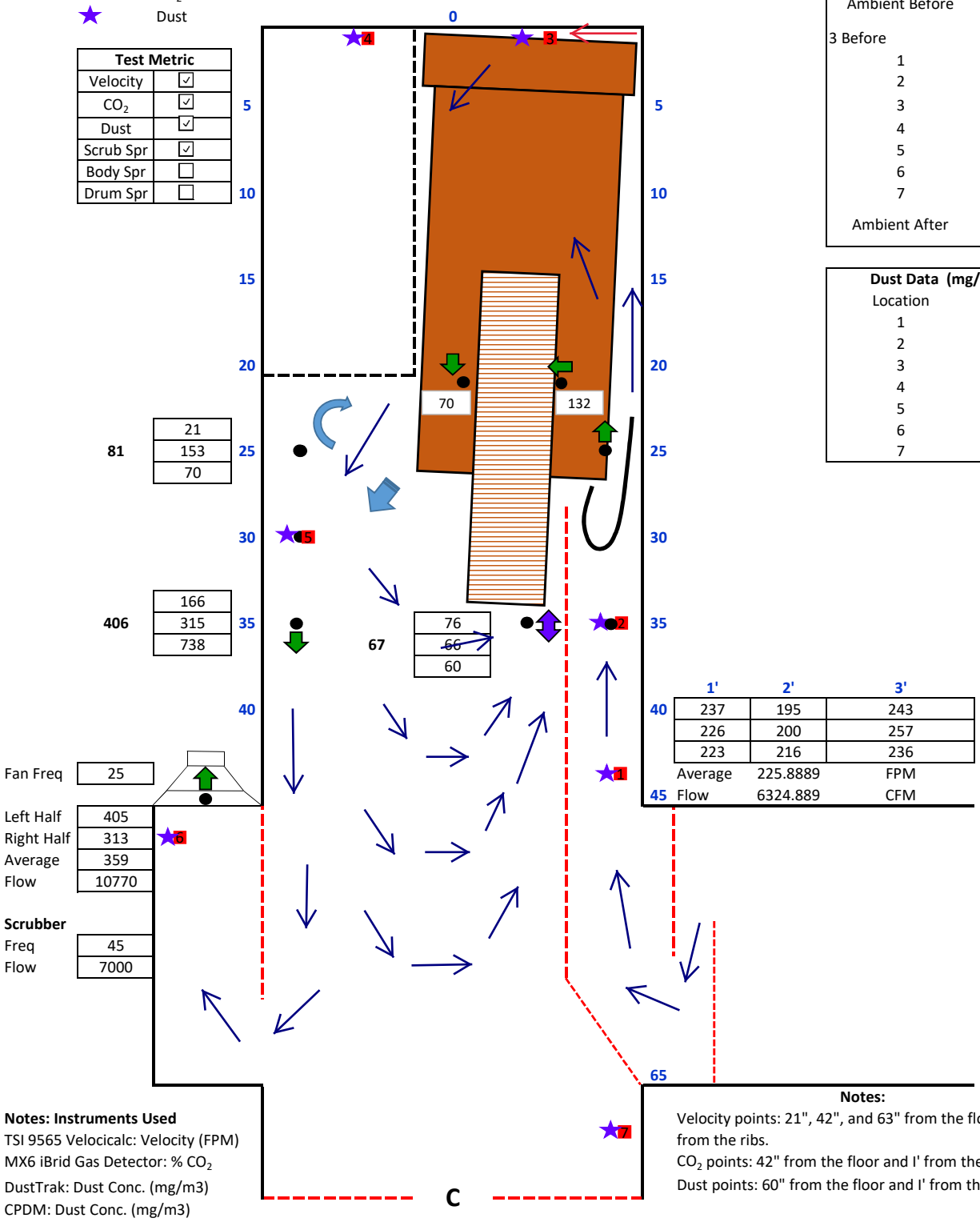
A4 : Setback 25, Box Cut, With Wing, 8000 Curtain, 7000 Scrubber, No Drum Sprays

Date	6/28/18
Time	1:45 PM
●	Velocity
■	CO_2
★	Dust

Test Metric	
Velocity	☑
CO_2	☑
Dust	☑
Scrub Spr	☑
Body Spr	☐
Drum Spr	☐

CO_2 Data	
Outlet Pr.	50 PSI
Location	% Conc
Ambient Before	0.06
3 Before	0.06
1	0.06
2	0.06
3	0.53
4	
5	0.19
6	0.17
7	0.11
Ambient After	0.06

Dust Data (mg/m3)	
Location	Conc.
1	1.03
2	1.63
3	30.40
4	
5	5.18
6	3.30
7	2.54



	1'	2'	3'	
	237	195	243	63"
	226	200	257	42"
	223	216	236	21"
	Average	225.8889	FPM	
	Flow	6324.889	CFM	

Fan Freq	25
Left Half	405
Right Half	313
Average	359
Flow	10770
Scrubber	
Freq	45
Flow	7000

Notes: Instruments Used
TSI 9565 Velocicalc: Velocity (FPM)
MX6 iBrid Gas Detector: % CO_2
DustTrak: Dust Conc. (mg/m3)
CPDM: Dust Conc. (mg/m3)

Notes:
Velocity points: 21", 42", and 63" from the floor and 1' from the ribs.
CO_2 points: 42" from the floor and I' from the ribs.
Dust points: 60" from the floor and I' from the ribs.

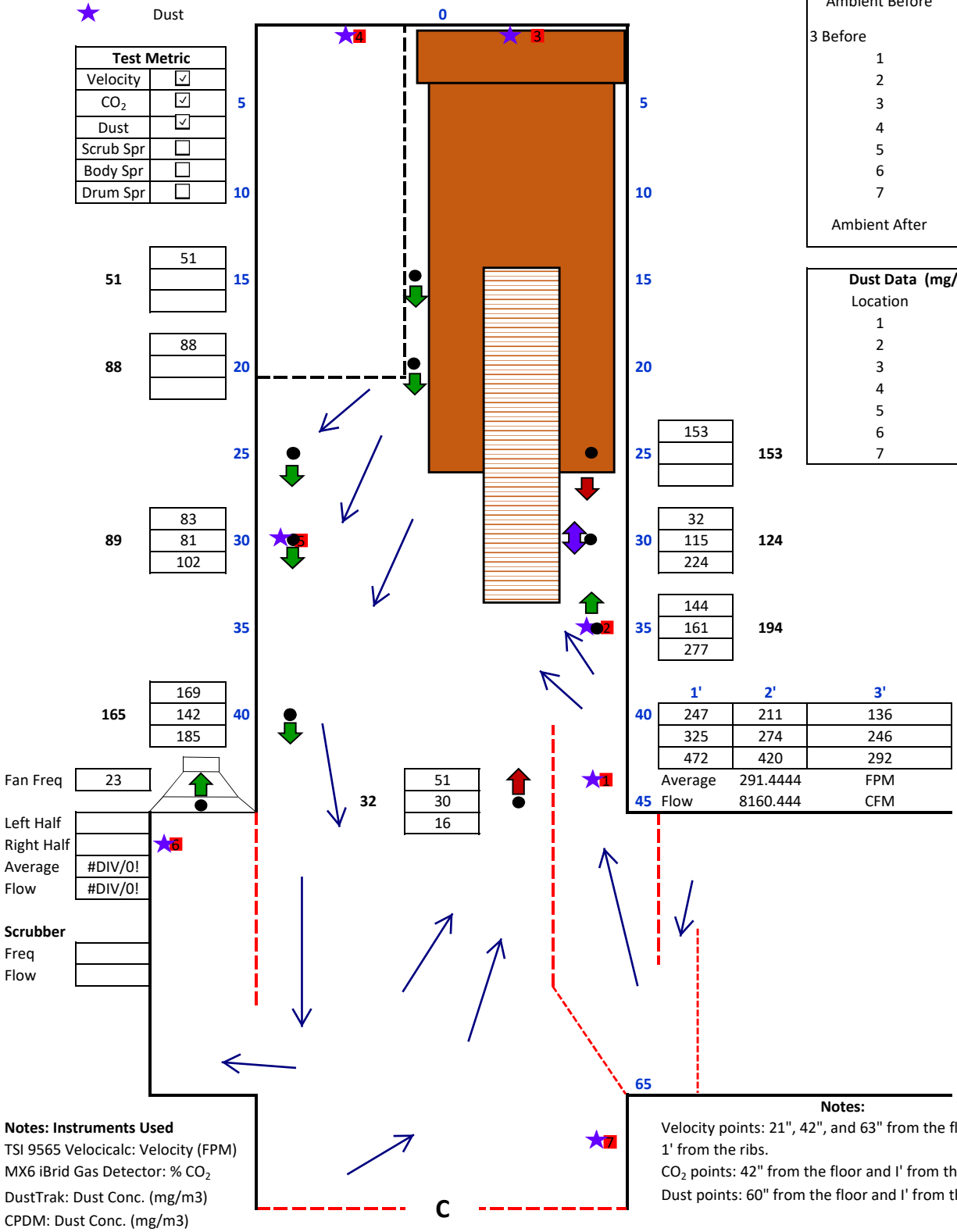
A5 : Setback 40, Box Cut, No Wing, 8000 Curtain, No Scrubber, No Drum Sprays

Date	6/28/18
Time	10:57 AM
●	Velocity
■	CO_2
★	Dust

Test Metric	
Velocity	☑
CO_2	☑
Dust	☑
Scrub Spr	☐
Body Spr	☐
Drum Spr	☐

CO_2 Data	
Outlet Pr.	50 PSI
Location	% Conc
Ambient Before	0.06
3 Before	0.06
1	0.06
2	0.06
3	2.06
4	
5	0.31
6	0.14
7	0.06
Ambient After	0.06

Dust Data (mg/m3)	
Location	Conc.
1	0.54
2	0.87
3	70.40
4	
5	40.40
6	7.77
7	3.41



	1'	2'	3'
	247	211	136
	325	274	246
	472	420	292
Average	291.4444		FPM
Flow	8160.444		CFM

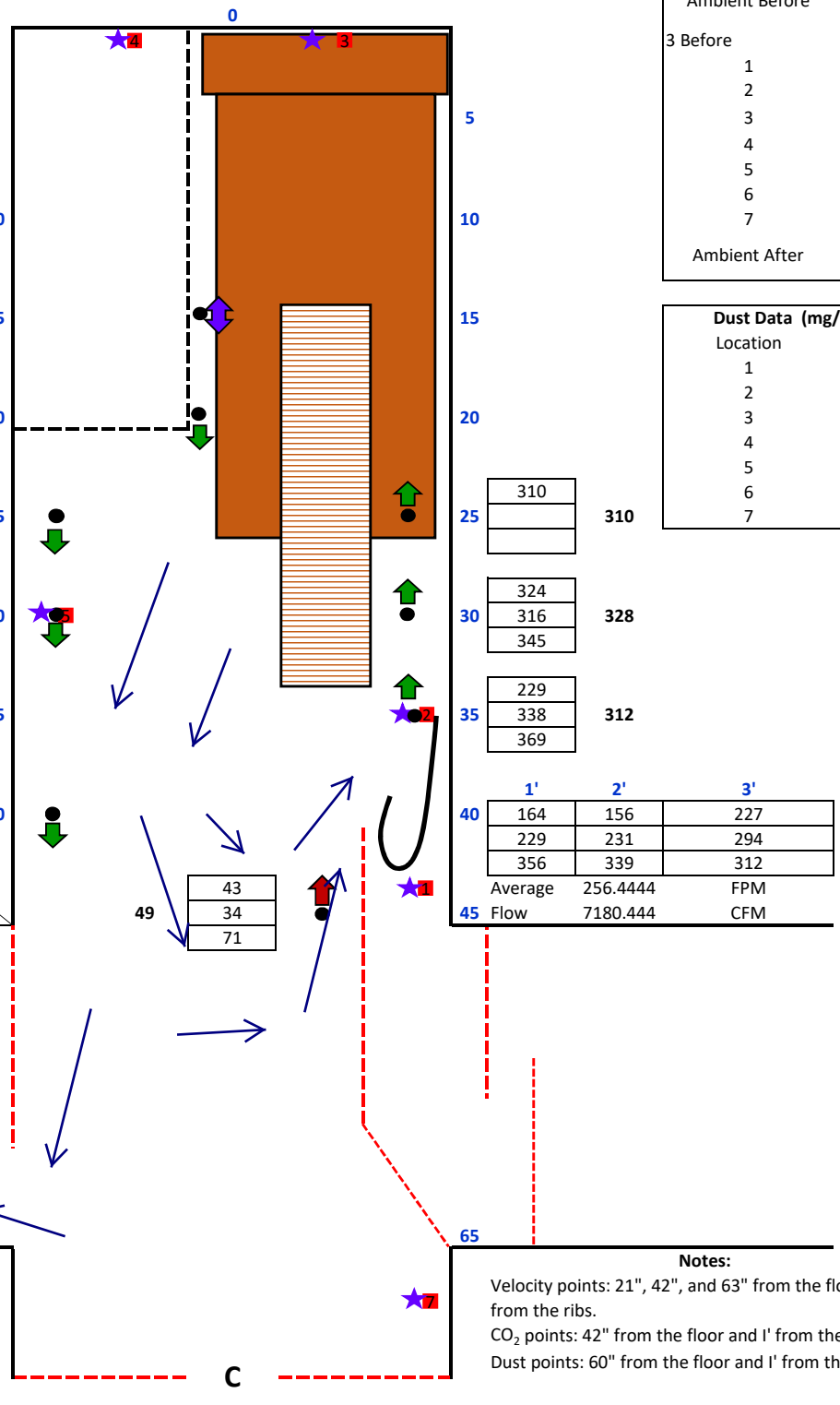
Notes: Instruments Used
TSI 9565 Velocicalc: Velocity (FPM)
MX6 iBrid Gas Detector: % CO_2
DustTrak: Dust Conc. (mg/m3)
CPDM: Dust Conc. (mg/m3)

Notes:
Velocity points: 21", 42", and 63" from the floor and 1' from the ribs.
CO_2 points: 42" from the floor and I' from the ribs.
Dust points: 60" from the floor and I' from the ribs.

A6 : Setback 40, Box Cut, With Wing, 8000 Curtain, No Scrubber, No Drum Sprays

Date 6/28/18
Time 11:54 AM
● Velocity
■ CO_2
★ Dust

Test Metric	
Velocity	☑
CO_2	☑
Dust	☑
Scrub Spr	☐
Body Spr	☐
Drum Spr	☐



	1'	2'	3'	
40	164	156	227	63"
	229	231	294	42"
	356	339	312	21"
	Average	256.4444	FPM	
45	Flow	7180.444	CFM	

Fan Freq	23
Left Half	378
Right Half	271
Average	324.5
Flow	9735

Scrubber

Freq	
Flow	

CO_2 Data

Outlet Pr.	50 PSI
Location	% Conc
Ambient Before	0.06
3 Before	0.06
1	0.06
2	0.06
3	2.28
4	
5	0.14
6	0.16
7	0.20
Ambient After	0.06

Dust Data (mg/m3)

Location	Conc.
1	0.63
2	1.87
3	117.00
4	
5	44.00
6	22.70
7	9.69

Notes: Instruments Used
TSI 9565 Velocicalc: Velocity (FPM)
MX6 iBrid Gas Detector: % CO_2
DustTrak: Dust Conc. (mg/m3)
CPDM: Dust Conc. (mg/m3)

Notes:
Velocity points: 21", 42", and 63" from the floor and 1' from the ribs.
CO_2 points: 42" from the floor and I' from the ribs.
Dust points: 60" from the floor and I' from the ribs.

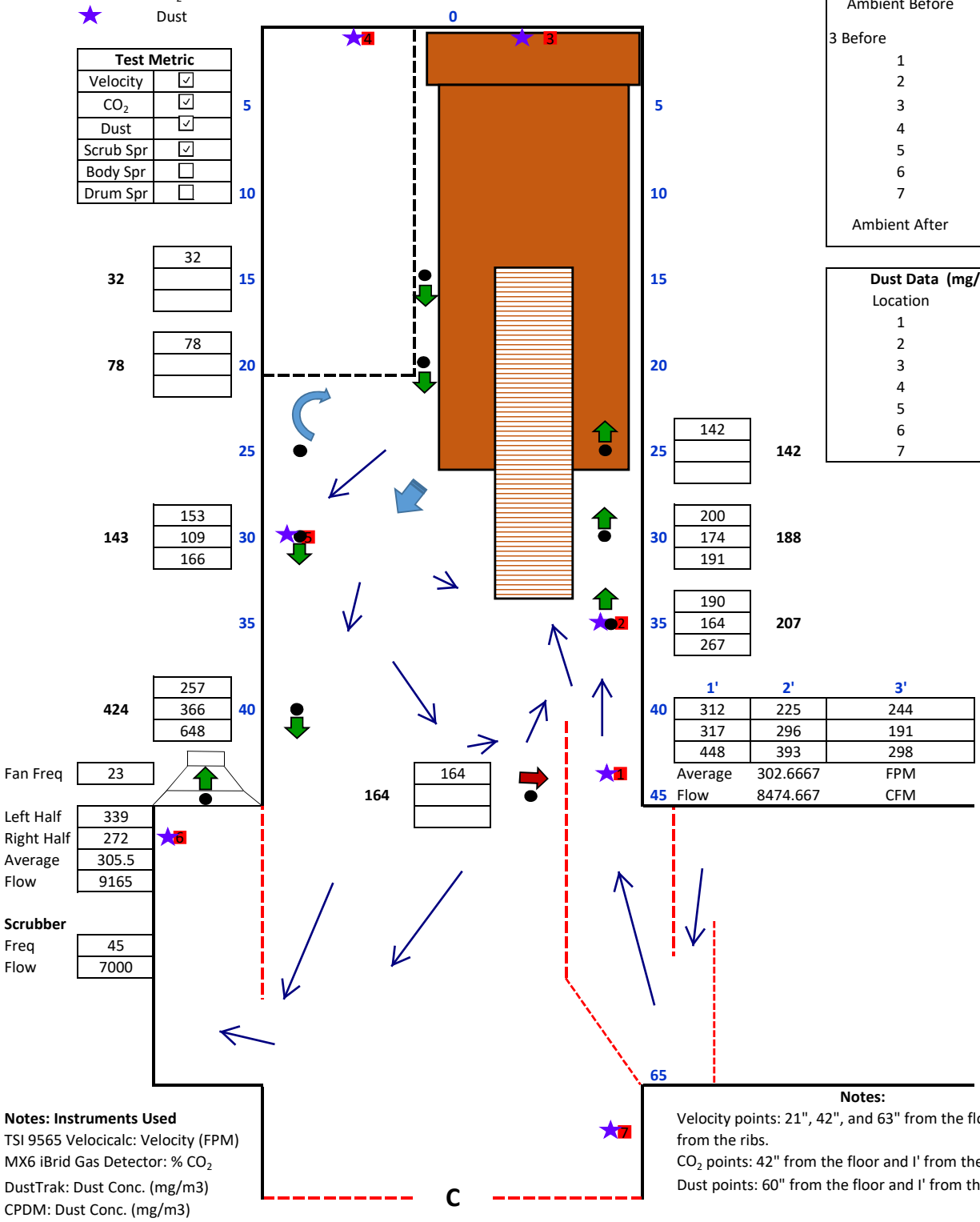
A7 : Setback 40, Box Cut, No Wing, 8000 Curtain, 7000 Scrubber, No Drum Sprays

Date	6/28/18
Time	9:30 AM
●	Velocity
■	CO_2
★	Dust

Test Metric	
Velocity	☑
CO_2	☑
Dust	☑
Scrub Spr	☑
Body Spr	☐
Drum Spr	☐

CO_2 Data	
Outlet Pr.	50 PSI
Location	% Conc
Ambient Before	0.06
3 Before	0.06
1	0.08
2	0.10
3	0.90
4	
5	0.14
6	0.14
7	0.08
Ambient After	0.06

Dust Data (mg/m3)	
Location	Conc.
1	0.61
2	1.58
3	84.40
4	
5	1.52
6	1.77
7	1.19



32	32		
78	78		
143	153	109	166
424	257	366	648
164	164		
142	142		
188	200	174	191
207	190	164	267

	1'	2'	3'	
40	312	225	244	63"
	317	296	191	42"
	448	393	298	21"
	Average	302.6667	FPM	
45	Flow	8474.667	CFM	

Fan Freq	23
Left Half	339
Right Half	272
Average	305.5
Flow	9165

Scrubber

Freq	45
Flow	7000

Notes: Instruments Used

TSI 9565 Velocicalc: Velocity (FPM)
MX6 iBrid Gas Detector: % CO_2
DustTrak: Dust Conc. (mg/m3)
CPDM: Dust Conc. (mg/m3)

Notes:

Velocity points: 21", 42", and 63" from the floor and 1' from the ribs.
CO_2 points: 42" from the floor and I' from the ribs.
Dust points: 60" from the floor and I' from the ribs.

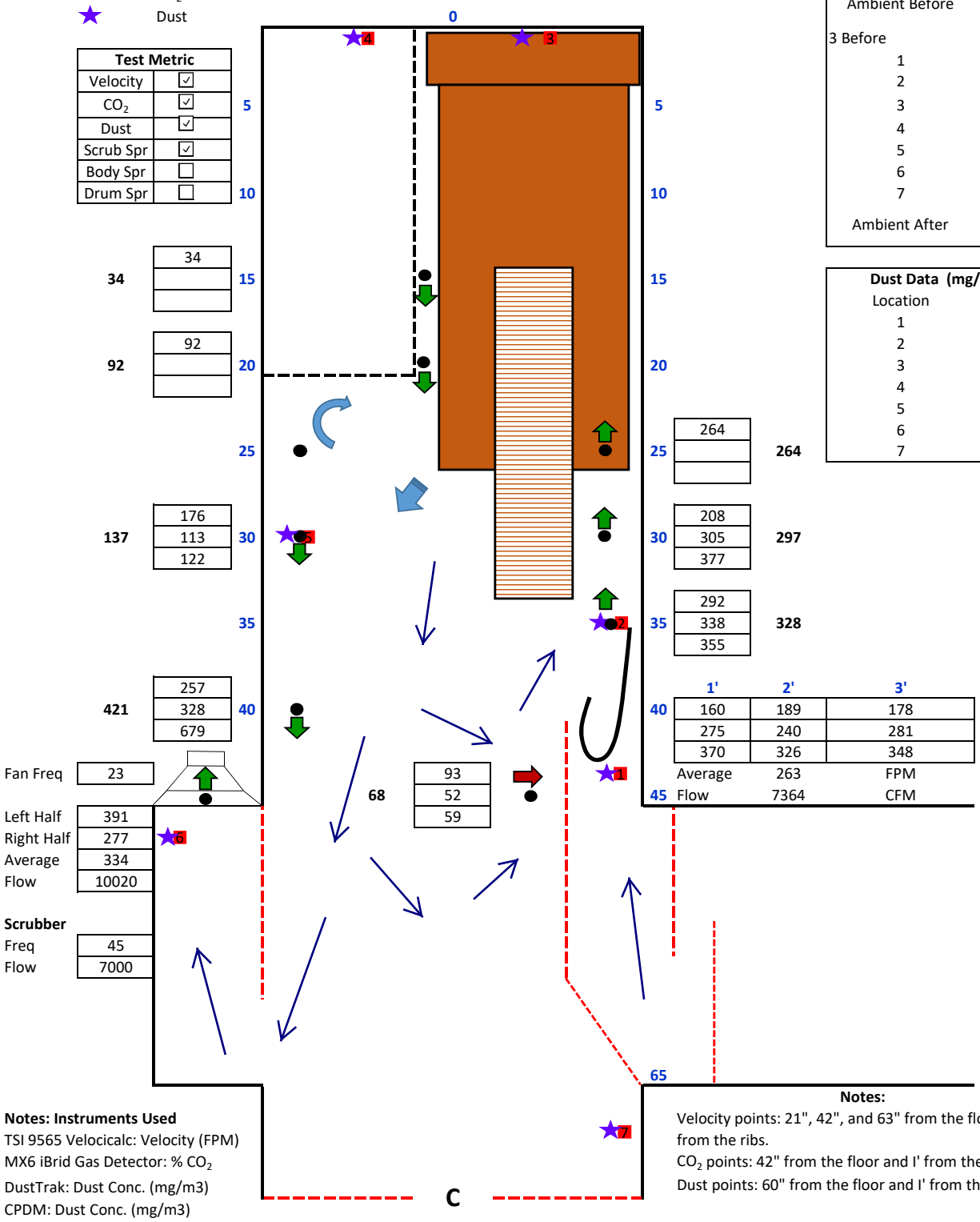
A8 : Setback 40, Box Cut, With Wing, 8000 Curtain, 7000 Scrubber, No Drum Sprays

Date 6/28/18
Time 12:45 PM
● Velocity
■ CO_2
★ Dust

Test Metric	
Velocity	☑
CO_2	☑
Dust	☑
Scrub Spr	☑
Body Spr	☐
Drum Spr	☐

CO_2 Data	
Outlet Pr.	50 PSI
Location	% Conc
Ambient Before	0.06
3 Before	0.06
1	0.08
2	0.12
3	0.76
4	
5	0.14
6	0.17
7	0.08
Ambient After	0.06

Dust Data (mg/m3)	
Location	Conc.
1	0.33
2	1.43
3	72.40
4	
5	4.69
6	2.30
7	1.41



34				
92				
137	176	113	122	
421	257	328	679	
264	264			
297	208	305	377	
328	292	338	355	
68	93	52	59	

	1'	2'	3'	
40	160	189	178	63"
	275	240	281	42"
	370	326	348	21"
	Average	263	FPM	
45	Flow	7364	CFM	

Fan Freq	23
Left Half	391
Right Half	277
Average	334
Flow	10020
Scrubber	
Freq	45
Flow	7000

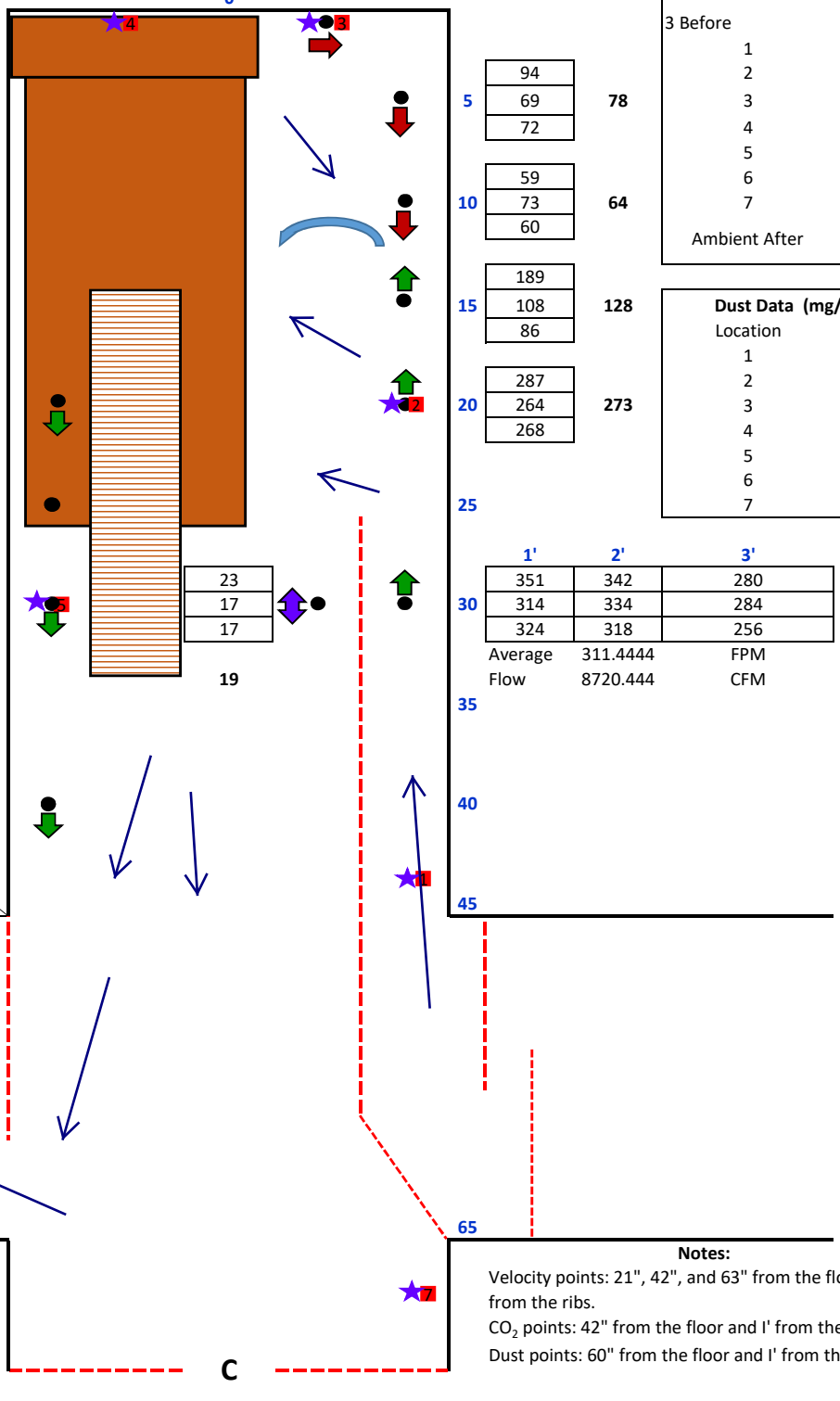
Notes: Instruments Used
TSI 9565 Velocicalc: Velocity (FPM)
MX6 iBrid Gas Detector: % CO_2
DustTrak: Dust Conc. (mg/m3)
CPDM: Dust Conc. (mg/m3)

Notes:
Velocity points: 21", 42", and 63" from the floor and 1' from the ribs.
CO_2 points: 42" from the floor and I' from the ribs.
Dust points: 60" from the floor and I' from the ribs.

B1 : Setback 25, Slab Cut, No Wing, 8000 Curtain, No Scrubber, No Drum Sprays

Date	07/03/18
Time	12:30 PM
●	Velocity
■	CO_2
★	Dust

Test Metric	
Velocity	☑
CO_2	☑
Dust	☐
Scrub Spr	☐
Body Spr	☐
Drum Spr	☐



CO_2 Data	
Outlet Pr.	50 PSI
Location	% Conc
Ambient Before	0.17
3 Before	0.17
1	0.17
2	0.22
3	0.47
4	0.64
5	0.25
6	0.25
7	0.17
Ambient After	0.17

Dust Data (mg/m^3)	
Location	Conc.
1	1.53
2	1.84
3	47.90
4	45.50
5	16.10
6	19.80
7	9.90

Notes: Instruments Used

TSI 9565 Velocicalc: Velocity (FPM)
MX6 iBrid Gas Detector: % CO_2
DustTrak: Dust Conc. (mg/m^3)
CPDM: Dust Conc. (mg/m^3)

Notes:

Velocity points: 21", 42", and 63" from the floor and 1' from the ribs.
CO_2 points: 42" from the floor and I' from the ribs.
Dust points: 60" from the floor and I' from the ribs.

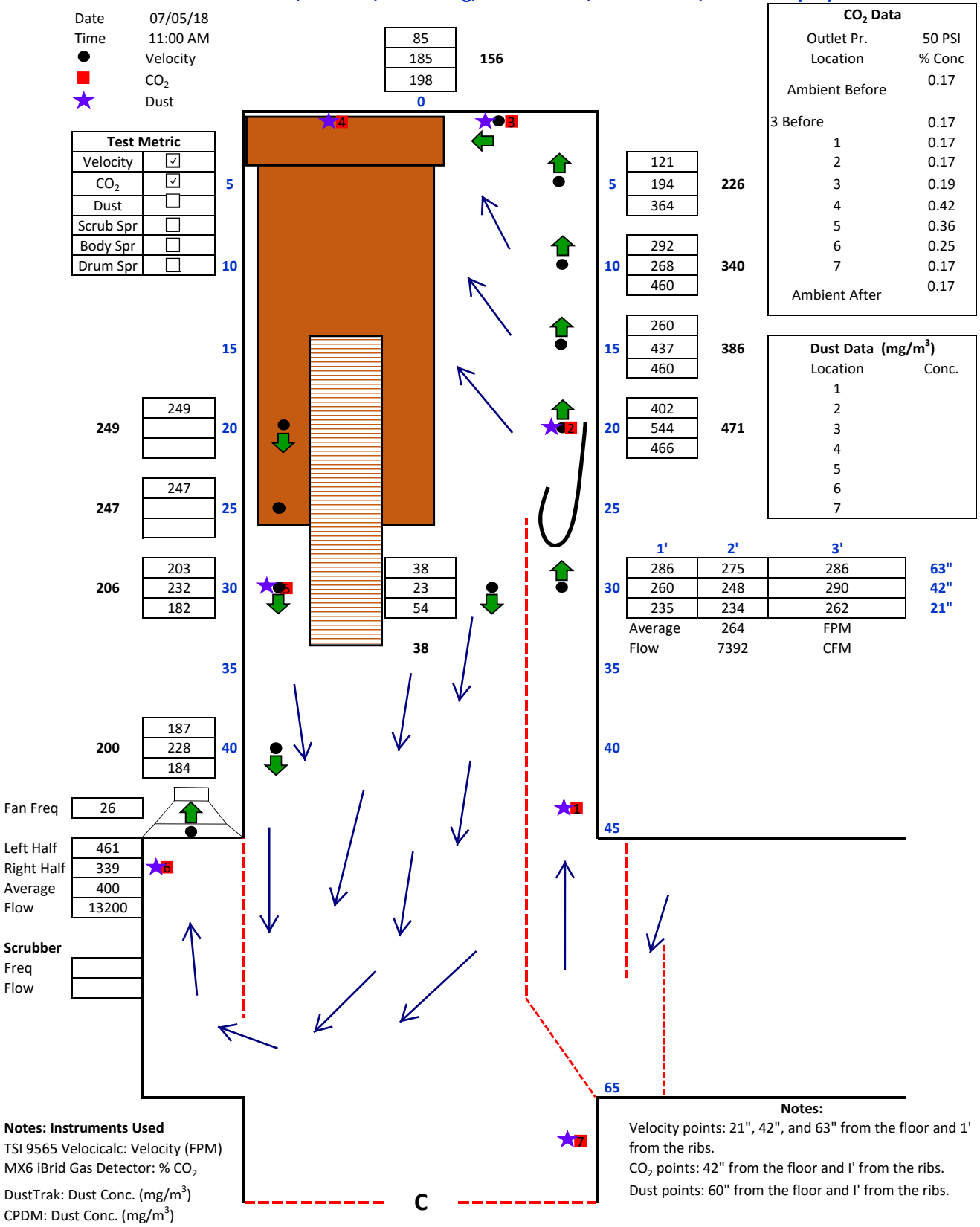
B2 : Setback 25, Slab Cut, With Wing, 8000 Curtain, No Scrubber, No Drum Sprays

Date	07/05/18
Time	11:00 AM
●	Velocity
■	CO_2
★	Dust

Test Metric	
Velocity	☑
CO_2	☑
Dust	☐
Scrub Spr	☐
Body Spr	☐
Drum Spr	☐

CO_2 Data	
Outlet Pr.	50 PSI
Location	% Conc
Ambient Before	0.17
3 Before	0.17
1	0.17
2	0.17
3	0.19
4	0.42
5	0.36
6	0.25
7	0.17
Ambient After	0.17

Dust Data (mg/m^3)	
Location	Conc.
1	
2	
3	
4	
5	
6	
7	



Notes: Instruments Used

TSI 9565 Velocicalc: Velocity (FPM)
MX6 iBrid Gas Detector: % CO_2
DustTrak: Dust Conc. (mg/m^3)
CPDM: Dust Conc. (mg/m^3)

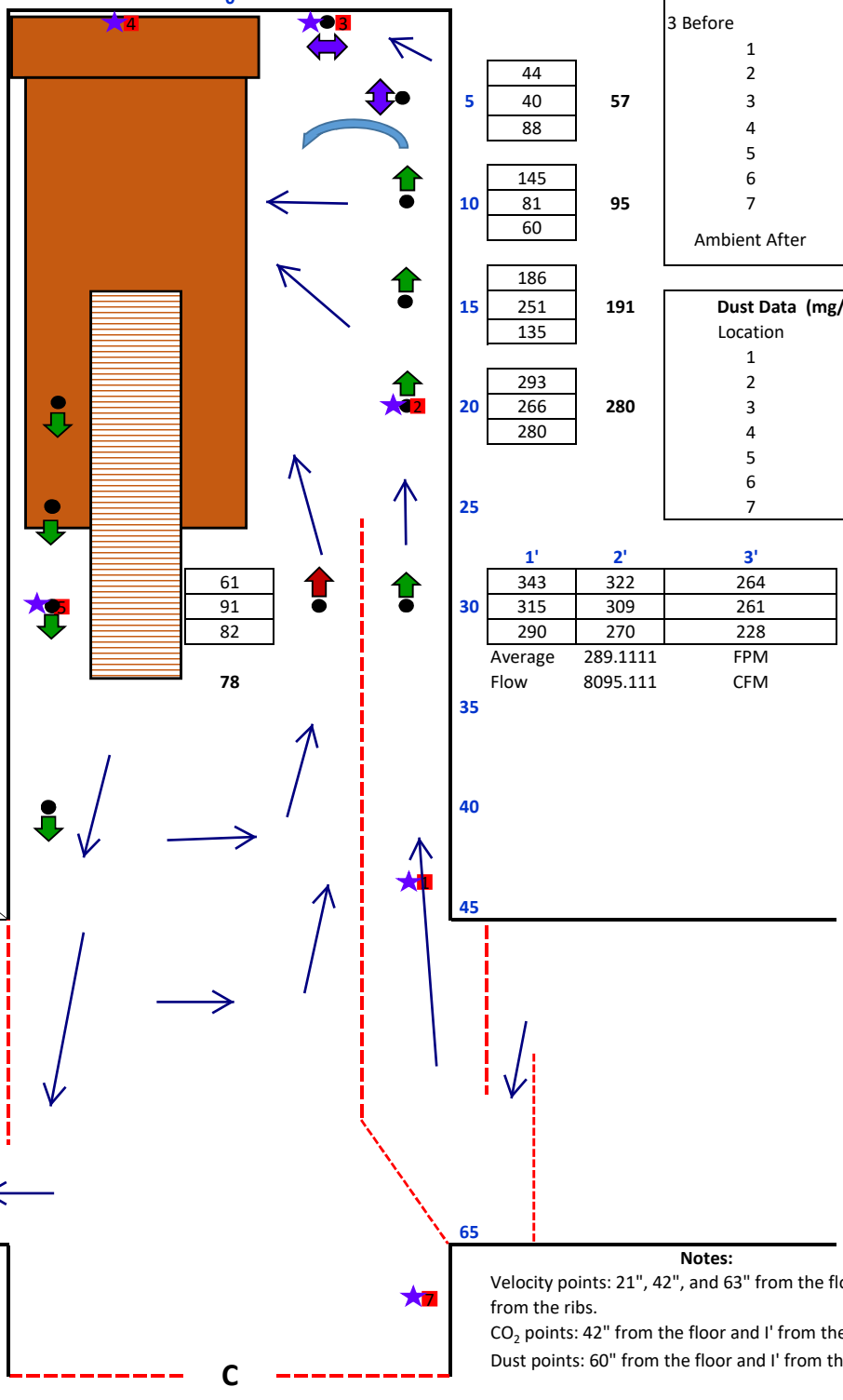
Notes:

Velocity points: 21", 42", and 63" from the floor and 1' from the ribs.
CO_2 points: 42" from the floor and I' from the ribs.
Dust points: 60" from the floor and I' from the ribs.

B3 : Setback 25, Slab Cut, No Wing, 8000 Curtain, 7000 Scrubber, No Drum Sprays

Date	07/03/18
Time	11:00 AM
●	Velocity
■	CO_2
★	Dust

Test Metric	
Velocity	☑
CO_2	☑
Dust	☑
Scrub Spr	☐
Body Spr	☐
Drum Spr	☐



Fan Freq	26
Left Half	418
Right Half	372
Average	395
Flow	13035
Scrubber	
Freq	45
Flow	7000

6

CO_2 Data	
Outlet Pr.	50 PSI
Location	% Conc
Ambient Before	0.14
3 Before	0.14
1	0.14
2	0.17
3	0.33
4	0.44
5	0.25
6	0.22
7	0.22
Ambient After	0.14

Dust Data (mg/m^3)	
Location	Conc.
1	1.15
2	1.46
3	1.31
4	2.28
5	9.25
6	7.17
7	5.60

	1'	2'	3'	
	343	322	264	63"
	315	309	261	42"
	290	270	228	21"
Average	289.1111	FPM		
Flow	8095.111	CFM		

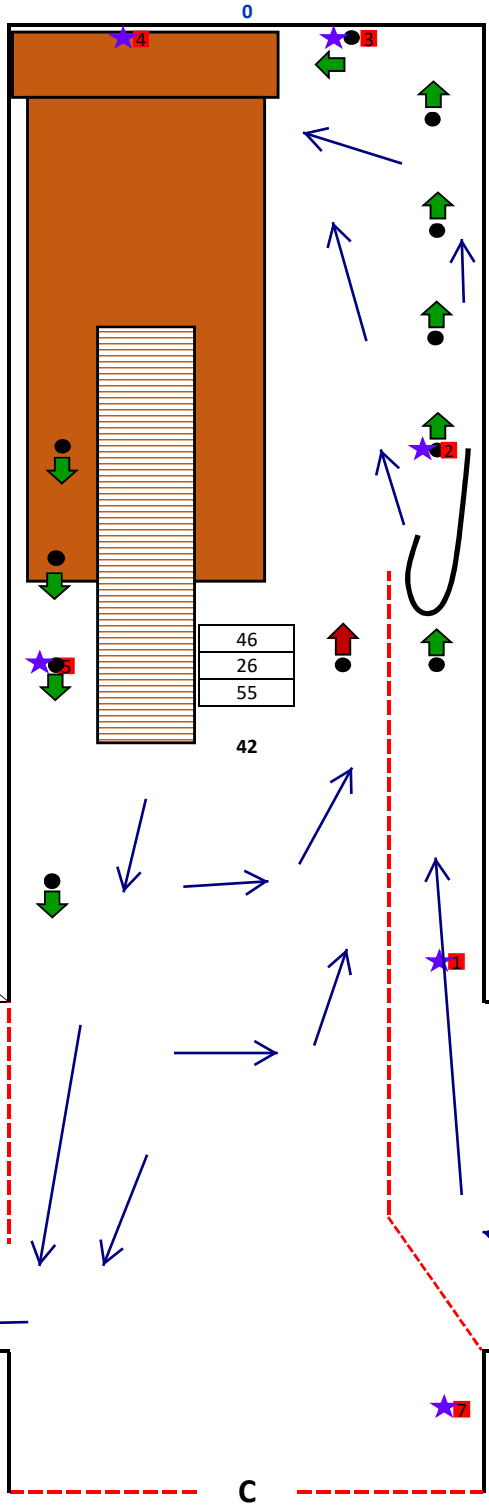
Notes: Instruments Used
TSI 9565 Velocicalc: Velocity (FPM)
MX6 iBrid Gas Detector: % CO_2
DustTrak: Dust Conc. (mg/m^3)
CPDM: Dust Conc. (mg/m^3)

Notes:
Velocity points: 21", 42", and 63" from the floor and 1' from the ribs.
CO_2 points: 42" from the floor and I' from the ribs.
Dust points: 60" from the floor and I' from the ribs.

B4 : Setback 25, Slab Cut, With Wing, 8000 Curtain, 7000 Scrubber, No Drum Sprays

Date	07/05/18
Time	12:00 PM
●	Velocity
■	CO_2
★	Dust

Test Metric	
Velocity	☑
CO_2	☑
Dust	☐
Scrub Spr	☐
Body Spr	☐
Drum Spr	☐



Fan Freq	26
Left Half	413
Right Half	347
Average	380
Flow	12540

Scrubber

Freq	45
Flow	7000

	1'	2'	3'	
	301	284	292	63"
	260	239	274	42"
	242	232	286	21"
Average		267.7778	FPM	
Flow		7497.778	CFM	

CO_2 Data

Outlet Pr.	50 PSI
Location	% Conc
Ambient Before	0.17
3 Before	0.17
1	0.17
2	0.19
3	0.22
4	0.36
5	0.28
6	0.25
7	0.25
Ambient After	0.17

Dust Data (mg/m^3)

Location	Conc.
1	
2	
3	
4	
5	
6	
7	

Notes: Instruments Used

TSI 9565 Velocicalc: Velocity (FPM)
MX6 iBrid Gas Detector: % CO_2
DustTrak: Dust Conc. (mg/m^3)
CPDM: Dust Conc. (mg/m^3)

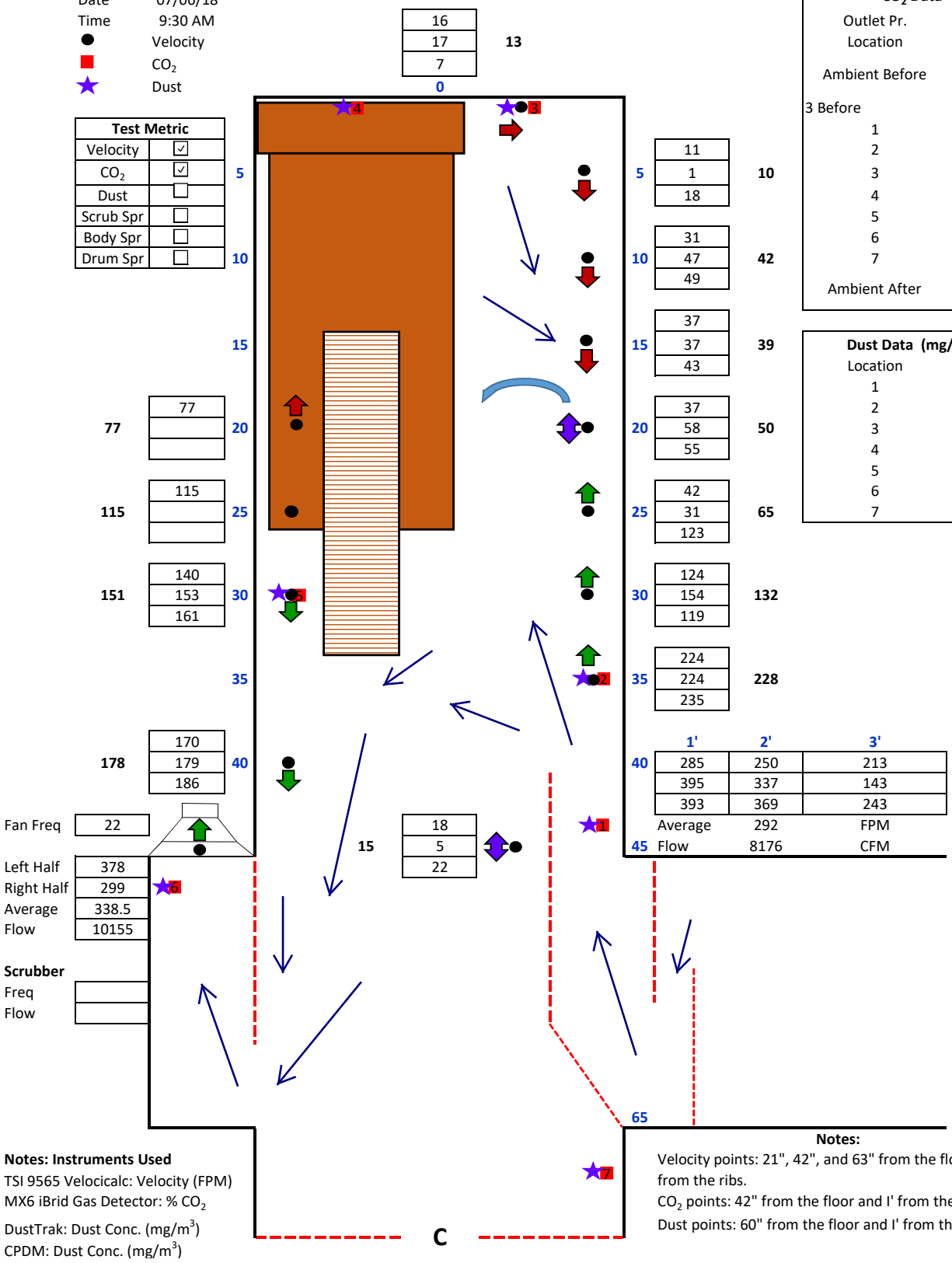
Notes:

Velocity points: 21", 42", and 63" from the floor and 1' from the ribs.
CO_2 points: 42" from the floor and I' from the ribs.
Dust points: 60" from the floor and I' from the ribs.

B5 : Setback 40, Slab Cut, No Wing, 8000 Curtain, No Scrubber, No Drum Sprays

Date	07/06/18
Time	9:30 AM
●	Velocity
■	CO_2
★	Dust

Test Metric	
Velocity	☑
CO_2	☑
Dust	☐
Scrub Spr	☐
Body Spr	☐
Drum Spr	☐



CO_2 Data	
Outlet Pr.	50 PSI
Location	% Conc
Ambient Before	0.11
3 Before	0.11
1	0.11
2	0.11
3	1.08
4	0.97
5	0.19
6	0.19
7	0.14
Ambient After	0.11

Dust Data (mg/m^3)	
Location	Conc.
1	2.01
2	2.59
3	92.40
4	148.00
5	17.10
6	29.40
7	5.29

Notes: Instruments Used

TSI 9565 Velocicalc: Velocity (FPM)
MX6 iBrid Gas Detector: % CO_2
DustTrak: Dust Conc. (mg/m^3)
CPDM: Dust Conc. (mg/m^3)

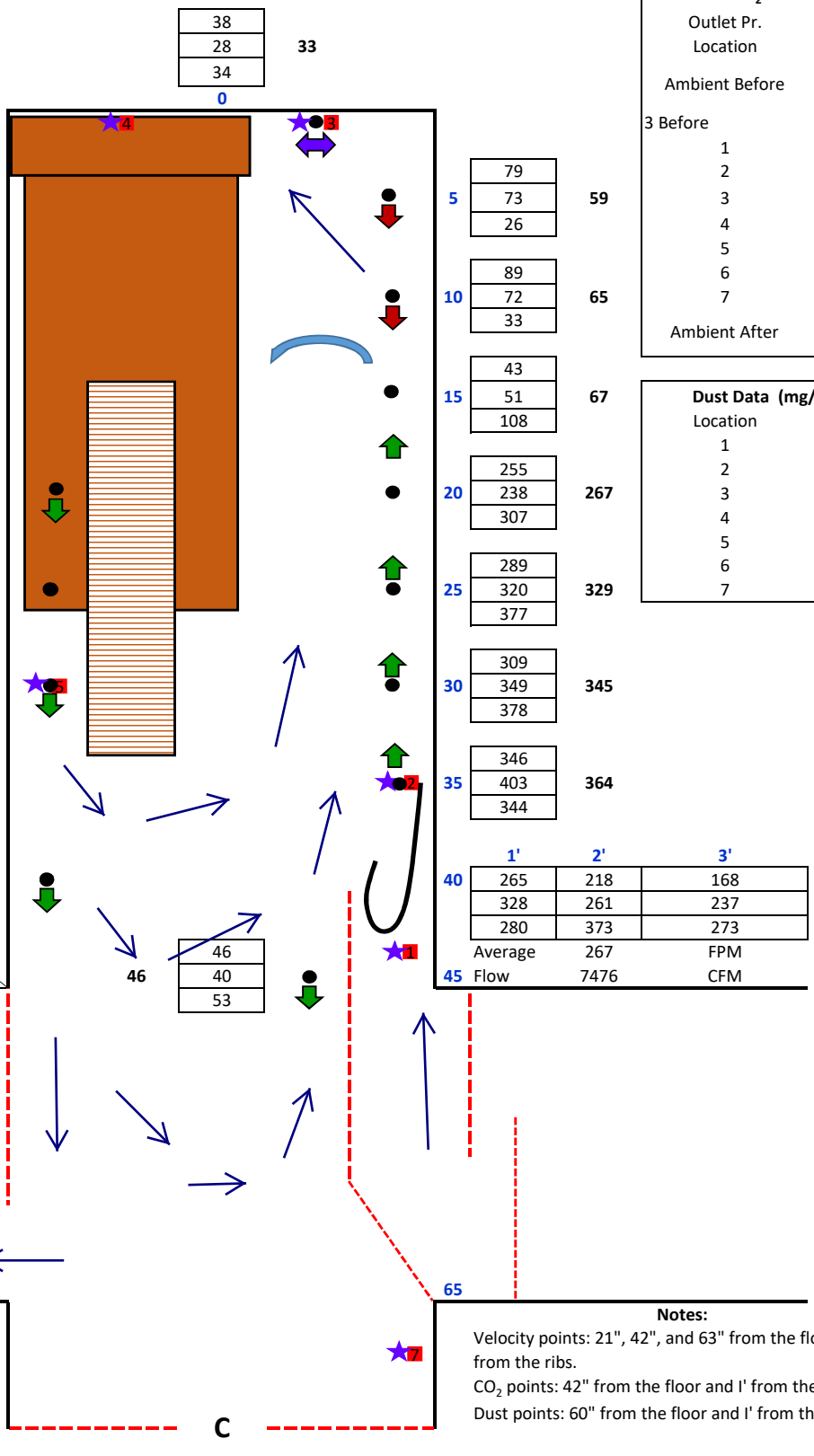
Notes:

Velocity points: 21", 42", and 63" from the floor and 1' from the ribs.
CO_2 points: 42" from the floor and I' from the ribs.
Dust points: 60" from the floor and I' from the ribs.

B6 : Setback 40, Slab Cut, With Wing, 8000 Curtain, No Scrubber, No Drum Sprays

Date	07/06/18
Time	11:00 AM
●	Velocity
■	CO_2
★	Dust

Test Metric	
Velocity	☑
CO_2	☑
Dust	☐
Scrub Spr	☐
Body Spr	☐
Drum Spr	☐



Fan Freq	22
Left Half	358
Right Half	293
Average	325.5
Flow	9765
Scrubber	
Freq	
Flow	

CO_2 Data	
Outlet Pr.	50 PSI
Location	% Conc
Ambient Before	0.11
3 Before	0.11
1	0.11
2	0.11
3	0.42
4	0.61
5	0.19
6	0.19
7	0.14
Ambient After	0.11

Dust Data (mg/m^3)	
Location	Conc.
1	3.10
2	6.93
3	5.32
4	85.20
5	18.40
6	28.80
7	10.20

Notes: Instruments Used

TSI 9565 Velocicalc: Velocity (FPM)
MX6 iBrid Gas Detector: % CO_2
DustTrak: Dust Conc. (mg/m^3)
CPDM: Dust Conc. (mg/m^3)

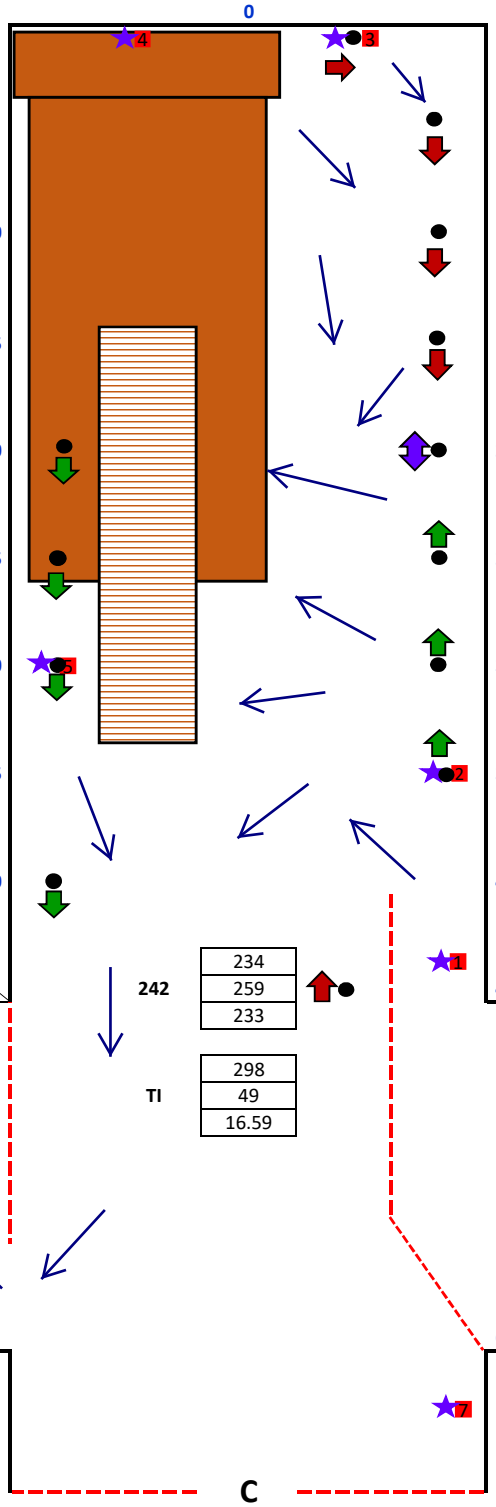
Notes:

Velocity points: 21", 42", and 63" from the floor and 1' from the ribs.
CO_2 points: 42" from the floor and I' from the ribs.
Dust points: 60" from the floor and I' from the ribs.

B7 : Setback 40, Slab Cut, No Wing, 8000 Curtain, 7000 Scrubber, No Drum Sprays

Date	6/27/18
Time	10:00 AM
●	Velocity
■	CO_2
★	Dust

Test Metric	
Velocity	☑
CO_2	☑
Dust	☑
Scrub Spr	☑
Body Spr	☐
Drum Spr	☐



	20	
	45	23
	5	
	0	

	13		
5	15	16	
	19		
	53		
10	26	29	
	9		
	21		
15	38	29	
	28		
	45		
20	33	69	
	128		
	52		
25	99	97	
	140		
	53		
30	46	90	
	171		
	171		
35	188	198	
	236		

	40		
40			
	36		
36			
	163		
717	196		
	1793		
	355		
422	307		
	604		

	234		
242	259		
	233		
	298		
TI	49		
	16.59		

	1'	2'	3'	
40	251	253	94	63"
	334	277	152	42"
	445	398	358	21"
	Average	284.6667	FPM	
45	Flow	7970.667	CFM	

Fan Freq	22
Left Half	340
Right Half	269
Average	304.5
Flow	9135
Scrubber	
Freq	45
Flow	7000

CO_2 Data	
Outlet Pr.	50 PSI
Location	% Conc
Ambient Before	0.00
3 Before	0
1	0.00
2	0.02
3	0.38
4	0.34
5	0.11
6	0.11
7	0.08
Ambient After	0.00

Dust Data (mg/m^3)	
Location	Conc.
1	1.83
2	1.91
3	2.95
4	149.00
5	3.23
6	3.72
7	1.94

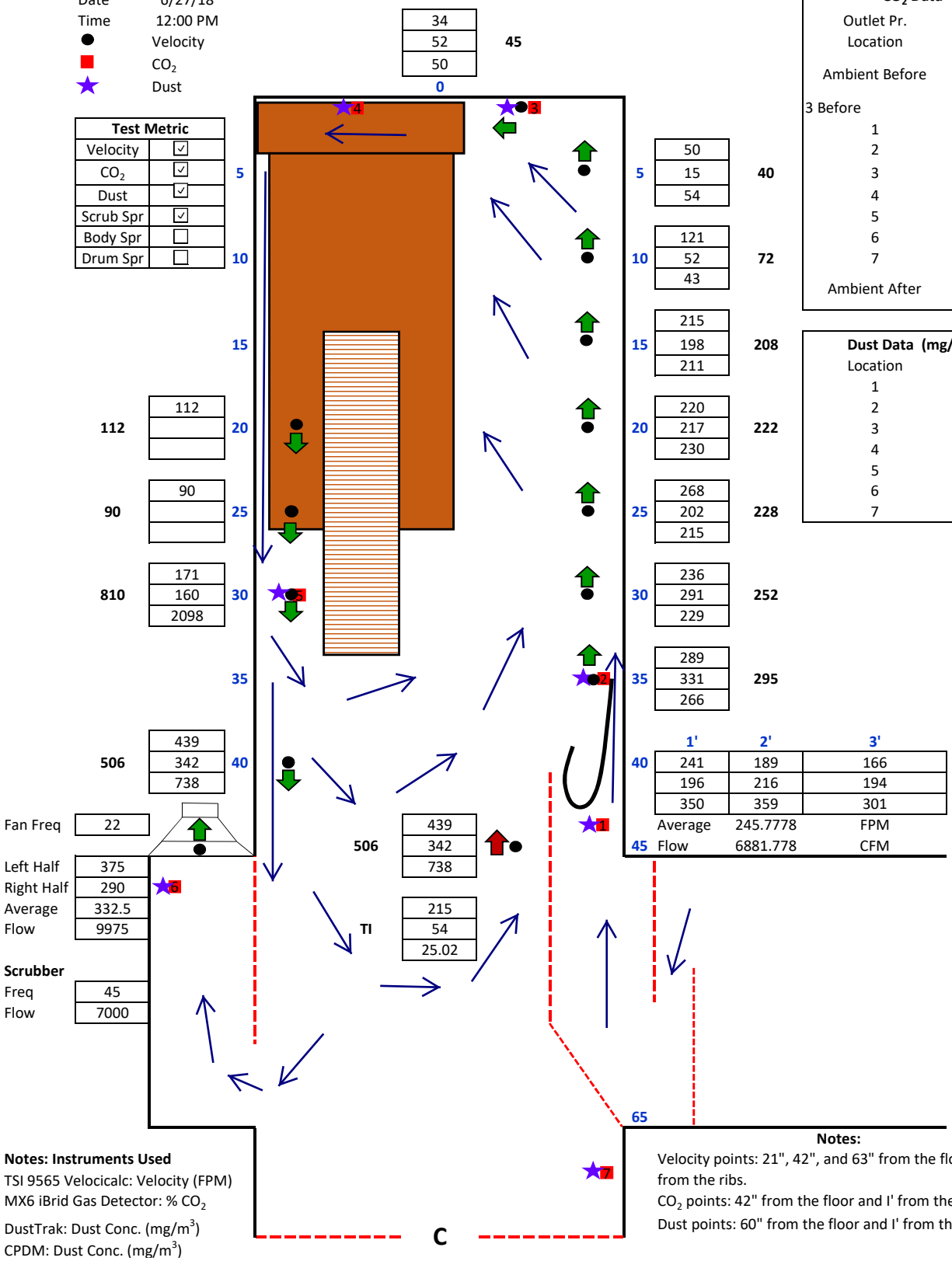
Notes: Instruments Used
TSI 9565 Velocicalc: Velocity (FPM)
MX6 iBrid Gas Detector: % CO_2
DustTrak: Dust Conc. (mg/m^3)
CPDM: Dust Conc. (mg/m^3)

Notes:
Velocity points: 21", 42", and 63" from the floor and 1' from the ribs.
CO_2 points: 42" from the floor and I' from the ribs.
Dust points: 60" from the floor and I' from the ribs.

B8 : Setback 40, Slab Cut, With Wing, 8000 Curtain, 7000 Scrubber, No Drum Sprays

Date	6/27/18
Time	12:00 PM
●	Velocity
■	CO_2
★	Dust

Test Metric	
Velocity	☑
CO_2	☑
Dust	☑
Scrub Spr	☑
Body Spr	☐
Drum Spr	☐



CO_2 Data	
Outlet Pr.	50 PSI
Location	% Conc
Ambient Before	0.00
3 Before	0
1	0.00
2	0.00
3	0.32
4	0.34
5	0.11
6	0.11
7	0.08
Ambient After	0.00

Dust Data (mg/m^3)	
Location	Conc.
1	3.49
2	4.29
3	4.41
4	78.50
5	7.48
6	7.09
7	8.77

Notes: Instruments Used

TSI 9565 Velocicalc: Velocity (FPM)
MX6 iBrid Gas Detector: % CO_2
DustTrak: Dust Conc. (mg/m^3)
CPDM: Dust Conc. (mg/m^3)

Notes:

Velocity points: 21", 42", and 63" from the floor and 1' from the ribs.
CO_2 points: 42" from the floor and I' from the ribs.
Dust points: 60" from the floor and I' from the ribs.

Dust and CO_2 data, 8000 cfm curtain air, 6600 cfm scrubber quantity, different inlet duct setting

Test Condition

Setback 40, Slab Cut, With Wing, 8000 Curtain, 6600 Scrubber, No Drum Sprays

Curtain air @ 43' from the face (19.5 Hz)

1'	2'	3'	
251	256	177	63"
376	284	159	42"
428	391	311	21"
Average	292.5556	FPM	
Flow	8191.556	CFM	

Gallery air

Left Half	Right Half	
332	290	
Average	311	FPM
Flow	9330	CFM

Dust concentration data (mg/m^3)

	Inlet Duct Setting			
Stn.	All three open	Right closed	Right and center closed	All three open + lid open
1	0.732	0.793	0.882	0.644
2	1.24	1.23	1.35	0.892
3	34.6	57.9	36.2	20.9
4	92.8	88.2	80.8	65.5
5	7.39	5.41	7.58	4.7
6	8.16	8.21	8.57	5.91
1	1.08	0.874	0.85	0.73

Dust concentration data (%)

	Inlet Duct Setting			
Stn.	All three open	Right closed	Right and center closed	All three open + lid open
3 before	0.06	0.06	0.06	0.06
4 before	0.07	0.07	0.09	0.07
3 after	0.75	0.63	0.72	0.64
4 after	0.36	0.38	0.33	0.31

Dust and CO_2 data, 8000 cfm curtain air, different scrubber flow

Test Condition

Setback 40, Slab Cut, With Wing, 8000 Curtain, No Drum Sprays

Curtain air @ 43' from the face (22 Hz)

1'	2'	3'	
267	237	210	63"
379	320	181	42"
409	376	229	21"
Average	289.7778	FPM	
Flow	8113.778	CFM	

Gallery air

Left Half	Right Half	
386	312	
Average	349	FPM
Flow	10470	CFM

Dust concentration data (mg/m^3)

	Srubber Quantity (CFM)					
Stn.	8000 (5.2 Hz)	7000 (4.6 Hz)	6000 (4.1 Hz)	5000 (3.3 Hz)	4000 (3.15 Hz)	0 (0 Hz)
1	0.547	0.483	0.502	0.478	0.506	0.658
2						
3	2	2.51	2.04	2.65	3.14	3.05
4	145	118	140	136	107	115
5						
6						
7						
1						

Dust concentration data (%)

	Srubber Quantity (CFM)					
Stn.	8000 (5.2 Hz)	7000 (4.6 Hz)	6000 (4.1 Hz)	5000 (3.3 Hz)	4000 (3.15 Hz)	0 (0 Hz)
3 before	0.08	0.08	0.08	0.08	0.08	0.08
4 before	0.09	0.07	0.09	0.09	0.09	0.09
3 after	0.58	0.75	0.83	0.61	0.41	1.08
4 after	0.33	0.36	0.4	0.4	0.36	0.54

Dust and CO_2 data, 6500 cfm curtain air, different scrubber flow

Test Condition

Setback 40, Slab Cut, With Wing, 6500 Curtain, No Drum Sprays

Curtain air @ 43' from the face (19.5 Hz)

1'	2'	3'	
198	205	85	63"
314	221	130	42"
389	327	199	21"
Average	229.7778	FPM	
Flow	6433.778	CFM	

Gallery air

Left Half	Right Half	
309	276	
Average	292.5	FPM
Flow	8775	CFM

Dust concentration data (mg/m^3)

Stn.	Srubber Quantity (CFM)					
	8000 (5.0 Hz)	7000 (4.25 Hz)	6000 (3.2 Hz)	5000 (3.0 Hz)	4000	0 (0 Hz)
1	2.16	1.51	1.41	1.48	1.88	1.89
2	2.8	2.46	2.58	1.85	4.16	4.28
3	34.2	58.5	13.1	50	11.3	99.4
4	95.3	117	149	140	119	133
5	4.65	7.37	7.49	14.4	27.9	80.7
6	4.38	7.19	7.16	16.6	17.4	37.8
7	3.95	6.18	4.48	10.5	7.52	13.6
1	1.86	1.89	1.86	2.02	2.7	2.86

Dust concentration data (%)

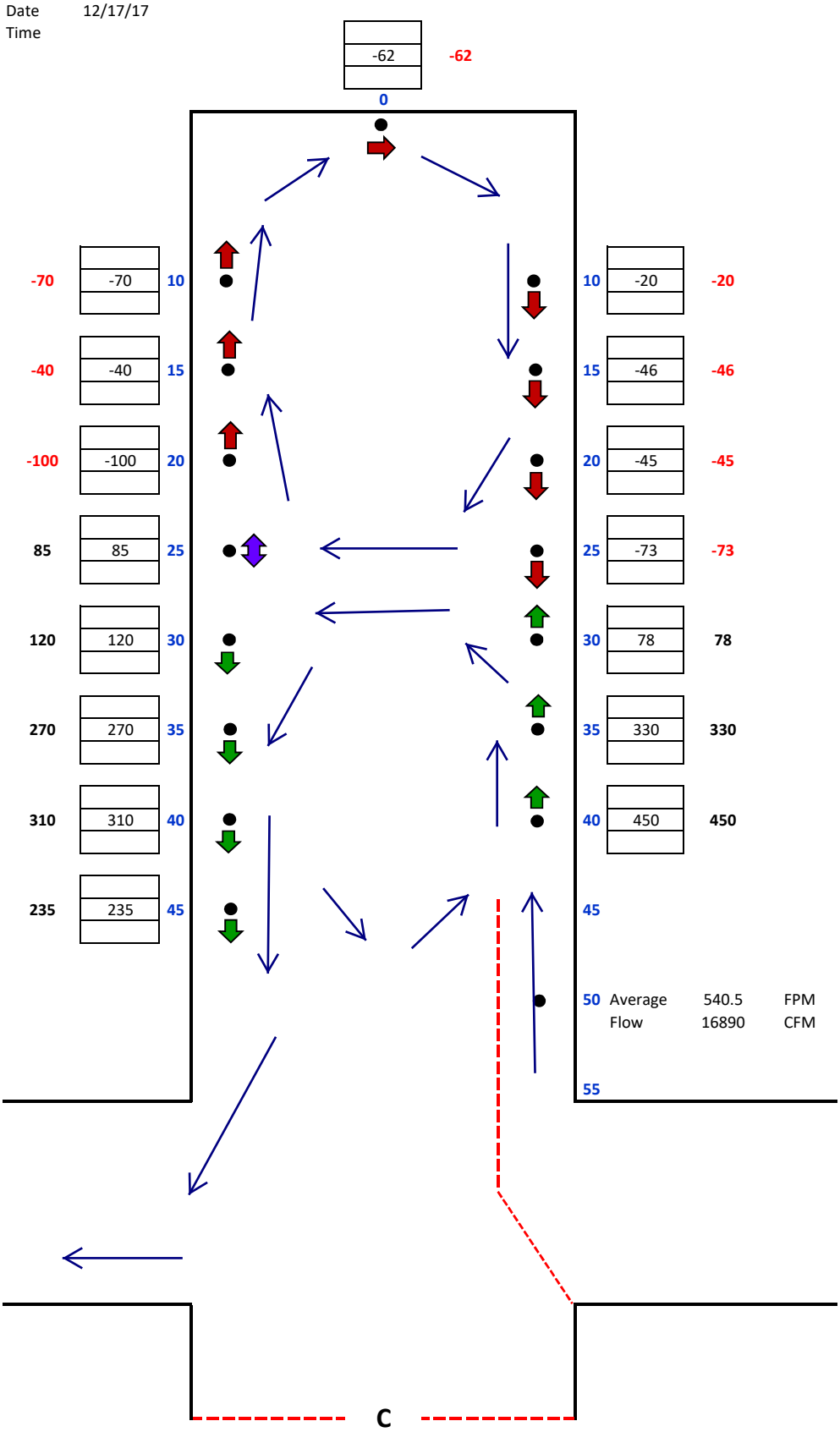
Stn.	Srubber Quantity (CFM)					
	8000 (5.0 Hz)	7000 (4.25 Hz)	6000 (3.2 Hz)	5000 (3.0 Hz)	4000	0 (0 Hz)
3 before	0.11	0.11	0.11	0.11	0.11	0.11
4 before	0.11	0.13	0.11	0.11	0.11	0.11
3 after	0.33	0.75	0.47	0.37	0.36	0.69
4 after	0.78	0.49	0.29	0.31	0.31	0.36

APPENDIX D: MINE FIELD DATA AND NOTES

This appendix includes diagrams with measurements made during the field visits to partner mine locations in a diagram consistent with Appendix C. Points indicate the sampling locations, with boxes displaying the measured values and arrows to indicate the flow. Thick arrows indicate the direction of flow for measurements, while thin arrows represent the observations of flow. Measurements of dust and gas, if sampled, are indicated near the point of the sample. Conditions are described in the title.

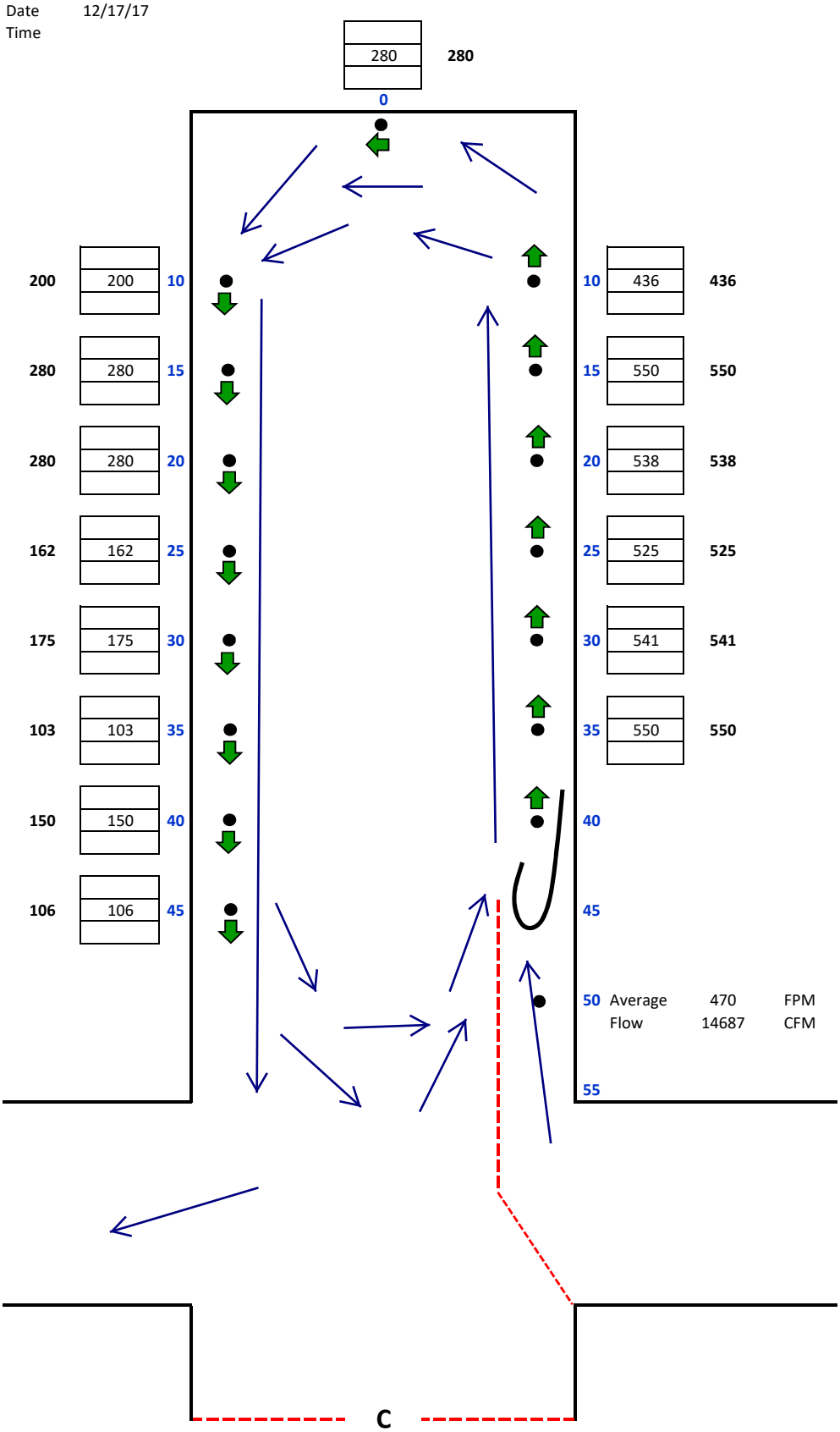
Warrior Mine, Setback 45, Slab Cut, No Wing, No Equipment

Date 12/17/17
Time



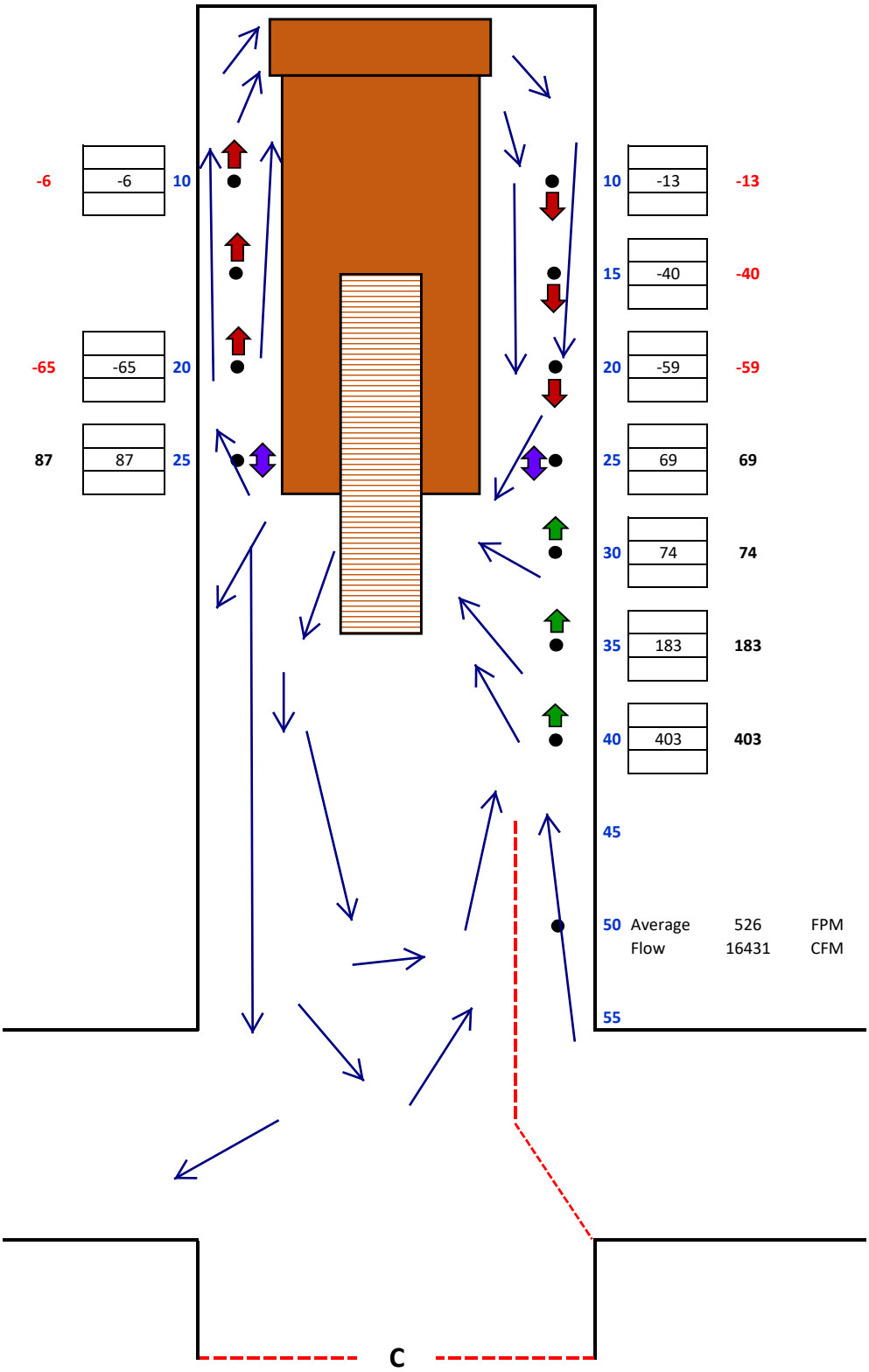
Warrior Mine, Setback 45, Slab Cut, With Wing, No Equipment

Date 12/17/17
Time



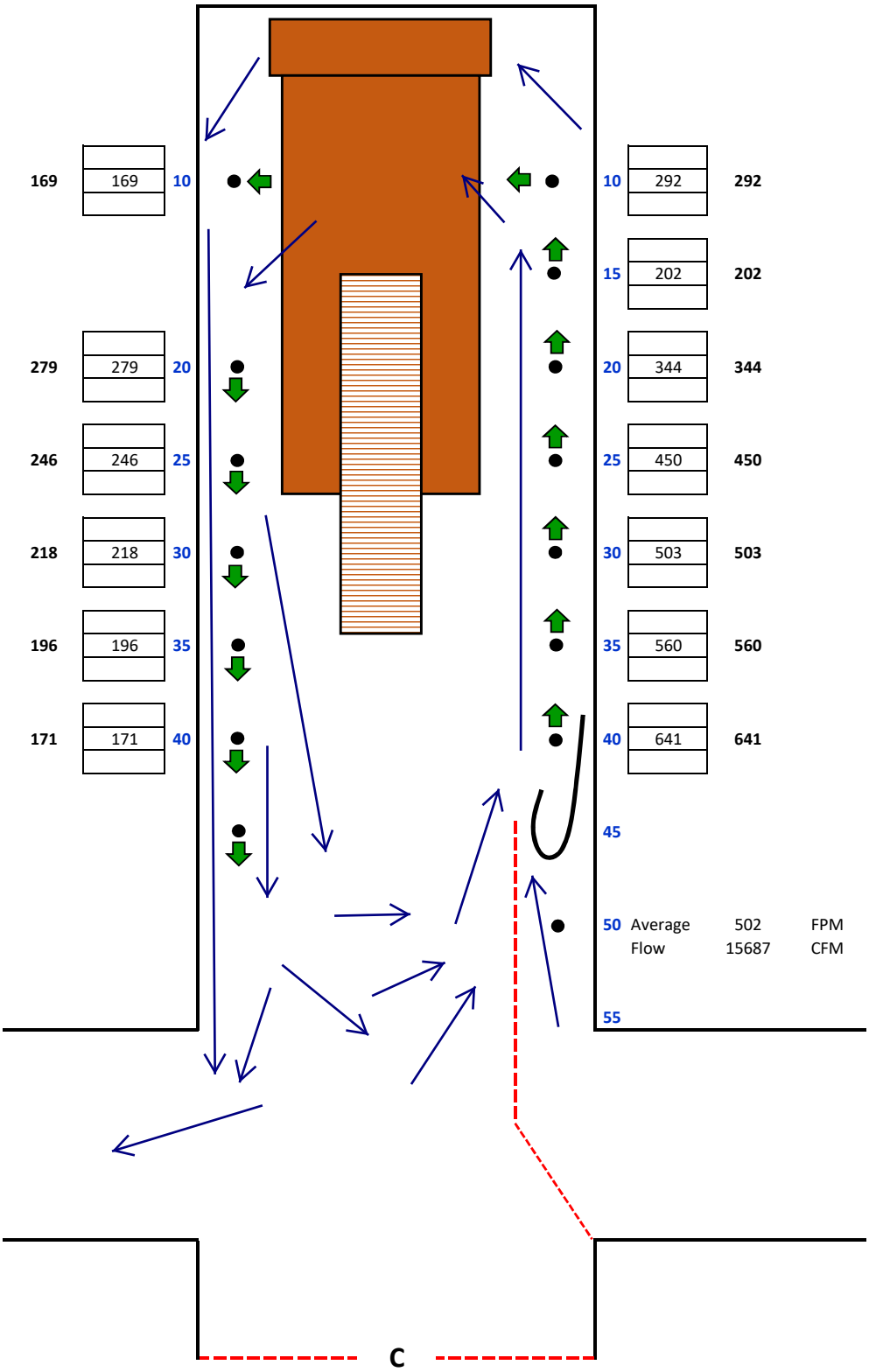
Warrior Mine, Setback 45, Slab Cut, No Wing, With Equipment

Date 12/17/17
Time



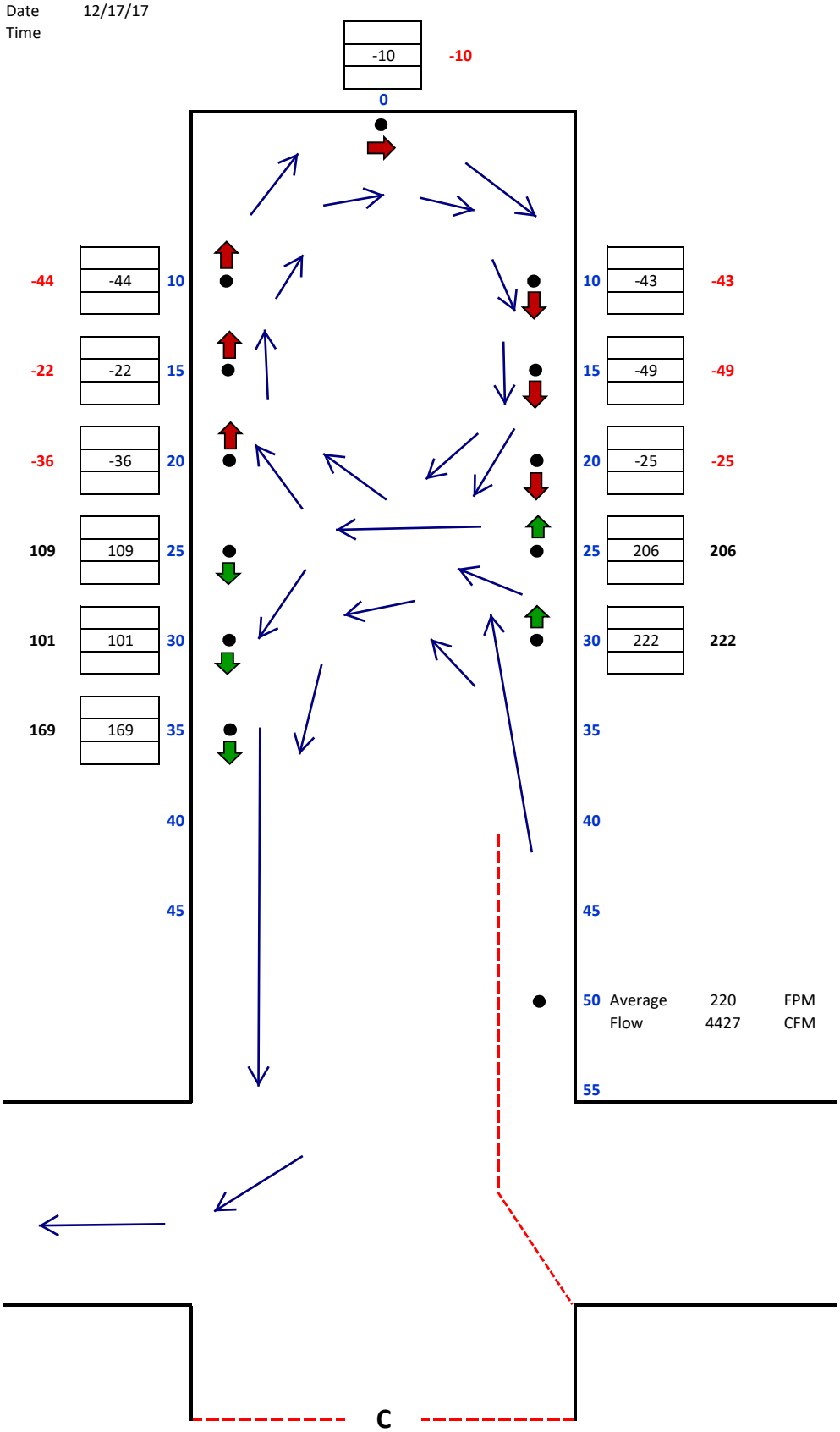
Warrior Mine, Setback 45, Slab Cut, With Wing, With Equipment

Date 12/17/17
Time



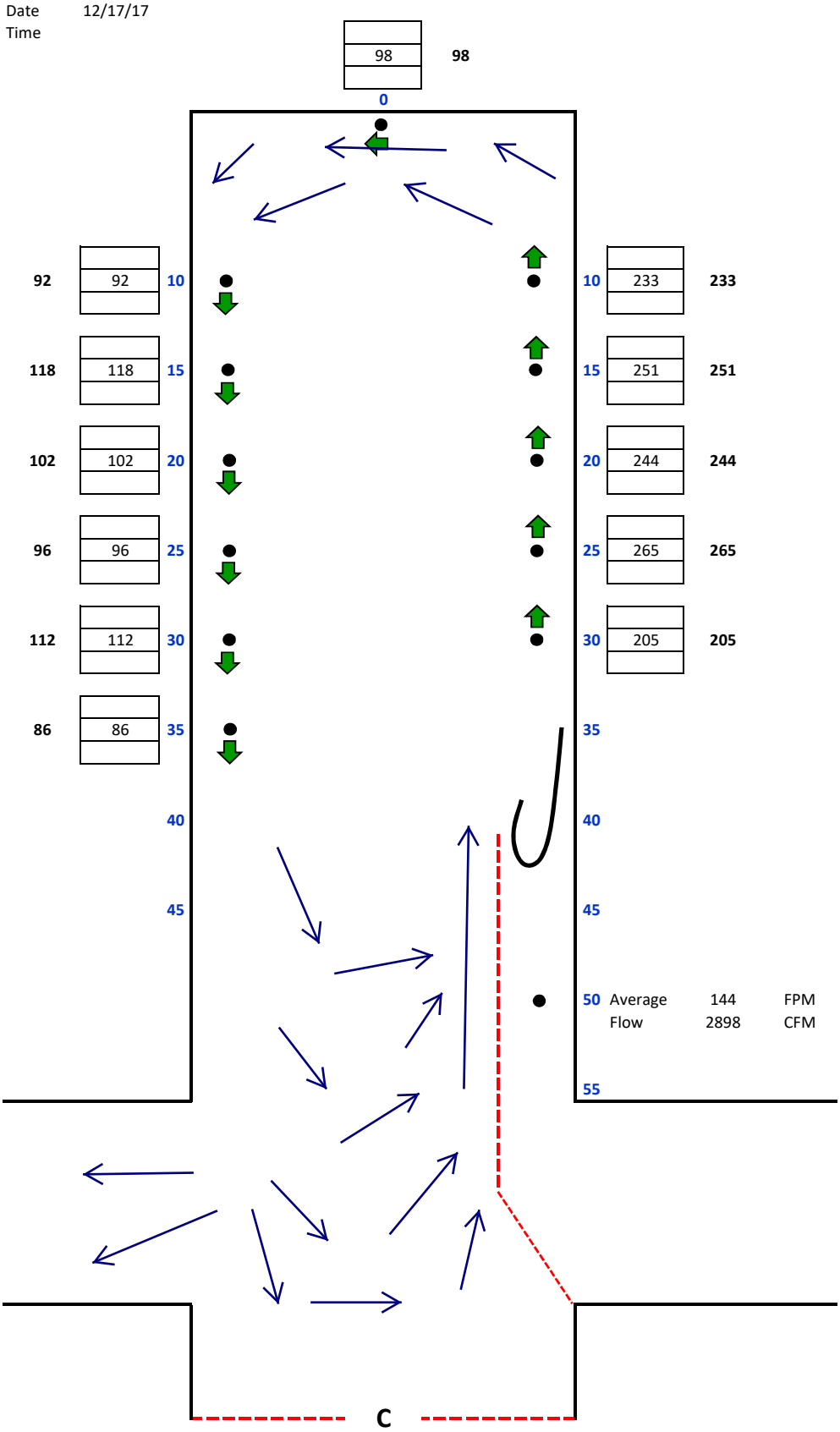
Survant Mine, Setback 40, Slab Cut, No Wing, No Equipment

Date 12/17/17
Time



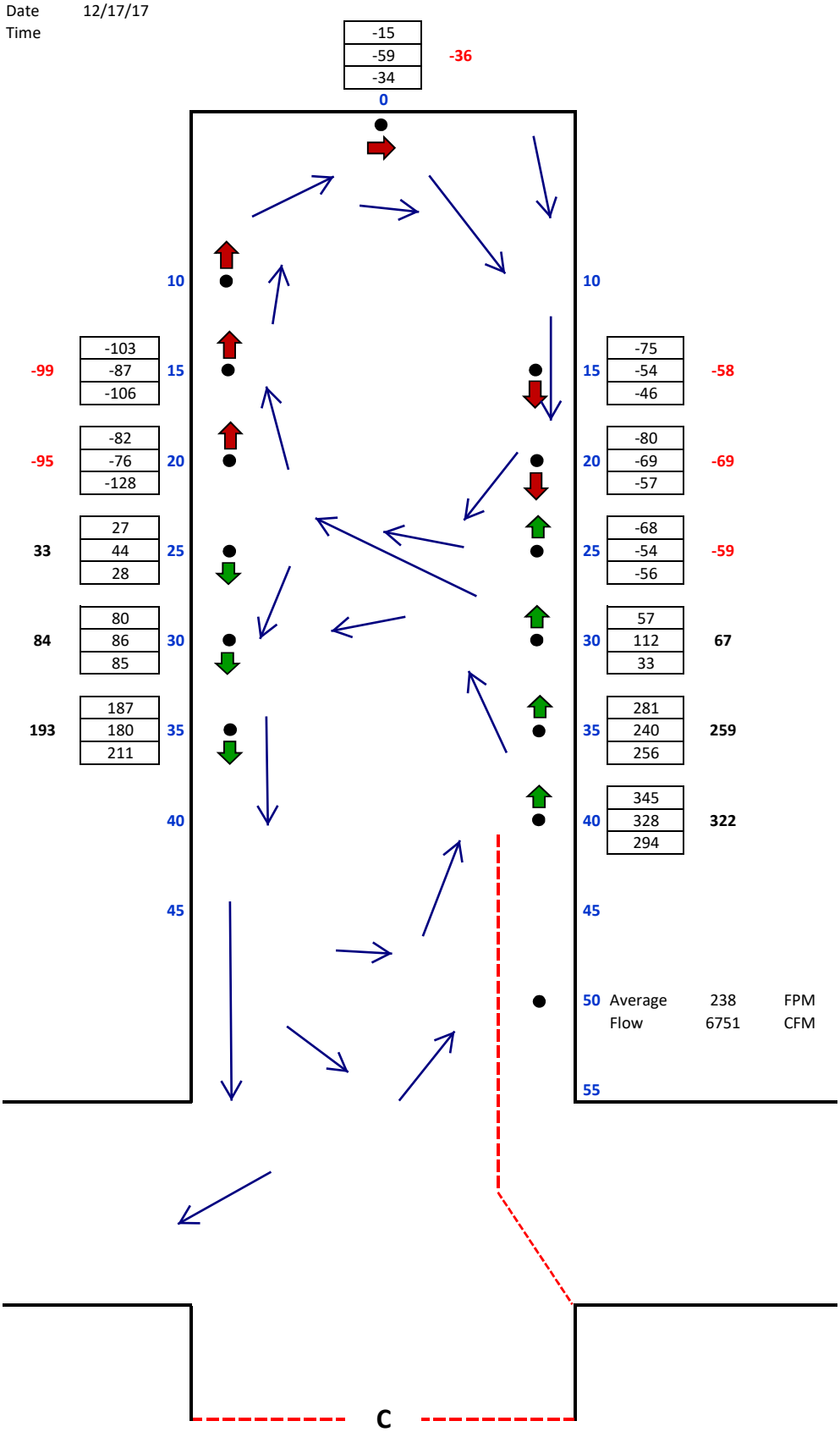
Survant Mine, Setback 40, Slab Cut, With Wing, No Equipment

Date 12/17/17
Time



Eagle Mine, Setback 40, Slab Cut, No Wing, No Equipment

Date 12/17/17
Time



Eagle Mine, Setback 40, Slab Cut, No Wing, No Equipment

Date 12/17/17
Time