VENTILATION DURING TUNNEL CONSTRUCTION INDUSTRY CONSIDERATIONS

Air Quality Working Group Information Package - Part 7 of 12

December 2018

Ventilation during Tunnel Construction

This document was produced to provide information on control measures that can be used to reduce exposure to dusts and silica during tunnel construction. It has been developed by volunteers of the ATS Air Quality Working Group drawing on the collective experience of those working across some of Australia's largest tunnelling projects.

The AQWG membership collectively produced reference material for purposes of communicating information that currently does not exist in the tunnel construction industry's body of knowledge. There are 12 parts to the information package, and each part must be considered in the context of the other. This document represents Part 7 of 12 total parts as listed in **Table 1**. Documented material is considered to benefit the wider tunnelling industry and therefore is freely available on the ATS website.

Table 1 – Complete list of material produced by the AQWG

Part	Document Title	Document Reference
Part 1	NSW Air Quality Working Group Background & Methodology – Silica Dust Exposure and the Tunnelling Industry	Doc No. AQWG_0_0.07
Part 2	Good Practice to Control Silica Dust Exposure During NSW Tunnel Construction	Doc No. AQWG_1_0.08
Part 3	Silica Dust Awareness Package	Doc No. AQWG_2_0.21
Part 4	Silica Dust Awareness Package Speakers Notes	Doc No. AQWG_2a_0.04
Part 5	Design and Procurement - Industry Considerations	Doc No. AQWG_3_0.09
Part 6	Scrubber System - Case Study	Doc No. AQWG_4_0.09
Part 7	Ventilation During Tunnel Construction - Industry Considerations	Doc No. AQWG_5_0.08
Part 8	Portal Misting System - Case Study	Doc No. AQWG_6_0.05
Part 9	Roadheader Cabin Air Filtration - Case Study	Doc No. AQWG_7_0.06
Part 10	Respiratory Protective Equipment - Industry Considerations	Doc No. AQWG_8_0.07
Part 11	Monitoring RCS Exposure - Industry Considerations	Doc No. AQWG_9_0.07
Part 12	Health Monitoring for NSW Tunnel Construction Workers – Industry Considerations	Doc No. AQWG_10_0.14

This document provides information on ventilation during tunnel construction to reduce exposure to silica dusts during mined tunnelling. It is targeted towards non-ventilation engineers for basic information.

There are many types of ventilation systems used during tunnel construction. Each tunnel construction project is unique and therefore the ventilation system used will also be unique to that project. Each ventilation system has limitations in terms of dust control, with the selection of a system for a project being dependant on the targets to be achieved, the construction sequence, the cost of the materials and the ease of maintenance. Notwithstanding, this document provides general information on the common types of ventilation used in the tunnelling environment and how they are used to reduce silica dust exposure.

1.1. Types of Ventilation

1.1.1. Forced Ventilation System

A forced ventilation system is the most common type of primary ventilation system used in a tunnel under construction. In this type of ventilation system, the air is forced by a fan into the tunnel via a duct or a vent bag.

Air moves when there is a difference in pressure between two points until the pressures are balanced. Difference in pressure occurs naturally and also can be created artificially. Air flows from a higher pressure point to a lower pressure point.

The pressure inside the tunnel is always higher than the pressure compared to the outside environment. This difference in pressure causes the air from the tunnel to exhaust into the outside atmosphere.

With forced ventilation, fresh air exits at the inbye end of the tunnel via the bag and collects the contaminants as it moves towards the opening of the tunnel. In this type of system, outbye areas normally have higher level of contaminants. This type of system is typically used during shaft development where little room is available to install a scrubber system.

A forced ventilation system is relatively cost effective, straight forward to install and maintain, and is preferred in most projects for primary ventilation.

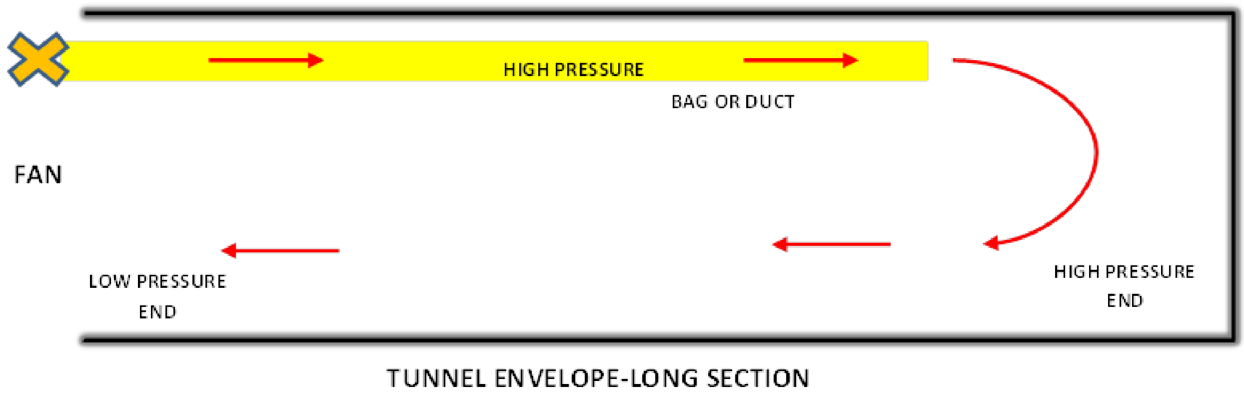
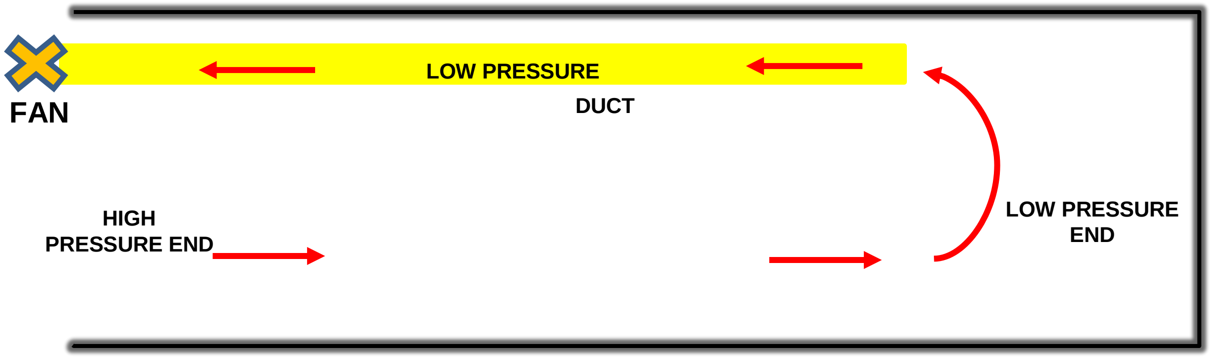


Figure 1 - Example layout of a Forced Ventilation System

1.1.2. Exhaust ventilation system

An exhaust ventilation system is where air is drawn through the tunnel profile from the outside atmosphere and is then exhausted via a series of non-collapsible ducts or cans and a fan. The negative pressure in the tunnel is created by the fan connected to the ducts. This makes the air from outside environment to flow into the tunnel.



TUNNEL ENVELOPE- LONG SECTION

Figure 2 – Example layout of an Exhaust Ventilation System

With this type of ventilation, when fresh air is pulled into the tunnel, the outbye areas are generally in fresh air and as the air moves into the tunnel towards the suction end of the ducts, the inbye end of the tunnel contains more contaminants.

Exhaust ventilation systems can perform slightly better than forced ventilation in terms of dust control, as most dust will tend to travel towards the face (which may be the main source), which results in the outbye areas generally consisting of fresh air.

1.1.3. Longitudinal ventilation system using thrust from jet fans

Longitudinal ventilation is effective when the tunnel has two or more openings to the surface. Air is moved from one end to the other using the thrust generated by the jet fans. This type of system has a high degree of variability as the thrust required to maintain the constant air flow may change depending upon the number of vehicles in the tunnel, natural ventilation direction, and the direction of ventilation.

TUNNEL ENVELOPE- LONG SECTION

Figure 3 – Example layout of a Longitudinal Ventilation System with Jet Fans

1.1.4. Longitudinal ventilation system using forced fans

This system of ventilation requires at least one open end and enough room for fresh air to be supplied from the other end via the fan. An airlock is required to maintain the pressure side inside the tunnel. This type of ventilation is better suited if there is a high variance due to the vehicle movement inside the tunnel or high variance due to natural ventilation direction.

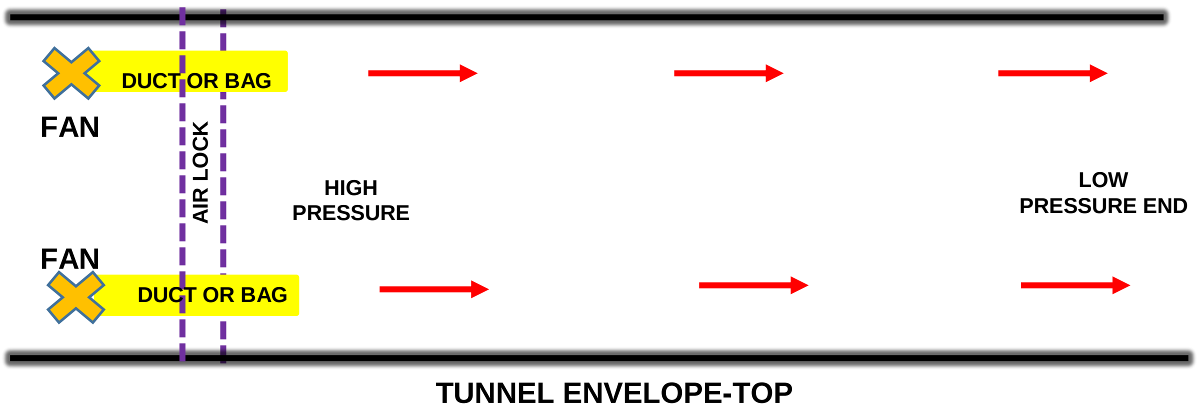


Figure 4 – Example layout of a Longitudinal Ventilation System with Forced Air Fans

1.1.5. Longitudinal ventilation system using exhaust fans

This system of ventilation is the reverse of the above. In this system, fresh air from the outside environment is drawn into the tunnel due to the negative pressure created by the fans through an airlock. The forcing and exhaust system can be interchanged depending on the availability of power and any requirements on exhaust location of containment air.

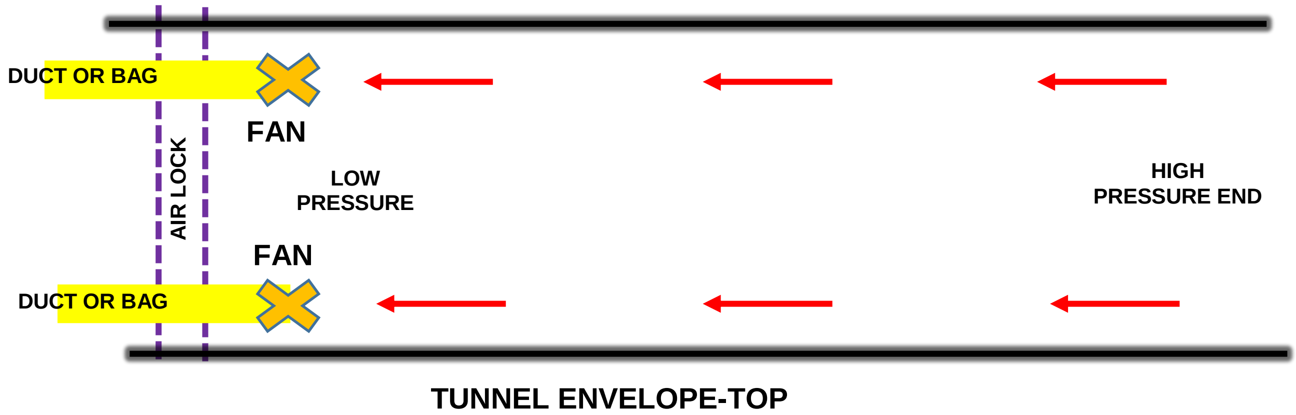


Figure 5 – Example layout of a Longitudinal Ventilation System with Exhaust Fans

1.1.6. Combination of push (forced) and pull (exhaust) systems.

This type of ventilation utilises both forcing and exhausting fans in combination. In Figure 6 below, forced ventilation is used to ventilate the ramps and exhaust ventilation is used to ventilate the mainline tunnels.

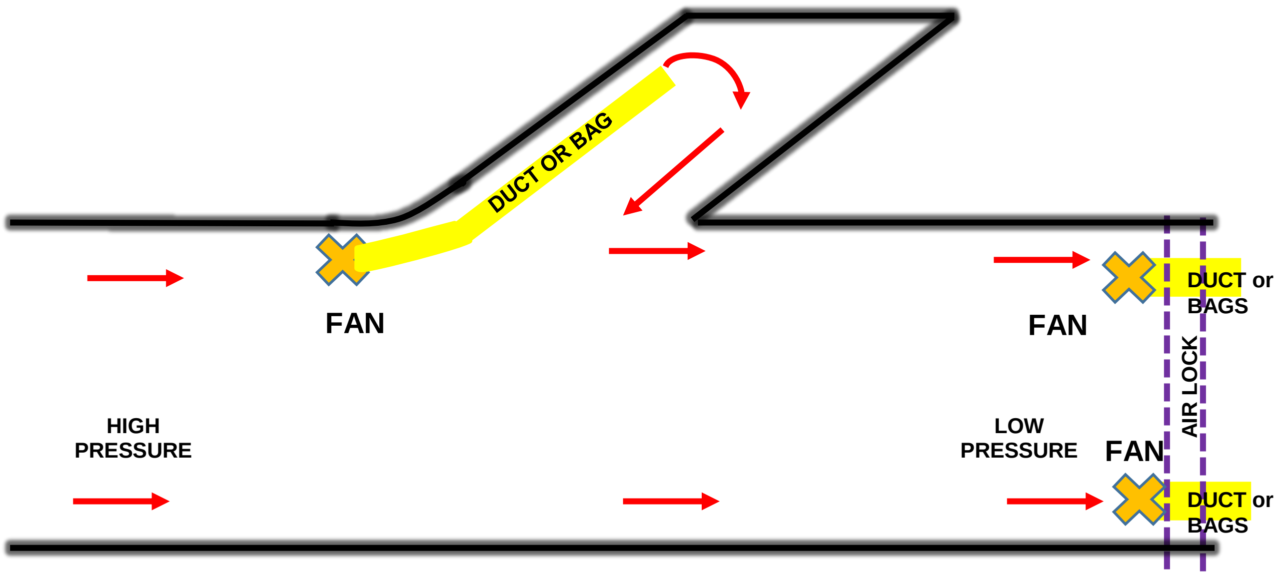


Figure 6 – Example layout of a Push and Pull Ventilation System

A forced overlap system, which is normally deployed in the extraction face of roadheader tunnel for example, is a hybrid system where both forced and exhaust ventilation systems are used. In the forced overlap system, air is pushed into the tunnel using a forcing fan and the scrubber is overlapped with the ventilation outlet.

1.2. Ventilation to Reduce Exposure to Dusts and Diesel Emissions

Ventilation is important to dilute the contaminants in the air. To increase the ability to dilute contaminants in the tunnel, fresh air is required to be delivered to the tunnel system.

Ideally, the majority of work fronts should be provided with fresh air, however the use of recycled (filtered) air can be acceptable, providing that air recirculation can be avoided and contaminants that cannot be filtered (e.g. diesel exhaust gases) will not cause over-exposure to workers. Typically, the primary cutting face (e.g. roadheader operations) receive fresh air delivered to the face

There are two key factors used to quantify ventilation in the tunnel which are *Air Velocity* (m/s) and *Air Quantity* (m^3/s).

1.2.1. Measurement of Air Velocity

The measurement of underground air velocities can be undertaken through one or more of the following methods.

1.2.1.1. Spot Ventilation Surveys

Spot ventilation surveys are performed to ensure that there is the necessary minimum velocity at the working areas. This is done by dividing the airway section into 4 x equal vertical areas and measuring the air velocity using an anemometer from a representative spot within each area. An average of the four readings can provide the average velocity across the cross sectional area.

Spot ventilation surveys should be undertaken at least 20 m (or as far as practicable) away from any item of plant that is in the roadway. This is to reduce the turbulence effect affecting the air velocity measurements.

1.2.1.2. Traversing the Roadway

A ventilation survey through traversing the roadway is the preferred method to calculate the air quantity in a tunnel section. This method of ventilation survey can be undertaken using an anemometer attached to a telescopic stick. The anemometer must be attached in a way such that the impeller is straight and parallel with the stick. This is to ensure the anemometer is facing the air direction straight and to reduce any errors in reading during the traversing motion. The impeller section of the anemometer must not be hindered by the stick when measuring *velocity.*

Step 1: *Divide the roadway into two equal sections. Mark a line in the roadway to indicate the approximate midway point. Have a timer or watch ready to keep time.*

Step 2: *Have the telescopic stick extended and turn on the anemometer to measure the average velocity*[1]*.*

Step: 3: *Note the start time of the vent survey. With a slow and steady motion, traverse the roadway as per the pattern shown in Figure 7.*

Step 4: *When the half way point is reached, make a note of the time and continue to complete the second half of traversing area with the same amount of time. This will ensure the average reading remains true for the cross section as much as practicable.*

Step 5: *Repeat the process at least one more time. If the two readings taken are within +- 10% from each other, this is generally considered to be acceptable. If the two readings drift by more than 10%, then it is recommending to perform one more reading and use the average of the closest two readings*[2]*.*

Traverse ventilation surveys should be undertaken at least 20m away from any machine that are in the roadway as much as practicable. This is to reduce the turbulence effect affecting the air velocity measurements.

Care must be taken to ensure the impeller is always perpendicular to the air direction during the ventilation survey and when manoeuvring the telescopic stick, ensure the body doesn't impede the air flow at any point.

[1] Note: Some vane anemometers have a one minute time lapse under which traversing the section of roadway must be completed. If the anemometer is electronic, anemometer may turn on with the previous setting. In this case, ensure it is reset.

[2] As a rule of thumb, if the velocity is fluctuating, it could be because of turbulent effect from machines working inside the tunnel.

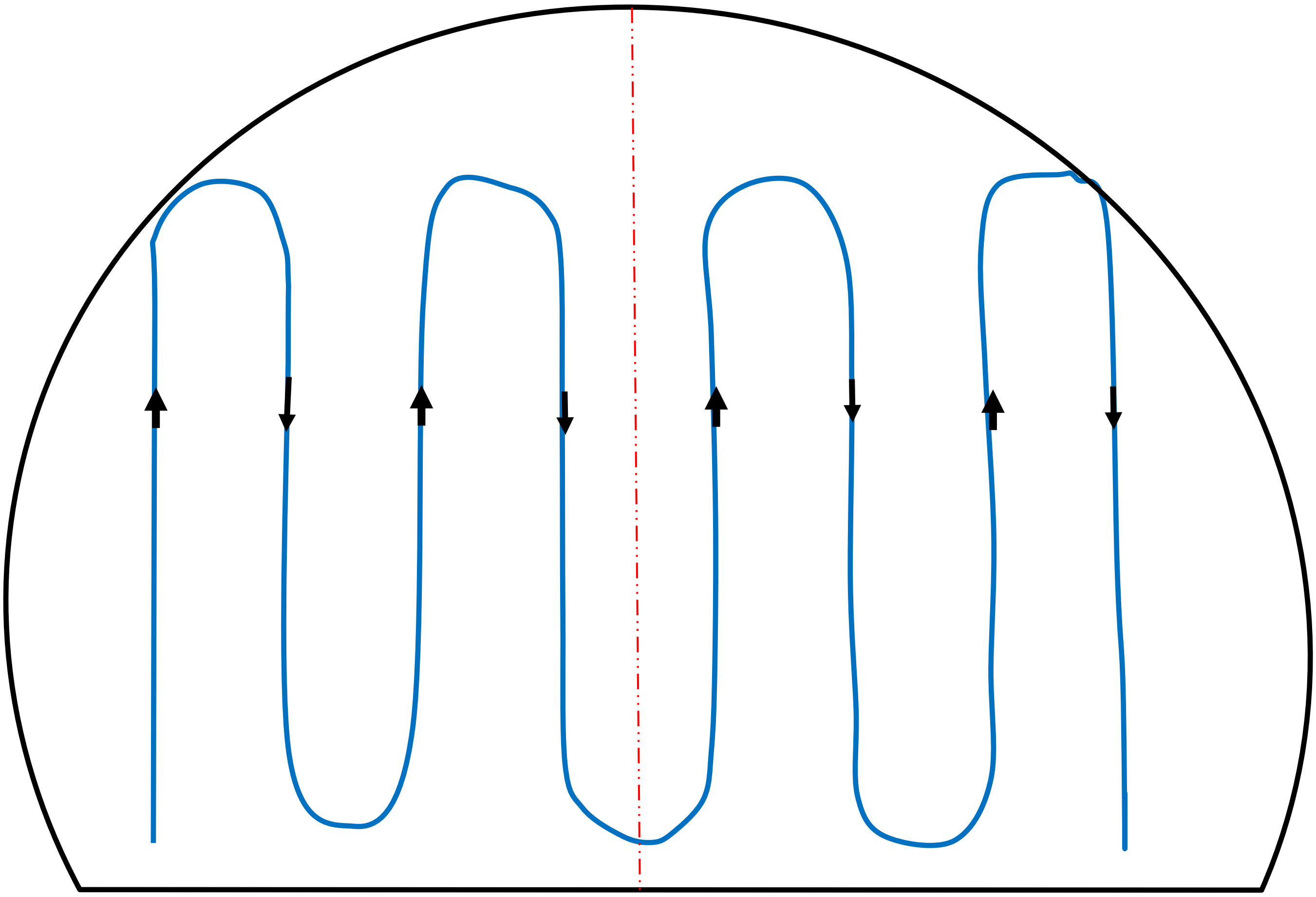


Figure 7 – Traversing pattern for ventilation surveys: Cross section of the tunnel

1.2.1.3. Measurement Equipment

Airflow testing within the ventilation ducting can be completed by the use of a hotwire anemometer. Hotwire anemometers use a very fine wire electrically heated up to a temperature above the ambient air temperature. Air flowing past the wire has a cooling effect. As the electrical resistance of most metals is dependent on the temperature of the metal, a relationship can be obtained between the resistance of the wire and the flow velocity.

This type of anemometer is used for measuring the velocities within the duct or vent bags because the hotwire anemometer doesn't require a bigger opening to feed the measurement stick.

Smoke tubes may be used to determine the air flow direction within the tunnel or to identify any leakage paths in the duct. Smoke tubes produce visible smoke that can be traced to follow the air movement. Smoke tubes require a puffer and air current tubes. These tubes have a chemical which produce visible smoke when it reacts with air.

Realtime direct dust reading instruments, or "dust monitors" fitted with impactor heads suitable for measurement of respirable dust, can be used to determine the sources of respirable dust.

1.2.2. Calculation of Air Quantity

The air quantity is the volumetric flow rate of air in the tunnel. It is the product of cross sectional area (m^2) where the velocity reading was taken and air velocity (m/s). Air velocity is measured by one of the methods above and the cross sectional area obtained from survey.

The following equation is used to calculate the air quantity.

$$Volumetric\ air\ flow\ (Q\ m3/s) = Air\ velocity\ (V\ m/s)\ x\ Cross\ sectional\ area\ (A\ m2)$$

1.2.3. Dilution of contaminants

Dilution is a key function of the ventilation system in reducing exposure of atmospheric contaminants to be under an acceptable standard. Recycling of air with filtration cannot be achieved in all circumstances however. Dilution can only be achieved if additional fresh air can be added to the ventilation system rather than an increase in air velocity in the area. The following example shows a method to calculate the quantity of air required to dilute concentrations of silica dust in a tunnel environment.

An occupational hygienist has measured the general level of silica dust in a particular area of the tunnel to be 0.25 mg/m^3. The air velocity measured at that time was 0.5 m/s in the area where the cross sectional area is 60 m^2. The fan used to ventilate this area is able to add capacity to provide additional fresh air and can be adjusted. The aim is to reduce silica dust exposure in the area to be below the Workplace Exposure Standard.

The formula, $Q = V\ x\ A$ is used to calculate the air quantity present at the time that the measurement was collected as follows:

$$Q = 0.5\ m/s\ x\ 60\ m2$$
$$Q = 30\ m3/s$$

With 30m^3/s of air flow, the measured contaminant (C_1) is 0.25 mg/m^3. To dilute the contaminant to the level of the Workplace Exposure Standard of 0.1 mg/m3 (C_2), the following formula is used:

$$Q2 = Q1\ x \frac{C1}{C2}$$

$$Q2 = 30\ x \frac{0.25}{0.1}$$

$$Q2 = 75\ m3/s$$

Therefore, to dilute the concentration of silica dust in the tunnel area, we require 75 m^3/s of air at that location. Given the cross sectional area of 60m^2 at that location, the air velocity in the same area should measure 1.25 m/s of fresh air.

1.2.4. Finding Recirculation

Ventilation in any air network should be setup in such a way that the air that's used at a working face is removed from the area and fresh air is supplied to replenish it.

Air recirculation increases heat and increases the concentration of gases and dusts in the area unless it's treated for the respective contaminants. In case of heat and toxic gases, this may potentially lead to an environment that is immediately dangerous to life and health. Air recirculation must be avoided and where otherwise unavoidable, recirculation ventilation should be setup be in a controlled manner considering all the risks.

An air network follows two principles in most occasions without considering for density change which are:

1) Air that goes inside the tunnel must come out
2) The summation of air quantity flowing towards a junction and outwards a junction is zero.

1.2.4.1. Air inside must come out

Figure 8 provides an example of a quantity survey method used to measure the total quantity of air going inside a tunnel. In the example below, to measure the total quantity of air going inside the tunnel, a quantity survey at locations Q_1 and Q_2 can be taken.

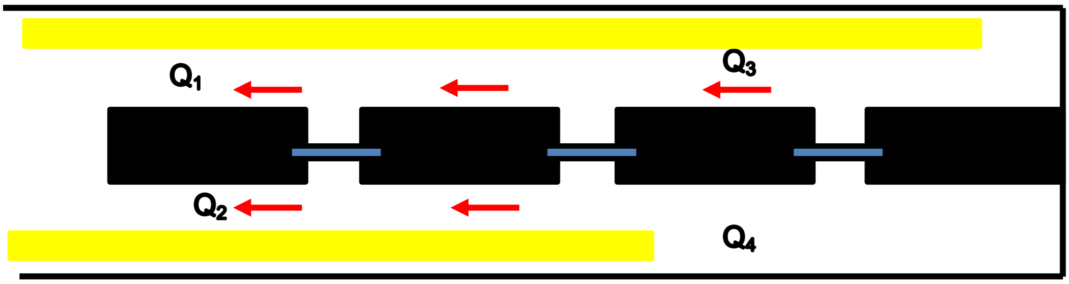


Figure 8 – Example of Quantity Survey Method A

Using the example in Figure 9 below, a quantity survey conducted at areas Q1 and Q2 will provide the total quantity. However a quantity survey at Q3 and Q4 would provide a false quantity as air is seen recirculating in the area.

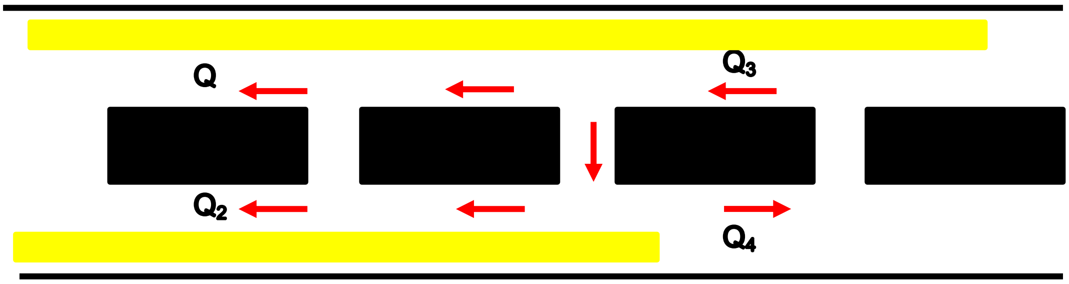


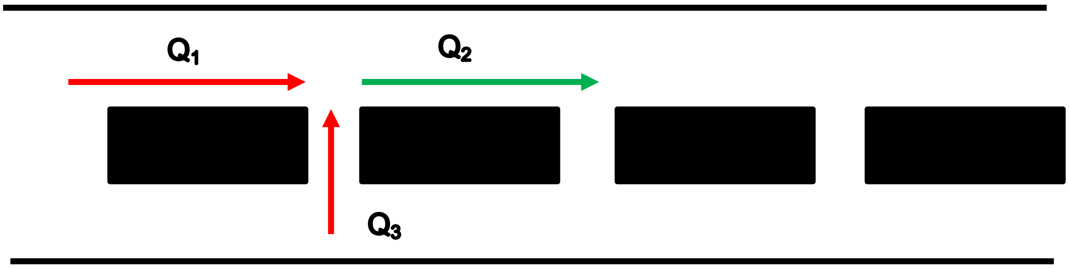
Figure 9 – Example of Quantity Survey Method B

1.2.4.2. Air quantity towards outwards a junction is Zero

When calculating the quantity of air where junctions are present, it is represented by the formula below.

$$Q1 + Q2 + Q3 = 0$$

For example, in the network below, the air quantity provided by Q1, Q2, and Q3 is zero. Air Quantity moving towards a junction is represented by positive values and air quantity moving away from a junction is represented by negative values.

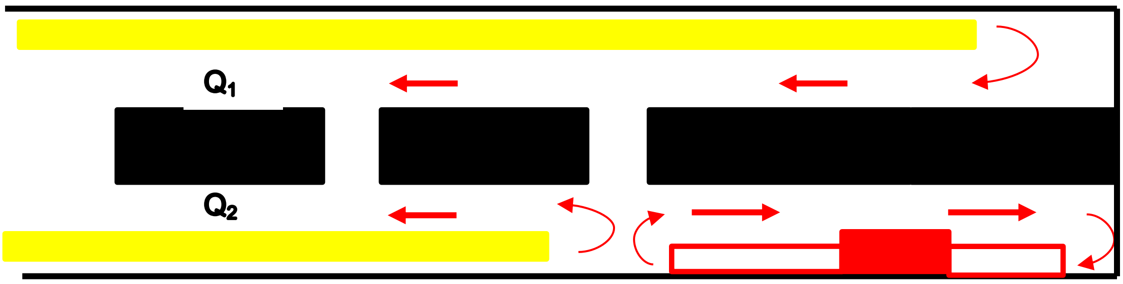


1.2.4.3. Recirculation due to ventilation equipment

Two of the most common instances in a construction tunnel where recirculation can happen, are:

1. At the face using standalone ventilation equipment, when there is not enough fresh air supplied; and
2. At locations where there is no proper segregation of ventilation circuit and thrust ventilation. When recirculation occurs, there will be air flow in the area but the quality of the air reduces if recirculation is allowed to continue for a long time.

As an Example, in the diagram below, when the overlap is not properly designed, or when the fresh air supplied is not adequate, air within the area ventilated by scrubber will recirculate. This is evident by the increased temperature level in the area. As a thumb rule in a construction tunnel with low risk of gas ingress, the fresh air supplied must be at least equal to the capacity of the scrubber.



When jet fans are used in the two tubes which are not segregated, the imbalance in thrust creates a recirculation circuit. This is evident by high velocities in localised areas where there is a jet fan nearby. Recirculation can be effectively used in certain occasions to increase the personnel comfort. Care must be given in all instances to avoid build-up of toxic atmospheres.

Disclaimer

This document has been developed by volunteers of the ATS Air Quality Working Group and draws on the collective experience of those working across some of Australia's largest tunnelling projects. The publication comprises 12 parts, and each part should be considered in the context of the other parts.

The information contained in this document is for general information and educational purposes only; it is not a comprehensive list of all factors to be considered and is not a substitute for legal or technical advice. Accordingly, you should consult with appropriate professionals and make your own inquiries as to the suitability of the information for your specific purposes.

 While details of suppliers are provided, it is noted that the ATS does not make recommendations on specific suppliers or organisations. Material is provided for information only and Contractors would be expected to make independent enquiries as to the suitability of such for their own use.

The ATS acknowledges and thanks Matt Lennon and Adroito Xavier for providing the information contained herein.