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Mining — Air quality control systems for operator enclosures — Performance requirements and test methods

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 82, *Mining*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Safety in mining operations is of concern to all involved in owning, developing, managing, and working in mining environments. Routine mining activities can generate airborne particulates which are hazardous to human health. Therefore, it is necessary to develop controls which limit the operator's exposure to airborne particulates while operating equipment from within the operator enclosure. With the rise in the number of countries regulating air quality in mining, construction, and industrial environments, machine manufacturers have become increasingly aware of the need for standard practices in the design and performance of operator enclosures. This document seeks to address the fundamental design requirements that will allow for operator enclosures to perform at a level that provides sustained air quality, reducing concentrations of respirable particulate matter and carbon dioxide that are harmful to human health. The emphasis of this document is in three areas: 1) design, 2) air quality control system performance testing, and 3) maintenance and operation instruction for the operator enclosure.

All operator enclosures, either on new machines or existing machines currently in operation, meeting the requirements of this document are expected to provide consistent air quality performance. The technical aspects of an operator enclosure are universal as are the design and performance testing methods. Therefore, every attempt has been made to make this an inclusive document which addresses the needs of fixed and mobile operator enclosures.

This document was developed to provide for the occupational health and safety of personnel who work inside operator enclosures. It primarily addresses air quality concerns by establishing parameters to determine air quality control system effectiveness. The control of these airborne contaminants is through an effective air quality control system (for both external air and recirculated air), dilution of CO_2, routine testing of the air within the operator enclosure, and effective maintenance throughout the life cycle of the operator enclosure. Extensive research and subsequent publications have produced a substantial body of knowledge around the air quality control systems and are the basis of this document. See Bibliography.

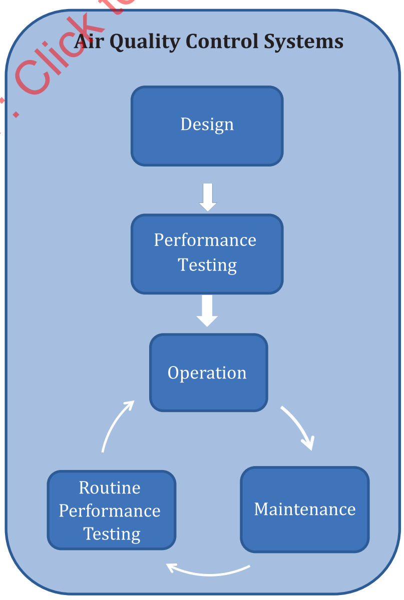


Figure 1 — Air quality control system life cycle

As illustrated in Figure 1, this document presents a life cycle approach to operator enclosure air quality control system design, performance testing, and maintenance.

Mining — Air quality control systems for operator enclosures — Performance requirements and test methods

1 Scope

This document specifies performance and design requirements for air quality control systems for operator enclosures and their monitoring devices. The design specifications are universal in their application and do not contemplate specific mining environments. They are intended to meet identified parameters of both pressurization and respirable particulate and carbon dioxide concentrations. This document also specifies test methods to assess such parameters and provides operational and maintenance instructions. Recommendations are made for operational integration of the air quality control system.

Gases and vapours that can be a hazard in the work environment outside of the operator enclosure are excluded from this document.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 18158, *Workplace air — Terminology*

ISO 29463-1:2017, *High efficiency filters and filter media for removing particles from air — Part 1: Classification, performance, testing and marking*

ISO 29463-2, *High-efficiency filters and filter media for removing particles in air — Part 2: Aerosol production, measuring equipment and particle-counting statistics*

ISO 29463-3, *High-efficiency filters and filter media for removing particles in air — Part 3: Testing flat sheet filter media*

ISO 29463-4:2011, *High-efficiency filters and filter media for removing particles in air — Part 4: Test method for determining leakage of filter elements - Scan method*

ISO 29463-5:2011, *High-efficiency filters and filter media for removing particles in air — Part 5: Test method for filter elements*

ISO/IEC 17000, *Conformity assessment — Vocabulary and general principles*

ISO/IEC 17050-1, *Conformity assessment — Supplier's declaration of conformity — Part 1: General requirements*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/IEC 17000, ISO 18158, ISO 29463-1 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1 Terms related to air quality

3.1.1
airborne particle
airborne particulate
fine matter, in solid or liquid form, dispersed in air

[SOURCE: ISO 18158:2016, 2.1.2.3, modified — The preferred term "airborne particulate" has been added.]

3.1.2
hazardous to human health
in such a quantity and/or quality of *airborne particulates* (3.1.1) or *CO_2* (3.1.7) or noise, that it has adverse health effects

3.1.3
contaminated environment
area where *airborne particulates* (3.1.1) *hazardous to human health* (3.1.2) are present in the ambient air

3.1.4
breathing zone
air space around the worker's face from where they take their breath

3.1.5
ambient CO_2 level
CO_2 (3.1.7) concentration present in the air outside of the *operator enclosure* (3.2.1), to which people can be exposed

3.1.6
respirable particulate matter
materials that are deposited in the gas-exchange region of the lungs

Note 1 to entry: The median cut point for respirable particulate matter is 4,0 µm, according to ISO 7708:1995.

3.1.7
CO_2
carbon dioxide emitted as a by-product of human respiration

3.2 Terms related to the operator enclosure design

3.2.1
operator enclosure
structure that completely surrounds the operator, preventing the free passage of *external air* (3.2.7), dust or other substances into the area around the operator

[SOURCE: ISO 10263-4:2009, 3.1, modified – "part of the machine which" has been replaced with "structure that".]

3.2.2
air quality control system
operator enclosure (3.2.1) that includes structural components, *external air* (3.2.7) and recirculation air systems designed to protect an operator from environmental factors such as dust, heat, cold, wind, and *airborne particulates* (3.1.1) *hazardous to human health* (3.1.2)

3.2.3
sustained quality
quality achieved through designs that work together to create an effective *air quality control system* (3.2.2) that allows *operator enclosure* (3.2.1) pressure and effective filtration to be maintained continuously between *planned maintenance intervals* (3.2.4)

3.2.4
planned maintenance interval
interval when routine maintenance is performed

3.2.5
operator enclosure pressurization
situation when the *operator enclosure* (3.2.1) *external air* (3.2.7) intake is greater than the operator enclosure leakage

3.2.6
operator enclosure work environment
space inside the *operator enclosure* (3.2.1)

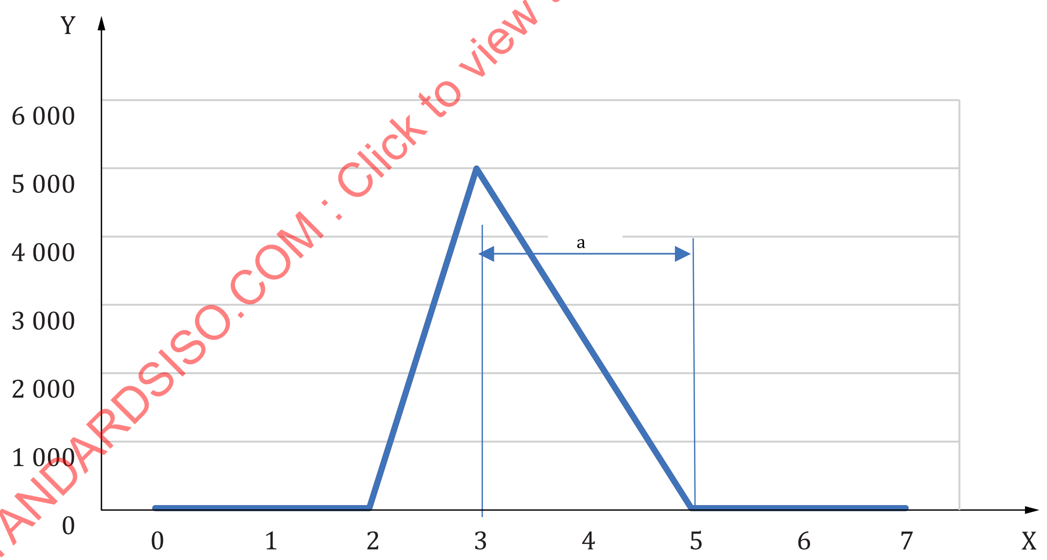
3.2.7
external air
controlled air entering the system or opening from outdoors before any air treatment

[SOURCE: ISO 16818:2008, 3.97]

3.3 Terms related to measurement

3.3.1
decay time
time that it takes for the *airborne particles* (3.1.1) to be removed from the air inside the *operator enclosure work environment* (3.2.6)

Note 1 to entry: See Figure 2.



Dust concentration within the operator enclosure starts at 7 µg/m^3 and at the 2-minute interval it begins to rise. At the 3-minute interval it peaks at 5 000 µg/m^3, and at the 5-minute interval it returns to 7 µg/m^3. In this example, the decay time is two minutes.

Key

X time, min

Y concentration, µg/m^3

a 2 min

Figure 2 — Decay time — Example

4 Requirements

4.1 Performance requirements

The air quality control system objective is to prevent ingress of respirable particulate matter from the contaminated environment, through means of filtration and operator enclosure pressurization. The air quality control system shall meet the following performance requirements.

a) The maximum sustained CO_2 shall be the ambient level of CO_2 + 400 ppm, refer to Annex A for further information.

b) At the start and the end of the decay test, the maximum respirable particulate matter concentration shall be ≤25 μg/m^3.

c) The respirable particulate decay time shall be of 120 s maximum.

d) The minimum sustained pressurization, when the machine starting device is in the “on” position (activating the electrical system) shall be ≥ 20 Pa.

e) The maximum sustained pressurization shall not exceed 200 Pa.

4.2 Engineering design

4.2.1 Operator enclosure

The following requirements shall be met.

a) The machinery safety standard for the specific machine type shall be consulted when designing or retrofitting an operator enclosure to a machine.

b) If the operator enclosure is built on the machine, the interface with the machine frame shall be properly sealed to ensure that there are no leakage points created under vibration during machine operations.

c) Operator ingress, egress, and field of view, and operator enclosure serviceability and maintainability, shall be considered when retrofitting an operator enclosure with an air quality control system.

d) Operator roll over protective structures (ROPS) and falling-object protective structures (FOPS), or other protective structure systems, shall not be modified without permission from the machine manufacturer.

e) Consideration should be given to materials used in the enclosure to ensure that they do not accumulate particulate and are easily cleaned. Operator seats should be covered in a smooth, easily cleaned material, for example vinyl.

f) Weld joints or connections in the engine exhaust system, which are prone to leakage over time, should not be near the external intake air system.

g) The operator enclosure shall be designed such that all ingress points are sealed so that the system holds pressure. All structural members, such as ROPS and FOPS, weld points, stitch welds, electrical and hydraulic penetrations, windows, etc. shall ensure that the operator enclosure holds pressure sufficiently to meet the minimum pressurization performance requirement, see 4.1 d), e).

h) Operator enclosures with air quality control system components and plumbing that are built with attachment to two different planes shall have means to relieve the vibration stress, for example by flexible connectors.

4.2.2 Air quality control system

4.2.2.1 General

The following shall be considered.

a) The ventilation system should allow for airflows to be directed away from the operator.

b) Air quality control systems components added to the operator enclosure should be fitted such as not to impede the field of view of the operator. If visual impediment is unavoidable, an assessment shall be performed to determine the best mitigation measures, for example through the use of cameras or mirrors.

c) The air quality control system shall not create levels of noise that are hazardous to human health or that contribute to existing sources of noise, generating levels hazardous to human health.

d) Filter maintenance intervals shall be considered in the design. Sustained quality requires that the prefilter be appropriately sized so that it does not require maintenance between the planned maintenance interval.

e) Prefilters or cyclonic precleaners are recommended to remove airborne particulates from the external air prior to the primary filter. This prolongs the service life of the filter and allows for the use of high efficiency filtration. The design solutions referenced in the list below are given in order of their effectiveness in providing sustained operator enclosure pressurization when operating in dust conditions typical of mining environments:

   1) powered precleaner using an integrated powered cyclonic separator;

   2) pressurizer blower using a non-powered cyclonic separator;

   3) pressurizer blower using a prefilter;

   4) heating ventilation air conditioning (HVAC) blower.

f) Leakage in low-pressure areas in the HVAC system and external filtration cause airborne particulates to flow directly into the operator enclosure without passing through the external air filter. Low pressure leakage can occur for a number of reasons, including the integrity of the external air seal, mounting surfaces, plastic and metal joints, ventilation tubing and attachments.

g) External air shall be ducted directly into the HVAC mixing plenum. Putting external air directly into the operator enclosure compromises the air quality in the operator enclosure by introducing humidity and/or heat/cold directly into the operator enclosure. This makes the operator enclosure the mixing plenum and compromises the air quality control system.

h) The air quality control system shall include a means to pressurize the operator enclosure.

i) External air devices, including the pressurization fan and all filters, shall be in place and switched on when the machine starting device is in the “on” position (activating the electrical system). This electrical configuration shall provide for continuous operator enclosure pressurization through the external pressurizer or through the HVAC blower. Continuous external air, through high efficiency filtration, prevents particulate ingress into the work environment.

j) When the machine starting device is in the “on” position (activating the electrical system), the air quality control system shall continuously bring external air into the HVAC mixing plenum to continuously dilute CO_2 concentrations. CO_2 levels in the air quality control system give a clear indication of sufficient air exchange. (See Annex A.)

4.2.2.2 External air and recirculation airflow systems

Air quality is directly related to the efficiency and integrity of the external air and recirculation airflow filtration systems. The following shall be considered.

a) The air quality control system shall be equipped with an external air filter and a recirculation airflow filter.

b) High efficiency filtration can restrict airflow, a factor that shall be taken into consideration in HVAC ventilation design.

NOTE The recirculation filter is the most effective means to rapidly remove the respirable airborne particulates from within the operator enclosure. High efficiency recirculation filtration allows the particulate to be removed with a single pass through the filter. The air volume of the operator enclosure can pass through the recirculation filter several times a minute. By removing the particulate in one pass through the recirculation filter, air quality is maintained.

c) The air quality control system's external air intake shall be installed so as to minimize ingress of the machine's exhaust emissions. Placement of the external air intake should take into consideration the exhaust emissions of other machines operating in close proximity.

d) In operator enclosure designs, ventilation should direct airflow from the top half of the operator enclosure to the bottom half of the operator enclosure. The airflow pattern in the operator enclosure is a major consideration in the design of the ventilation system. The filtered air coming from the HVAC should pass over the operator breathing zone and then down to the recirculation air intake. By placing the supply ventilation in the upper part of the operator enclosure and the return airflow in the lower part of the operator enclosure, below the seat index point (SIP) as defined in ISO 5353, the particles move in a downward direction, taking advantage of gravity. The location of the recirculation filter low in the operator enclosure allows particles that are brought into the operator enclosure on the boots and vestments of the operator to be drawn into the high efficiency recirculation filter without passing over the operator breathing zone. This factor should be considered in operator enclosure ventilation design. While all ventilation configurations might not follow this recommended airflow pattern, in all cases the operator enclosure air quality performance shall comply with the performance requirements. [See 4.1 a), b), c), d), e).]

e) External air filtration and recirculation air filtration shall be manufactured, tested, and classified in accordance with ISO 29463–1, ISO 29463–2, ISO 29463–3, ISO 29463–5 and ISO 29463-4: 2011, F.1 to F.5.

f) All filters shall be marked with their filter classification.

g) Filters shall be labelled in accordance with ISO 29463-1:2017, 9.1 a), b), c), d) e), f). If applicable, ISO 29463-5: 2011, Clause B.5, shall be included as a separate document in the filter packaging. Use of a machine-readable optical label (e.g. matrix barcode) on the filter label is recommended to allow for retrieval of the filter label information.

4.2.3 Filters and filter housings

4.2.3.1 General

Filter housings provide the delivery system for the operator enclosure filtration. Protection of the filter is critical to sustained quality and operator enclosure air quality performance.

4.2.3.2 Filter housings

The following items should be addressed in the filter housing:

a) the filter cannot be installed incorrectly (e.g. reversed airflow);

b) the filter housing is easily cleaned to avoid accumulation of particles;

c) all surfaces are easily cleaned;

d) edges, projections, and recesses are reduced or eliminated;

e) filters are easily removed and replaced without damaging the filter media or filter seal;

f) interior surfaces are smooth without ridges or crevices that can collect particles;

g) filter housing shall mate with the filter seal to insure zero seal leakage;

h) vibration and shock do not have an adverse effect of filter seal effectiveness.

4.2.3.3 Handling instructions for filter media made from glass fibre

A primary cause of filter leakage is damage to the media during shipping, removal from the packaging and installation on the machine. Glass fibre media is particularly susceptible to fibre breakage, puncture holes, water wicking, and fibre abrasion from vibration. For every step in the process, from manufacture to final installation, the filter efficiencies shall be maintained as classified.

The following requirements shall be met.

a) Handling instructions shall be provided on the label and packaging.

b) Packaging shall protect the media from excessive shock during shipping.

c) Labelling of the filter packaging shall include a warning not to touch the media.

d) Handling instructions for how to remove the filter from its original packaging without damaging the filter should be printed on the outside of the product packaging.

e) Filter shall be constructed with a protective screen to prevent damage, which is caused by touching the filter media when being removed from its packaging or when it is being installed into the machine.

4.3 Monitoring devices

4.3.1 General

Continuous monitoring is the means by which system performance is validated and maintained. The air quality control monitoring device shall be integrated into the air quality control system. Both pressure and CO_2 shall be monitored.

The pressure monitoring device shall have the following minimum features.

a) A minimum resolution of 5 Pa.

b) A minimum accuracy of ± 10 Pa.

The carbon dioxide monitoring device shall have the following minimum features.

a) Nondispersive infrared sensor (NDIR).

b) Range: 0,0 to 5 000 ppm.

c) Accuracy: ± 3,0 % of reading.

d) Response time: 20 s.

e) Altitude compensation — Due to variations in temperature and atmospheric pressure, air volumes change at different altitudes. The device shall have a temperature and atmospheric pressure sensor to automatically compensate for changes in these conditions to provide accurate CO_2 measurements.

f) The device shall be affixed to a location within the operator enclosure that is in the ventilation airflow, but out of the breathing zone of the operator.

Note CO_2 is in higher concentrations in areas that do not have air circulation. If the CO_2 monitor is improperly located, the CO_2 reading may not be accurate.

4.3.2 Carbon dioxide operator notification system for retrofit installations

Notification systems shall contain a first and second alarm state with visible and audible alarms.

a) First alarm:

1) a visual display shall be provided that shall be

i) green when operating within performance requirements,

ii) amber when the monitoring device detects concentrations within 10,0 % of the alarm value, and

iii) red when the audible alarm sounds;

2) the alarm shall be set to 1 000 ppm by the manufacturer of the monitoring device;

3) the adjustment of the first alarm limit threshold and timing of alarms shall be made through secure administrative controls;

4) the device shall be configurable by an individual with administrative control.

b) Second alarm:

1) audible and visual alarms shall meet the requirements of IEC 60073;

2) the second alarm setting shall be set to 2 500 ppm;

3) the device shall be configurable by an individual with administrative control;

4) the second alarm, if silenced, shall reoccur at a maximum of every 10 min if the alarm conditions remain. If configurable beyond the parameters of the first alarm limit threshold and timing of the alarms, the device shall be configurable by an individual with administrative control, see Clause B.4.

4.3.3 Carbon dioxide operator notification system for machine manufacturers

Notification systems shall contain a first and second alarm state with visible and audible alarms. Audible and visual alarms shall meet the requirements of IEC 60073.

a) First alarm:

1) the limit shall be set to 1 000 ppm by the manufacturer of the monitoring device;

2) the system shall be capable of adjusting the low alarm limit threshold and the timing of alarms through secure administrative controls;

3) the adjustment of the first alarm limit threshold and timing of alarms shall be made through secure administrative controls.

b) Second alarm:

1) the second alarm setting shall be set to 2 500 ppm;

2) through administrative controls, the equipment owner shall have the capability to activate the alarm silence function;

3) the second alarm, if silenced, shall reoccur at a maximum of every 10 min if the alarm conditions remain. If configurable beyond the parameters of the first alarm limit threshold and timing of the alarms, the device shall be configurable by an individual with administrative control. The duration and frequency of elapsed time between subsequent alarms should be configurable by an individual with administrative control. Refer to site protocols when the alarm sounds, see Clause B.4.

See ISO 6011 for guidance on placement of the visual warning.

4.3.4 Additional monitoring capabilities

The following events are recommended to be recorded or monitored.

a) Whether the external air filter is removed from the filter housing.

b) Whether an incorrect filter, or no filter, is installed in the filter housing.

c) Whether the filter life expires; the time to replace the filter; whether the filter is replaced.

d) Detection and reporting of the external air filter classification, the filter part number, and the filter life remaining.

e) Reporting of the recirculation filter classification, the part number, and the filter life remaining.

f) Data logging.

g) Particle concentration.

5 Performance testing

5.1 Requirements

5.1.1 Test set up

The following requirements shall be met.

a) An operator enclosure for testing shall be fully functional per its design.

b) All external air filters and recirculation air filters shall be in place on the operator enclosure.

c) Tests may be performed at the equipment manufacturer (e.g. OEM, HVAC manufacturer, cab manufacturer) or in an aftermarket environment (e.g. actual worksite, unaffiliated test facility).

d) To perform the test, the wind speed shall be < 0,55 m/s.

5.1.2 Test equipment

The following requirements shall be met.

a) Use a real time airborne particulate monitor with a minimum specification of:

1) concentration range: 1,0 μg/m^3 to 10 000 μg/m^3;

2) resolution: 1,0 μg/m^3;

3) particulate size: 0,3 μm to 10,0 μm;

4) airflow rate: the airflow rate depends on the size selector used and its performance characteristics.

b) Set the particulate monitor to the closest data reporting interval to 1 s.

c) Use a differential pressure monitor capable of measuring in maximum increments of 5 Pa of pressure.

d) Use an airborne particulate generator, which generates nontoxic airborne particulate (e.g. composed of glycerine and distilled water in a ratio of one-part glycerine and three-parts distilled water), equipped with remote operation capabilities (e.g. 400-watt, fog machine or equivalent).

5.1.3 Test methods

5.1.3.1 Pressure

The test shall be performed as follows.

Once the pressure monitor is installed in the operator enclosure, the operator enclosure pressure is determined by closing all windows and doors in the operator enclosure. A minimum of 20 Pa of operator enclosure pressure shall be indicated on the monitor when the machine starting device is placed in the "on" position (activating the electrical system). When the HVAC blower motor is turned to low fan speed, the pressure should increase. The maximum pressure is achieved by setting the HVAC blower to high fan speed. Record the minimum pressure reading and the maximum pressure reading in the test report.

5.1.3.2 External air system leakage

The external air system includes the external air filter, filter seal, and intake plenum. These components operate at a lower pressure than the entirety of the operator enclosure and, if there are leaks in the external air system, the airborne particles pass directly into the operator enclosure.

The test shall be performed as follows.

a) Install new minimum classification external air and recirculation air filtration as classified in accordance with ISO 29463-1 in the HVAC system. Filters should not be damaged when removing them from their packaging or when handling them.

b) Turn on the airborne particulate monitor, and place it in the airflow, on or near the operator seat. The particulate monitor display shall be visible from outside the enclosure.

c) Turn on the electrical power to the operator enclosure. Ensure that the HVAC blower motor is running at a fan speed sufficient to achieve 50 Pa ± 10 Pa of pressure. Confirm that all windows and doors are shut, and that the operator enclosure pressure monitor and particulate monitors are on. Record the pressure reading.

d) Set up the particulate generator so that the outlet of the particulate generator is 2 m ± 0,25 m and pointed directly at the HVAC external air filter.

e) Record the starting particulate concentration level, which shall be below 25 $\mu g/m^3$.

f) Turn on the particulate generator to emit a full stream of particles for approximately 1 s. Ensure that the particulate is impacting the external air filter for ≤ 3 s. If the particulate is not impacting the external air filter due to wind, construct a temporary plenum in front of the external air filter to block the wind.

g) Observe the particulate monitor display, and record the highest particulate level achieved over the 1-min interval after applying the particulate to the external air filter.

h) If the external air system is leak-free, the particle concentrations in the operator enclosure rise to < 100 $\mu g/m^3$. If the particle concentration is > 100 $\mu g/m^3$, the external air system should be examined to determine the source of the leakage. When there is leakage, particulate concentrations rise to a much higher level than 100 $\mu g/m^3$, for example 1 000 $\mu g/m^3$ to more than 10 000 $\mu g/m^3$ is typical.

NOTE 1 The same test can also be performed with an ISO 35 H filter. If the system is leak-free, then the particle concentrations in the cab will rise <10 µg/m^3.

NOTE 2 The test data can reveal seal leakage, leakage in the plumbing on the low-pressure side of the HVAC, and filter media damage.

5.1.3.3 Decay time

The decay time test is performed with a direct reading particulate monitor, a digital watch, a pressure monitor, and a particulate generator.

The test shall be performed as follows.

a) Install a new filter classified in accordance with ISO 29463-1 in the HVAC system. Filters should not be damaged when removing them from their packaging or handling them.

b) Confirm that the pressure monitor and the particulate monitor are turned on and installed in a location on or near the operator seat, easily visible from outside of the operator enclosure.

c) Place the particulate generator on the floor in the operator enclosure. Turn on the electrical power to the operator enclosure. Confirm that all windows and doors are shut and that the operator enclosure pressure and particulate monitors are on.

d) The test shall be done without an operator in the operator enclosure.

e) Confirm that the operator enclosure is pressurized to 50 Pa ± 10 Pa. Record the pressure reading.

f) Read the particulate monitor display and record the particulate concentration inside the operator enclosure.

g) Particle concentration shall be below 25 µg/m^3 at the start of the test.

h) Using the remote control, so that the device can be activated from outside of the operator enclosure, turn on the particulate generator so that it produces a constant stream of particulates for 1 s to 2 s.

i) For purposes of this test, the maximum particulate concentration created by the particulate generator should not exceed 5 000 µg/m^3 , and the minimum particulate concentrations shall not be below 2 000 µg/m^3.

j) If particle concentration exceeds 5 000 µg/m^3 , repeat steps h) to k).

k) Record the time when the particulate concentration is at its highest point.

l) Actively watch the particulate monitor and record the highest particulate concentration reading.

m) Continue to actively watch the particulate monitor until the particulate concentration falls to ≤ 25 µg/m^3, record the time.

n) Open the door, remove the particulate monitor.

o) Calculate the decay time and record it in the test report, see Table 1.

5.1.3.4 CO_2

There are two methods which can be used to introduce CO_2 into the operator enclosure. Either method may be used in a manufacturing environment or in the after-market. Both methods require that the ambient CO_2 concentrations be determined first. The test is performed using the monitoring devices installed in the operator enclosure, meeting the requirements of 4.3.1.

The test shall be performed as follows.

a) Determine the ambient CO_2.

1) Turn on the machine to the “on” position (activating the electrical system).

2) Close the operator enclosure door.

3) After 5 min, record the CO_2 reading.

b) Method one: using the operator to generate the CO_2 for the test.

1) Place an operator in the operator enclosure. The operator shall remain seated in the operator enclosure until the 15-min test is completed. The person performing the test can be the operator; however, only one person is required in the operator enclosure to generate the CO_2 for the test.

2) Close all openings in the operator enclosure.

3) Turn on the operator enclosure pressurization system.

4) Confirm that the operator enclosure pressure is 50 Pa ± 10 Pa, record the pressure reading.

5) After 15 min, record the CO_2 reading. CO_2 shall not exceed the initial ambient CO_2 level + 400 ppm.

c) Method two: using CO_2 from a cylinder which is metered at the human CO_2 generation rate of 0,3 l/min, value taken from ASTM D6245-18.

1) With the door closed, meter the CO_2 at the generation rate of 0,3 l/min into the operator enclosure.

2) Turn on the operator enclosure pressurization system.

3) Confirm that the operator enclosure pressure is 50 Pa ± 10 Pa, record the pressure reading.

4) Allow the CO_2 to continuously flow, while maintaining the operator enclosure pressurization for 15 min.

5) After 15 min, record the CO_2 level in the operator enclosure. The CO_2 shall not exceed the initial ambient CO_2 level + 400 ppm.

For operator enclosures designed for more than one occupant, repeat the test protocol with the following modifications.

— Modification to test method one: during the test, increase the number of operators present in the operator enclosure to equal the number of occupants for which the operator enclosure is designed.

— Modification to test method two: multiply the required CO_2 flow by the number of operators for which the operator enclosure is designed.

5.2 Test report

The reporting template in Table 1 can be used to record the performance test data from 5.1.3.1, 5.1.3.2, 5.1.3.3, and 5.1.3.4.

Table 1 — Example test report

Machine asset no.		External air filter classification			
Date of performance test		**Recirculation air filter classification**			
Equipment	**Make**	**Model**	**Serial no.**	**Calibration date**	
Airborne particulate generator				N/A	
Airborne particulate real time monitor					
Pressure					
Pressure (Pa)	**Fan speed**				
	Low	**Medium**	**High**		
External air system leakage					
External air system leakage	Pressure (Pa)	Max. concentration (µg/m3)			
Decay time					
Decay time (performed on low fan speed)	Initial concentration ($\mu g/m^3$)	Max. concentration ($\mu g/m^3$)	Time of max. concentration	Time of concentration ≤ 25 $\mu g/m^3$	Calculated decay time
CO_2					
Carbon dioxide	Pressure (Pa)	Ambient concentration (ppm)	Concentration of CO_2 after 15 min (ppm)		
One operator					
Additional occupant (if required)					
Additional comments:					

6 Operation and maintenance instructions

6.1 The machine manufacturer, HVAC supplier or retrofitter shall provide information for the operator (either in the machine operator manual or as a separate manual). ISO 6750-1 and IEC/IEEE 82079-1 should be used for guidance in providing information on safety, operation and maintenance of the air quality control system. This information shall contain at least the following.

a) Description of the air quality control system and its protective function against respirable airborne particulate.

1) Maximum number of persons for which the air quality control system is designed.

2) Description of how the air quality control system is activated (e.g. when the machine starting device is placed in the "on" position).

3) Instructions to keep doors and windows closed while the air quality control system is activated.

4) Description of filter classification(s) required to achieve the rated performance level(s).

5) Explanation of the variables that effect the filter life (e.g. respirable particulate concentrations).

6) Prohibition against cleaning and or reusing air quality control system filters that are intended only for a single use.

7) Explanation of filter labelling contents in accordance with 4.2.2.2 g).

b) Explanation of regular inspection and maintenance protocol.

c) Explanation of hygienic practices known to improve air quality control system performance, for example cleaning the operator enclosure at the end of every shift, keeping doors and windows closed, maintaining all aspects of the air quality control system according to the manufacture's maintenance schedule, as applicable. See Annex B.

d) Limitations of use (for example, gases present outside of the operator enclosure).

e) A declaration of conformity, see 6.3.

6.2 Suppliers of field-installed air quality control systems shall provide:

a) instructions for mounting of the air quality system devices;

b) instructions for electrical integration of air quality system devices;

c) a description of how the air quality system functions, for example a flow diagram;

d) instructions for filter installation and service.

6.3 The machine manufacturer or installer of the air quality control system shall provide a supplier's declaration of conformity that the operator enclosure and filtration system is in conformity with this document. The declaration shall be in accordance with ISO/IEC 17050-1.

Annex A
(informative)

CO_2 management

A.1 General

This annex provides information on the importance of CO_2 as a consideration in operator enclosure performance, a CO_2 standard reference value, physical aspects of CO_2, CO_2 monitoring devices, and a mathematical model for the relationship between external air and CO_2 concentrations in an operator enclosure.

A.2 Background

Operator enclosures are designed to protect operators from environments that are hazardous to human health. External factors are addressed through design of the air quality control system to prevent external contaminants from entering the operator enclosure. However, once inside the enclosure, the operator generates CO_2 through human respiration. CO_2 is an asphyxiant gas, which in concentrations above 1 000 ppm can compromise human cognitive functions, like decision making and alertness. Operator enclosures address internal contaminants, such as human generated CO_2, as well as external environmental contaminants.

Studies on CO_2 effects on human cognition, have consistently demonstrated the negative effects of higher than normal CO_2 on critical thinking. While operating a piece of mining equipment, operator alertness and critical thinking skills are necessary to operator safety and for the safety of those around the equipment. Dilution of CO_2 with the introduction of air with ambient oxygen levels is required to maintain safe levels of CO_2.

ISO 16000-26:2012 assigns a standard value to CO_2 concentrations that produce various levels of indoor air quality. 800 ppm is used as the standard reference value and assumes a 400 ppm ambient level of CO_2. Due to variation in ambient CO_2 concentrations, the method used in determining the standard reference value (400 ppm ambient + 400 ppm human generated CO_2) is applied. For use in this document, CO_2 limits for initial set up and on-going performance validation are ambient CO_2 level + 400 ppm.

A.3 Measuring CO_2 in operator enclosures

A.3.1 Understanding CO_2 concentrations

Carbon dioxide (CO_2) in air can be measured in parts per million (ppm) or as a percent concentration. Parts per million is a ratio between one gas and another.

The air volume required to contain one million air molecules is affected by air temperature and air pressure. Air pressure and air volume work in an inverse relationship. As air pressure increases, the volume required to contain one million air molecules decreases. The converse is also true, as air pressure decreases the air volume required to contain one million air molecules increases. The opposite is true of temperature. As the air temperature decreases, the air volume required to contain one million molecules decreases. As the air temperature increases, the air volume required to contain one million molecules increases. The net effect of temperature and air pressure on the concentration of CO_2 is that regardless of air volume, the concentration of CO_2 stays the same.

A.3.2 CO_2 Monitoring devices

Because air volumes are constantly changing due to variations in temperature and atmospheric pressure, CO_2 monitoring technology has been developed that provides for real time automatic temperature and pressure compensation, insuring an accurate CO_2 reading. This technology can also be referred to as automatic altitude compensation.

A.4 Calculating external air from CO_2 concentration in an operator enclosure

Methods for calculating external air intake using the CO_2 concentration within the operator enclosure are described in ASHRAE 62.1, Annex D.

Annex B
(informative)

Recommendations for the operational integration of this document

B.1 General

Consistent performance of an air quality control system is a result of the combined efforts of operator enclosure design, timely and accurate maintenance, and proper operation. Without the support of all three of these aspects, equipment operators can be at risk of short-term or long-term exposures to occupational health hazards.

After the operator enclosure is designed and conforms to the parameters in this document, it becomes the equipment owner's responsibility to maintain the air quality control system effectiveness to protect the safety, health and well-being of their equipment operators. Equipment operators are also responsible for using the operator enclosure in alignment with the manufacturer's manual to protect their own safety, health and well-being.

The successful integration of an air quality control system meeting the performance requirements of this document as an effective engineered occupational exposure control can require a standard operating procedure that is supported by the maintenance staff, operators, health and safety department, management, and all other concerned parties. This documentation can support the alignment and definition of responsibilities, and actions of the personnel involved in the use and maintenance of the air quality control system.

B.2 Operation and maintenance of the performance test equipment

The following should be considered.

a) Personnel using the performance test equipment should be trained in the operation and maintenance of these devices.

b) Monitoring devices and performance testing equipment specified in this document need be used and maintained as per their manufacturer's recommendations to provide accurate and reliable results.

B.3 Retrofitting operator enclosures

The following should be considered.

a) An existing operator enclosure should be evaluated to determine the current performance status in relation to this document's parameters. If the operator enclosure is known to be deficient, the evaluation should still be performed to determine a baseline of the operator enclosure's air quality control system performance and effectiveness. This recommended evaluation includes the following.

   1) Visual inspection of operator enclosure filters and the interior of the operator enclosure. An example of a visual inspection test is provided in Table B.1.

   2) Pressure, decay time and CO_2 test protocols aligned with Clause 5. Portable monitoring devices meeting the specifications in 4.3 should be used.

3) Interview of the operator to determine existing concerns of ingress of particulates.

b) Once the operator enclosure has been properly fitted with an air quality control system, handover should occur between the fitter and machine owner, providing written guidance on how to operate and maintain the operator enclosure.

B.4 Operating air quality control systems

The following should be considered.

a) Prior to use of the operator enclosure and air quality control system, it is recommended that maintenance personnel, equipment operators, health and safety personnel and any additional personnel who can complete performance tests, be made aware of the following.

1) Proper operation and maintenance of operator enclosures and air quality control systems to prevent occupational overexposure to respirable particulate and/or CO_2. This includes the appropriate actions to take in the event an alarm related to the air quality control system is activated.

2) Occupational health and safety hazards and risks specific to the operation and maintenance of air quality control system components (e.g. filter handling and changes).

3) Limitations of use (e.g. gases present outside of the operator enclosure).

4) Occupational health and safety hazards and risks if the operator enclosure and air quality control system is not maintained or operated properly.

b) Including an operator pre-use inspection of the air quality control system into existing equipment checks.

c) If more in-depth expertise is desired by maintenance or health and safety personnel, References [26] to [32] provide advanced education in the application of operator enclosure theory, maintenance practices, and occupational health and safety management system (OHSMS) integration.

B.5 Maintaining operator enclosures and air quality control systems

The following should be considered.

a) Operator enclosure maintenance inspections should take place immediately after the planned maintenance (PM) of the HVAC filters, halfway through the PM, and approximately 80 % of the way through the PM. If the results of the interim inspections are good, then the operator enclosure performance tests can be completed. An example of a maintenance inspection template is provided in Table B.1.

b) If the operator enclosure fails an interim inspection, the maintenance department should be notified of the deficiency and its probable cause.

c) The length of PM cycles is determined by the performance of the operator enclosure between required maintenance intervals. It is recommended that the performance of the operator enclosure be audited annually.

d) Performance testing can be completed at any time to identify operator enclosure effectiveness.

e) Adjusting first alarm settings — The first alarm level can be manually set to accommodate actual site conditions. The key variable is the level of ambient CO_2 in field condition. Subclause 5.1.3.4 gives specific instructions on how to determine the ambient CO_2 level. It is recommended to set the first alarm to reflect the ambient CO_2 + 400 ppm. The first alarm setting can be adjusted to any level below 2 500 ppm.

