Measuring Methane Emissions from Coal Mines

Technical Guidance Document for Source 3: Ventilation Air Methane - Vented

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Introduction to Steel Methane Partnership Technical Guidance Documents

Action on lowering the emission intensity of metallurgical coal mining is critical to limiting the impact of the industry on global warming. The aim of Technical Guidance Documents (TGDs) is to assist members of the Steel Methane Partnership (SMP) in standardising reporting of methane emitted from their assets while establishing a performance framework and action plan that achieves a rapid reduction of methane emissions, in accordance with an agreed schedule and defined targets.

This document is a part of a series that describes sources of methane emissions resulting from coal mining operations, as outlined by the SMP framework.

Source	Source of methane emissions
1	Pre-mine drainage
2	Surface Mine (Open Pit) Methane
3	Ventilation Air Methane (VAM) - Vented
4	Ventilation Air Methane (VAM) – Incomplete oxidation/utilisation
5	Drained Coal Mine Methane - Vented
6	Post-mining
7	Waste Coal Heaps
8	Strata Fracture Emissions
9	Closed and Abandoned Mine Emissions
10	Other Gas Infrastructure Losses

The TGDs are based on principles and are not intended to serve as detailed manuals. The global coal industry possesses a wealth of expertise and experience that should be harnessed to ensure the success of this initiative. Methane measurement methods for safety monitoring are well known and can be improved and expanded to provide more accurate quantification of emissions.

The guidance documents introduce suggested methodologies for quantifying methane emissions from specific sources and outlines established mitigation options.

List of Acronyms

CEMS	Continuous Emissions Monitoring Systems
CMM	Coal Mine Methane
IMEO	International Methane Emissions Observatory
RCO(s)	Regenerative Catalytic Oxidiser(s)
RTO(s)	Regenerative Thermal Oxidiser(s)
SMP	Steel Methane Partnership
TGD(s)	Technical Guidance Document(s)
UNEP	United Nations Environment Programme
VAM	Ventilation Air Methane

SMP Source 3: Ventilation Air Methane – Vented

1. Overview

This TGD is dedicated to methane emissions described under SMP Source 3 'Ventilation Air Methane (VAM) – Vented'. All emissions that occur within the mine portals are included by default. The scope of this TGD excludes methane emissions described under SMP Source 4 'Ventilation Air Methane (VAM) – Incomplete oxidation/utilisation'. Emissions from mined coal that has left the mine are considered separately under SMP Source 6 'Post Mining Coal Emissions.'

In this document, consideration is given to all sources of methane arising in an underground coal mine which are emitted at the surface from vertical and inclined ventilation shafts.

Coal mine methane, in most instances, comprises around 80-95% methane together with ethane, carbon dioxide, nitrogen, and other trace gases. There are mines in certain geological conditions which emit carbon dioxide rich gases. Only the methane component is considered in this guidance.

2. Introduction to SMP Source 3 'Ventilation Air Methane (VAM) – Vented'

Strata disturbance caused by the longwall extraction of coal leads to the release of methane from the coal being mined, from de-stressed coal seams, from abandoned coal faces and other gas bearing strata above and below the worked seam. The faster the mining rate, the greater the rate at which roof and floor gas sources are disturbed and hence the greater the gas flow. Thus, the emission rate from a working longwall, averaged over a few months, is approximately proportional to the run-of-mine coal production. Emissions peak during sustained high production, during barometer falls, and then decline during periods of no production such as maintenance, weekends, holidays, and unplanned stoppages. Roof and floor emissions are usually substantially lower where partial caving methods are used; these mining methods involve leaving pillar support to limit ground movement and hence the volume of strata de-stressed by mining to release gas is, in most instances, greatly reduced compared with longwall extraction.

For general estimation (levels 1 & 2) of gas flows, a specific gas emission factor (SGE), expressed in cubic metres (m^3) of methane released per tonne of coal mined (SMP reporting levels 1 & 2) is used.

Mine safety laws require that the concentration of methane within the workings must not exceed statutory safety limits otherwise mining must cease, and the affected working area evacuated. Regulations vary from country to country in detail, but all are designed to ensure that methane concentration in working areas does not fall within the explosive range. Different countries apply different safety factors (UNECE, 2016).

The primary method of controlling methane concentration is to dilute methane with ventilation air. Most coal mines use main exhaust ventilation systems so that all the methane liberated into the underground workings is vented at upcast shafts or drifts. Fresh air is drawn into one or more surface shafts or drifts (known as ventilation intakes or downcast shafts) by fans located at one or more upcast or bleeder shafts which exhaust ventilation air carrying methane, dust, heat, blasting fumes, moisture, and other pollutant gases out of the mine. When methane emissions are too high for ventilation control alone, coal production can continue only if a proportion of the released methane is captured before it can enter the mine airways. The captured gas is piped to the surface via a gas drainage system, thus ensuring methane concentrations in the mine workings remain within the safe range. In some mines, methane, often of low quality, is extracted from the goaf area behind a working longwall, piped to an underground drainage station and then discharged into a main ventilation airway where it is diluted to a safe concentration. Such drained gas will appear at the ventilation shaft as VAM. This particular TGD only considers the quantification and mitigation of the low concentration methane, typically less than 1% by volume, discharged at upcast ventilation shafts. The magnitude and variability of VAM flow and concentration is illustrated in Appendix Figure 3.1.

For higher SMP reporting levels (levels 3 & 4), the guidance highlights the principles of methane flow determination using both manual and continuous measurement monitoring techniques (SMP reporting levels 3 & 4). While simple methods for first order estimation of VAM emissions at levels 1 to 2 are described, the main emphasis is on direct measurement at mine sites (SMP reporting levels 4 and 5), essential for achieving and proving measurable and credible methane emission reductions. Specific sources and detail that may be relevant in assessing mitigation design factors are also mentioned.

Emissions from this source are aggregated with all other source-level methane emission measurements sources at a mine site for comparison site-level measurements to achieve level 5 reconciliation.

Any methane emitted into the airways in an operating underground mine will eventually be discharged at a ventilation shaft (upcast shaft) which is connected to one or more parallel fans. Some large mines may have more than one upcast shaft.

Methane from the following sources within a mine is emitted into the ventilation air:

- From roof and floor seams and other gas-bearing strata de-stressed by mining activity;
- From sealed, mined out areas (sealed goaf or gobs) comprising decaying roof and floor emissions plus emissions from remnant coal in the worked seam. Note that

due to the ground disturbance caused by mining, seals are invariably imperfect and gas will usually flow round them;

- Coal cutting at the face machine (e.g., longwall shearer);
- Coal cutting at a heading machine;
- Exposed coal faces;
- Coal comminuted by lump breakers or crushers at face ends or within the mine;
- Coal on conveyors;
- Coal in underground coal storage bunkers.

In addition to the rate of strata disturbance, VAM flow rate can also be influenced by rate of change of barometric pressure. Falling barometric pressure leads to an increased pressure gradient across seals in worked-out and working areas of the mine and hence may result in an increase in flow of the gas mixture from goaf areas. This effect is likely to be more significant in older, extensively worked mines because there are more disused or abandoned faces with larger lateral extents of fractured coal strata exposed.

Often gas is drained from sealed areas to minimise the impact of pressure drops on methane concentration in the airways.

Not only does VAM flow rate vary, so does also VAM concentration, the latter being important for mitigation applications. Airflow is relatively steady other than for transient conditions which occur when ventilation airlock doors are opened and closed. Therefore, variability in emissions at the sources listed above are releasing high concentration methane resulting in VAM concentration variations. Appendix Figure 3.2 derived from an example model, illustrates:

- Reduction in VAM concentration with increased drainage capture;
- Increase in VAM concentration with increased production rate, and
- Increase in VAM concentration with increase in seam methane content.

Methane concentrations during production in longwall return airways, typically, lie in the range 0.5-1.0% in gassy mining districts. However, in its journey out of the mine the methane is progressively diluted as a result of air leakages from intake to return within the ventilation circuit due to the nature of the mining activity and layout related to the access and preparation of the seams for mining.

Nevertheless, elevated VAM flows and concentrations can arise for relatively short durations due to:

- Sudden emissions from the floor of a longwall;
- Outburst events in a heading or less frequently in a longwall;
- Mining encountering an additional gas source e.g., interaction with a natural gas reservoir;

- A temporary disturbance of ventilation and hence higher methane concentration; Interruption of the gas drainage system so a greater proportion of the released methane appears in the ventilation air.

3. Quantification Methodologies

While distinct sources of methane within the mine can be identified, such granularity is not necessary for emission quantification. The sum of emissions can be measured at the ventilation shaft(s).

Five SMP reporting levels have been defined, grading from a very general estimate to high precision measurements:

Level 1 – Emissions reported by aggregated source categories at a country level.

Level 2 – Emissions reported by aggregated source categories using available source-specific activity data and regional or country-specific emission factors (EFs), reported at a site level.

Level 3 – Emissions reported by detailed source type using available source-specific activity factors (AFs) and generic emission factors for a given source type derived from existing literature, engineering calculations, or source-level spot measurements.

Level 4 – Emissions reported by detailed source type using source-specific AFs and source-specific EFs established with source-level measurements taken at an appropriate sampling frequency for a given source type.

Level 5 – Emissions reported similarly to Level 4, but with the addition of reconciliation with total site-level measurements.

The methodology at each level applied to VAM emissions are defined below.

It needs to be noted that while Level 1 to 3 are based on lower IPCC reporting levels, they are of little value to inform on the scale of emissions, determining mitigation strategies and policies, as well as progression against the reduction targets. They are nevertheless presented here to help mine owners assess their current reporting schemes and encourage employment of more robust measurement techniques.

Level 1: Estimates of VAM flow

At SMP reporting level 1, global emission factors can be used as a basis for estimating VAM flows for a company. It should be noted that due to the wide range of Emission Factors that can arise depending on the geology, level 1 estimates are of little value for setting targets or determining mitigation policy.

Calculations

Estimated VAM flow = EF(g) x VF(g) x coal production, $m^3.year^{-1}$;

Where:

- EF(g) is a global emission factor, $m^3.tonne^{-1}$
- VF(g), VAM factor, is the estimated fraction of VAM in total mine methane (post drained methane plus VAM), no units
- Coal production is the total raw coking coal production at the company level, $tonne.year^{-1}$.

Methodology

- For EF(g), IPCC Tier 1 offers the following range of global emission factors as a basis for best practice estimate of methane emission from coal mines ~~(IPCC, 2019):~~
  - Low methane Emission Factor = 10 $m^3.tonne^{-1}$
  - Average methane Emission Factor = 18 $m^3.tonne^{-1}$
  - High methane Emission Factor = 25 $m^3.tonne^{-1}$

  In practice, emission factors at different coal mines range from < 1 $m^3.tonne^{-1}$ to >75 $m^3.tonne^{-1}$, the highest values being exceptional but when they arise are major emitters The IPCC factors do not differentiate between thermal and metallurgical coal mines. As coking coal mines tend to be gassy and of higher coal rank than thermal coals, a global value of 18 $m^3.tonne^{-1}$ is suggested for a whole mine emission estimator
- For VF(g), the proportion of the total emission of methane from a mine venting as VAM is typically in the range 70% to 50% (i.e., factors 0.7 to 0.5). However, in a few instances, with intensive, modern drainage systems, the proportion of VAM can be as low as 25%. Where no drainage is necessary, more than 90% of the released gas can appear as VAM
- For coal production data, the companies should use total values for produced, as described in the SMP framework.

Emission factors derived by correlation of gas emission and coal production can be useful within the country in which they were derived but may not be applicable elsewhere due to geological differences.

The calculations should be adjusted accordingly to the units used. To convert from volume flow to mass flow of methane, use a density of 0.000716 $t.m^{-3}$ at 0°C, 101.325kPa.

Due to the wide range of EF(g) that can arise depending on the geology, level 1 estimates are of little value for setting targets or determining mitigation policy.

Level 2: Estimates of VAM flow

At SMP level 2, calculations follow the same principles as described for level 1, but with the use of country or regionally derived EFs for improved estimate on methane emissions. Any available whole mine drainage capture information could be used to help in the selection of an appropriate VF.

SMP level 2 is characterized by an increased granularity of the reported data, relative to level 1. This is achieved by reporting volumes of produced and marketed coal for all sites covered by the SMP framework and performing the calculation for all sites.

Level 3: Improved estimates of VAM flow

Level 3 builds on the refinement of level 2 estimates. The level 2 value may be refined through reference to existing knowledge about mine design and ventilation parameters at the surface fan duct. Manually derived main fan airflow and VAM concentrations from one or more mines will help to improve the overall estimates.

Calculations

Mine VAM emissions = $C(s)/100 \times V(s) \times A \times N \times T$, $m^3.year^{-1}$

Where:
C(s) is the average methane concentration (%) of return air at the surface fan duct
V(s) is average air velocity ($m.s^{-1}$) at the same measurement point
A is the cross-sectional area (m^2) at the velocity measurement location; a one-off measurement.
N is the number of shafts in which methane concentrations >0.1% have been detected
T is seconds in a year.

Methodology

- Values for C(s) and V(s) can be obtained through weekly manual spot measurements, taken on the same working day of the week at a selected time that is normally during a production shift but continued during both holidays and any stoppages for safety, technical, or other reasons
- Manual measurements of C(s) can be obtained using a portable gas analyser or by taking mine air samples for laboratory analysis. Values may also be taken from safety sensor network data, where available
- Manual measurements of V(s) can be obtained using a pitot tube or a handheld anemometer. Values may also be taken from safety sensor network data, where available
- N can be obtained from the mine ventilation departments
- Pressure and temperature measurements are needed to facilitate conversion of volumetric methane flow to mass flow (density of methane is 0.000716 $t.m^{-3}$ at $0^{o}C$, 101.325kPa).

Level 3 strongly encourages use of mine-by-mine specific data for all C(s), V(s), and N and shaft-by-shaft data for C(s) and V(s). However, if only one or two values for C(s), V(s), or N(s) are available, the default values at this level are Cs=0.7%; (A x Vs) = $200m^3s^{-1}$; N =1 in a new mine and 3 in a mature mine.

Where bleeder shafts are employed, shaft-by-shaft defaults of Cs=0.75%; (A x Vs) = $150m^3.s^{-1}$ should be used.

The above default values are based on experience and are in general accordance with accepted working practices.

It is encouraged that a C(s) and V(s) measurement frequency is chosen to give a rough estimate of the average values for these values over the reporting period.

Level 4: Measurement of VAM flow and concentration

Site-specific, direct measurement is essential to obtain accurate and reliable emission data and is straightforward because the emissions are channelled to shafts or drifts. Level 4 involves the use of continuous environmental monitoring systems (CEMS), thus increasing the precision of the total methane volumes from a given source, replacing the level 3 estimation process

Calculations

At this reporting level, calculations for volumes of methane released as VAM should be automatically performed for each shaft or drift and on a continuous basis, as specified in the methodology below. This reporting level also requires source-level data on temperature (T) and pressure (P) to adjust measured concentrations and volumes to standard conditions, as well as providing uncertainty margins for the reported emissions.

Methodology

- To obtain precise and accurate data, the measurement frequency for all parameters used in calculations (C(s), V(s), P(s), T(s)) should be in the range 1 - 10 minutes (UNECE, 2021) to enable continuous calculation of emitted volumes of methane.
- For concentration measurements, if a methane specific infra-red detector is used, care must be taken to employ a gas sampling system which removes excess moisture and dust before introducing the gas to the instrument. This is because the ventilation air methane arriving at the surface ventilation fan is typically close to moisture saturated and laden with dust particles. The monitoring system must therefore be designed accordingly. An alternative technology, more resilient to the adverse environment, capable of direct measurement is laser absorption spectroscopy (Wei et al., 2017). The dry air reading of a VAM concentration of 1.015% is equivalent to a moist air reading of 1.000% at the same temperature, at 98% humidity (Moreby, 2023). The precise correction for any conditions can be calculated using psychometric equations or charts (Burrows, 1989, McPherson, 2012). A measure of the humidity at the VAM sampling point is required.
- To obtain V(s), average velocity is multiplied by cross-sectional area. There are various velocity measurement devices available. Standard practice is to mount a fixed velocity measurement device in the airflow and multiply it by a position factor derived through measuring velocity at different positions traversing the cross section. Continuous flow measurement can be achieved using a differential pressure meter, anemometer, vortex shedder, or ultrasonic device, the latter generally being considered the most practical. Instrumentation options and details are summarised in Appendix Table 3.1.
- Pressure and temperature measurements are used to facilitate conversion of volumetric methane flow to mass flow (density of methane is 0.000716 $t.m^{-3}$ at 0°C, 101.325kPa).
- All electrical and electronic measurement equipment should be suitably rated for use in accordance with the assessed gas hazard to which it is exposed and calibrated at a frequency as advised by the manufacturer. The measurement precision of the equipment used should be sufficient to best inform a mitigation strategy.
- Details of the monitoring protocol should be recorded together with the types of instruments used, calibration details, frequency of measurement, measurement

precision, and the period over which data has been collected. Data obtained by CEMS should be securely stored and backed-up. The measurement management process is summarised in Appendix Table 3.2.
- Uncertainty of the reported emissions should be calculated and the methodology used should be included in the submission.

A method for treating lost, corrupted, or out-of-range data should be specified and implemented. Results should be cumulated and reported to the International Methane Emissions Observatory (IMEO) annually by a prescribed date.

Both airflow data and the distribution of concentration data should be recorded, the latter being necessary for mitigation design. Appendix Figure 3.2 illustrates a useful concentration plot for mitigation design.

Measurement and calibration should be undertaken by trained, competent staff under the supervision of a nominated senior manager who will also be responsible for data collection, processing, and reporting.

Level 5: Reconciliation of Level 4 and site-level measurement

This refers to reconciliation of the source-level mine measurements of methane vented at ventilation shafts and other SMP sources, as described in level 4 above, with top-down site-level measurements (such as ground-based, airborne, or spaceborne measurements of the methane concentrations in the atmosphere and the associated atmospheric modeling above, upwind, and/or downwind of the site). Top-down site-level emission estimates include all mine related methane emission sources except emissions from coal that has been transported elsewhere for export or for stockpiling at local coking plants.

The reconciliation process will be only applicable to sites emitting approximately 100 $kg.h^{-1}$, or higher, based on level 4 monitoring methods in respect of current top-down detection levels. If performed according to principles described for this level, CEMS data at the mine level is considered to represent the highest quality source of Level 4 methane emission information and is thus invaluable for comparison with top-down site-level measurements.

The spatial-temporal resolution and time stamps of Level 4 and top-down site-level measurements should be recorded and a comparison between the latter and site-level data made over a common timescale where practical.

A Technical Guidance Document 'Uncertainty and Reconciliation' developed at a later stage will specify the principles of level 4 and level 5 data reconciliation processes and offer non-prescriptive guidance for operators to improve their methodologies if scientifically significant discrepancies are found. This may address potential questions such as resolving differences in granularity of measurements between top-down (quantifying the total of all site-level emissions) and level 4 (quantifying largest sources only).

4. Mitigation Options

Both VAM concentration and flow are critical factors in determining mitigation potential, technology, energy, capital, and operating costs. Ventilation leakage between intake and return airways which leads to VAM dilution, can be a major issue when planning a VAM mitigation or utilisation project. Ventilation air leakage occurs across airlock doors and air crossings within the mine and sometimes at the surface through cracks and fissures. Not only is VAM diluted progressively on its way to the upcast shaft; dust and other pollutants are similarly diluted which is a beneficial side-effect.

Taking account of the distribution of air and leakages within a ventilation circuit, in new, modern mines, approximately 60% of the airflow produced by the main surface fan may be delivered to the working faces. In older, extensively worked mines, the fresh airflow delivered to working faces could be as low as 10% of the main surface fan quantity.

Newer mines, especially with through-ventilation from drift to shaft, experience lower leakage losses and may produce consistently higher VAM concentrations than older deep mines. However, in extensively worked mines there may be opportunities to reduce ventilation leakages to deliver VAM at higher concentration to the upcast shaft. In addition, methane from sealed goaf areas could be used to supplement VAM concentration and flow when not being drained.

The technologies currently applied to VAM abatement involve Regenerative Thermal Oxidisers (RTOs) and Regenerative Catalytic Oxidisers (RCOs). RTOs function by oxidizing methane to carbon dioxide and water as methane molecules pass through a heated medium. The process flow is periodically reversed to sustain the temperature of the medium. The viability of RTOs designed for VAM applications typically requires a minimum VAM concentration of around 0.2%-0.3%. Otherwise, additional energy will be required to sustain the oxidation process. RTOs were adapted from manufacturing industries where they were introduced in the 1970s to prevent emissions of volatile organic compounds for compliance with mandatory pollution controls.

RCOs operate on similar mechanical principles as RTOs but with the advantage of using catalysts to reduce energy required for methane breakdown. Consequently, RCOs can effectively operate at lower methane concentrations compared to RTOs. However, high costs of catalysts remain a significant challenge in the widespread commercial deployment of RCOs.

The only commercially viable VAM mitigation technology implemented at coal mines to date have involved the use of RTOs. Information on dust particle distribution, moisture content and any additional contaminants of the ventilation air is usually requested by the supplier to check that the efficacy of the RTOs will not be compromised. Safety systems incorporated within current designs have been accepted by the mine safety regulatory authorities in the countries where VAM RTOs are in operation.

A VAM abatement unit consumes power through use of a fan to drive the ventilation air through the process independently of the mine fan but its net impact is a significant reduction in greenhouse gas emissions to the atmosphere. For safety reasons, the connection to the mine évasée is of vital importance and must be designed to isolate surface VAM processing from the mine ventilation and mine-related equipment. The mine air intake for VAM oxidation units are usually physically decoupled from the fan évasée, a collector hood being used to capture up to about 90% of the flow; attempting to take all of the flow would lead to fresh-air dilution of the VAM. Nevertheless, properly designed directly coupled systems are considered safe and feasible. A gas detector and flow monitor incorporated into the VAM unit inlet system provides process control and safety protection. Well-designed isolation and purge dampers systems prevent any explosive gas concentrations from entering the RTO units. The mine ventilation must always be secured regardless of the status of the abatement. Where necessary, a two-way damper can allow switching between évasées after ventilation fan changeovers.

Some mitigation only RTO installations have overheated and suffered thermal damage when processing VAM concentrations above 1% for a prolonged period of time (USEPA, 2011). This problem can be partially addressed by extracting heat for energy use. Various technologies have been developed for using VAM as a fuel for power generation, but most require methane concentrations above those normally encountered at the upcast shaft. Heat generated from oxidation of the proportion of methane that exceeds the minimum self-sustaining oxidation concentration for the system can be recovered and used as an energy source

Where regulations and circumstances allow VAM concentrations consistently above 1%, power generation using a steam turbine can be technically feasible. In some instances, VAM has been enriched with drained drainage methane to fully utilize a power generation system even during periods of lower methane concentrations in the ventilation air. With such an action, the safety implication of diluting large volumes of gas through the explosive range must be carefully considered.

Use of heat for power generation could be feasible when gassy vent shafts have an operational life in excess of 15-20 years but may be too costly for short life vent shafts. However, it makes sense to exploit the heat from an abatement only unit, where practical, to meet local direct heating demand. The thermal energy is suitable for shaft heating, hot water and space heating for mine buildings and through use of absorption technology for mine cooling.

Ongoing research may lead to more innovative and lower cost solutions to VAM abatement and use. Thus, watch should be kept on such developments.

5. References

IPCC 2019. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, in 2019 refinements to the 2006 IPCC guidelines, Chapter 4.1 fugitive emissions, volume 2: Energy.

Moreby, 2023. Personal communication with Dr Roy Moreby, Morvent Mining Ltd.

UNECE 2021. Best Practice Guidance for Effective Management of Coal Mine Methane at National Level: Monitoring, Reporting, Verification and Mitigation. ECE Energy Series No. 71. Geneva 2021.

Urosek et al, 2006. J.E. Urosek, W.J. Francart, and D.A Beiter, Bleeder systems in underground coal mines, Handbook for Methane Control in Mining, F.N. Kissell (ed.), CDC NIOSH IC 9486 (2006).

USEPA, 2011. Ventilation Air Methane Measurement Methodologies EPA 430-R-21-042 Ventilation Air Methane Measurement Methodologies (epa.gov). U.S. Environmental Protection Agency, Feb 2011

Wei et al, 2017. Wei Y, Hu J, Zhang T, Fu X, Yang B, Bi W, et al. Mine laser methane sensor and its application development. In: 2017 2nd International Conference for Fibre-optic and Photonic Sensors for Industrial and Safety Applications (OFSIS). IEEE; Jan 8-10; Brisbane, Australia (2017). 56–62. doi:10.1109/OFSIS.2017.15

Burrows, J, 1989 (editor). Environmental engineering in South African mines, the Mine Ventilation Society of South Africa, 1989 p437-442.

McPherson, M. J. Subsurface Ventilation and Environmental Engineering. Springer Netherlands, 2012.

6. APPENDICES

Table 3.1 VAM measurement instrumentation in the fan drift/duct

Parameter	Issues	Solution	Measurement technology	Calibration
Velocity	Non-uniform distribution of flow. Aggressive environment due to humidity, dust, high air velocity	Undertake a velocity survey using remote devices and determine a position factor to obtain the average velocity at the selected sampling location in the drift/duct	• Averaging pitot • Pitot • Ultrasonic • Vortex shedder • Anemometer for cross sectional survey	Certified by the manufacturer on supply and subsequently at an accredited laboratory wind tunnel. Commissioning check using other methods.
Cross-section	Site specific, may be difficult to determine accurately in the absence of as-built drawings	Measure prior to fan start	• Survey • Laser scan • Design drawings • As built drawings	On site
Methane concentration	Aggressive environment due to humidity, dust, high air velocity	Draw a sample of the gas though a hydrophobic filter before introducing it to the gas detector or use an open path laser device in the airstream	Narrow spectrum infra-red detector, open path laser detectors. Take test samples in bottles, pressurised tubes or proprietary bags for FID chromatography laboratory calibration checks.	Certified by the manufacturer on supply and subsequently at an accredited laboratory. Commissioning check using other methods. Regular on site checks
Pressure	None		For spot and check readings, measure using differential pressure gauge and barometer. For continuous measurements use an electronic device	Commissioning check using other methods. Calibrate electronic devices at an accredited laboratory and regularly on-site checks
Temperature	Careful handling of mercury thermometers		Use a mercury thermometer, or a handheld remote surface temperature sensor. For continuous measurements use an electronic device	Commissioning check using other methods. Calibrate electronic devices at an accredited laboratory and regular on-site checks

Table 3.2 Managing source measurements at Levels 4 & 5

Facility monitoring and reporting activities			Verification
Measurement	Frequency of measurements	Continuous (typically 1-10 minutes sampling rate) preferred where feasible	Check for consistency with the monitoring scheme
	Data processing	Data pre-processing and statistical analysis based on user specification	Check that the agreed data analysis protocols have been followed
		Out of range/failed state data treatment	
		Missing data treatment	
	Management of raw data	Remote transmission and storage	Ensure data backup and data security are in place
		On-board storage	
	Installation and operation of measurement instrument	Position sensitivity	Inspect installation of measurement instruments
		All-weather proofing	
		Parameter sample conditioning	
		Parameter measurement frequency	
		Maintenance	Work sheets signed off
	Proper operation of the sensors	Calibration	Check calibration dates and certificates of sensor
		Accuracy	Ensure that the measurement system compliant with standard
		Performance limits	
		Failure characteristics	
	Measurement of required variables	Monitor each required parameter	Ensure that the required parameters are monitored
Results	Calculations	Calculate and organise results to match required output specification	Check compliance with the monitoring methodology
		Combine relevant parameters to produce required output	Check formulae in the algorithm
	Documentation	Compile all data, supporting information, calculations and results in safe storage with backup for an agreed period of time	Site for retrospective checks
Reporting	Record results	Note any issues	Examine report for completeness and correctness

Based on UNECE, Best Practice Guidance for Effective Management of Coal Mine Methane at National Level: Monitoring, Reporting, Verification and Mitigation. ECE Energy Series No. 71. Geneva 2021, Table 6.4.

Figure 3.1 VAM flow and concentration trend at a ventilation shaft in Shanxi Province, China

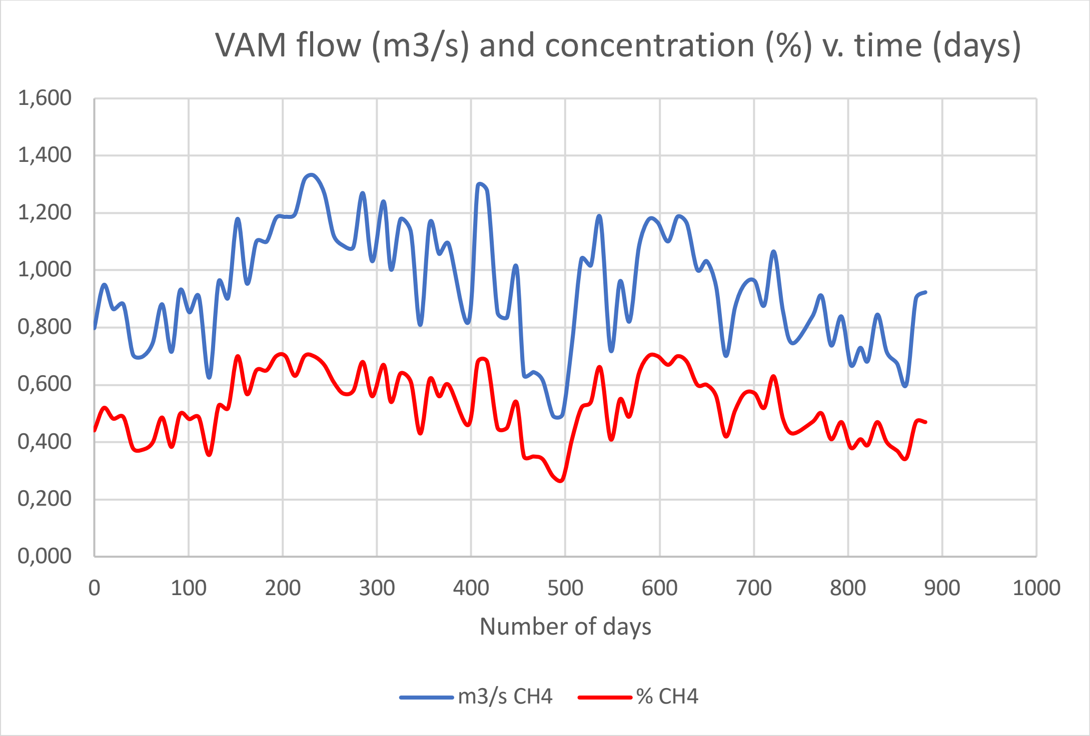
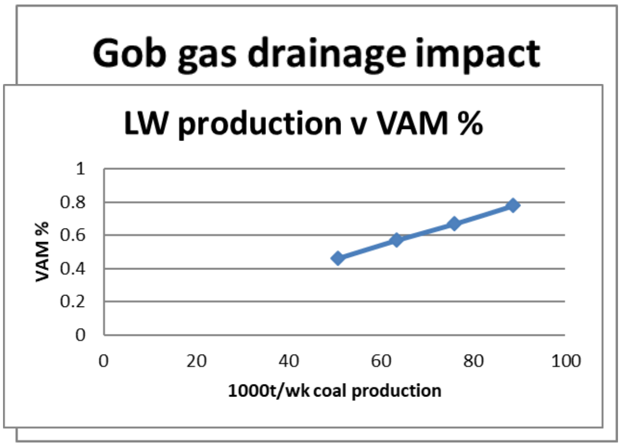


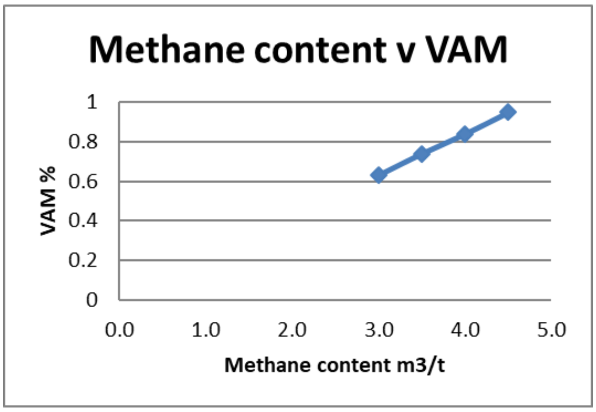
Figure 3.2 Example empirical model results illustrating basic concepts of

(i) reduction in VAM concentration with increased drainage capture;



(ii) increase in VAM concentration with increased production rate and

(iii) increase in VAM concentration with increase in seam methane content.



7. GLOSSARY

1. **Bleeder Shaft** means vertical ventilation shafts located to serve a specific series of longwalls through which gas-laden air is discharged from bleeder systems to the surface. They are not usually used for miner and materials transport. Bleeder systems are that part of the mine ventilation network used to ventilate areas of the mine in which pillars have been wholly or partially removed, including the areas where coal has been extracted by longwall mining. Effective bleeder systems control the air passing through the area and continuously dilute and move any methane-air mixtures and other gases, dusts, and fumes from the worked-out area away from active workings and into a return air course or to the surface of the mine (Adapted from Urosek et al, 2006).
2. **Goaf (gob)** means a part of a mine from which the coal has been partially or wholly removed and includes the de-stressed strata around the extraction from which methane is emitted in addition to the worked coal seam sources.
3. **Emission factor** means a coefficient that quantifies the emissions of gas per unit activity. Emission factors are often based on a sample of measurement data, averaged to develop a representative rate of emission for a given activity level under a given set of operating conditions.
4. **Site** refers to a coal mine and all associated equipment and geological structures outlined in section 4 of SMP framework which emit methane due to the coal mining activities at this mine. Sites may include closed mines owned by the operator.
5. **Source-specific emission factor** means emission factor derived through empirical measurements for a specific source.
6. **Generic emission factor** means a standardised emission factor for each type of emission source which is derived from inventories or databases, but not verified through empirical measurements for a specific source.