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Best Practice Guidance on Ventilation Air Methane (VAM) Processing.

Note by the Secretariat[1]

I. Introduction

1. In a world increasingly committed to reducing greenhouse gas emissions in which large scale emission reductions are necessary to meet global targets, mitigation of large point sources of methane emissions is among the lowest hanging fruits.

2. When coal is formed, the gas methane is a by-product. When the coal is excavated, methane is released. This poses a safety problem, as methane in certain concentrations (between 5% and 15%) in the air is explosive. How much methane there is in a specific location depends on many factors, such as permeability and depth of the coal seam.

3. In most surface mines, the methane either migrates to the atmosphere during coal extraction or requires pre-mine drainage to be captured. Actions to mitigate VAM therefore focus on underground mines.

4. In underground coal mines, sufficient amounts of ventilation air need to be passed through the mine to dilute the released methane to concentrations safely below the explosive range, and then to evacuate it to the surface through ventilation shafts.

5. There are three main emission pathways for methane in underground coal mines:

(a) mine gas drainage systems;

(b) ventilation shafts; or,

(c) fracture systems that connect to the surface.

[1] The Secretariat provided guidance and assistance in developing this document. Mr. Richard Mattus, a member of the UNECE Group of Experts on Coal Mine Methane and Just Transition is the primary author. Members of the Bureau of Group of Experts: Mr. David Creedy, Mr. Raymond Pilcher, Mr. Clark Talkington, and Ms. Volha Roshchanka reviewed the document and provided input to it. The document was also subject to a review by a number of experts from within as well as beyond the Group of Experts.

6. While concentration of the drainage gas ranges typically between 30-60% (in extreme cases even reaching 100%), methane in ventilation air (VAM) is typically below 1% (0.3-0.7% on average). Legal limits on VAM concentrations vary among countries, some of which under certain conditions allow even for concentrations greater than 1%.

7. Very low concentration of VAM makes its destruction and conversion into CO_2, which a much less powerful (in terms of global warming potential) greenhouse gas, difficult without an additional fuel source.

8. Typically, VAM is estimated to account for around 70% of global methane emissions from underground coal mines. Some studies, however, indicate a substantially greater share.

9. A large coal mine ventilation shaft can emit around 1 million cubic meters per hour (m^3/h), which is equivalent to approximately 634 thousand cubic feet per minute (cfm), of mine air containing 0.8% methane. Over a year that corresponds to around 50,000 metric tons of methane from a single emission source.

II. Potential Climate Wins

10. Almost 200 countries have signed the Paris Agreement, thus committing themselves to substantially lowering their greenhouse gas emissions. Despite that fact, global greenhouse gas emissions continue to increase. According to the International Energy Agency (IEA), since 1990, global energy production has increased by around 65%. Over that time, the supply of energy based on coal, oil, and natural gas has grown at the same rate. As a result, despite all the undertaken efforts, the percentage of fossil-based energy in the global energy mix is still at the same level of around 80% at which it was 30 years ago before the Kyoto Protocol was signed.

11. Coal, the fossil fuel with the highest negative environmental impact, still provides 25-30% of the total energy mix. The world must accelerate transition away from coal as a fuel, Meanwhile, as the phasing out can be expected to take time, serious efforts need to be made to minimize greenhouse gas emissions related to its current sourcing and usage.

12. When methane is emitted to the atmosphere, it has an atmospheric lifetime (residence time) of approximately 12 years after which it oxidizes to CO2. However, as compared to the latter, taken on a 100-year basis, methane is 30 times more powerful as a greenhouse gas. Based on a 20-year comparison, that ratio grows to 82. Hence, reducing methane emissions offers an immediate and very powerful impact in slowing the rate of global warming.

13. Addressing VAM emissions is a climate opportunity. Due to their size and characteristics as a point source, relevant mitigation options exist, which can help achieve quick climate wins. For example, one large coal mine ventilation shaft emitting 50,000 metric tons of methane has the same warming effect as methane emissions originating from 1 million cows, or as CO_2 emissions generated by either a coal fired power plant of 500 MWe, or 2 million combustion engine cars (the latter two compared on a 20-year methane to CO_2 conversion basis) (see Appendix I).

III. VAM Technology Options

14. For safety reasons, the explosive range for methane (5% to 15%) must be avoided. Drainage gas, being safely above that threshold can be utilized to run gas engines, generate electricity, and/or (when at very high concentration) be fed into a natural gas grid. Another option for mitigation is flaring, which can be done safely with concentrations down to around 20%.

15. At the same time, processing VAM is difficult for two reasons:

(a) the volumes of ventilation air that need to be processed (to clean out methane) are enormous; and

(b) the concentration of the methane that is to be destroyed (mitigated/oxidized) is extremely low.

16. So far, by 2023, only one technology has been successful in large scale processing of VAM, namely Regenerative Thermal Oxidation (RTO). This technology was developed in the 1970's to clean industrial emissions to air from low concentrations of hydrocarbon gasses.

17. Over the years, tens of thousands of RTO plants have been installed successfully processing emissions from various industries in uses such as odor control, destruction of solvents from printing and painting, applications in the chemical, petrochemical and pharma industries, petroleum depots, biogas production and many more uses.

18. Several of these applications involve substances such as ether, hydrogen, and other flammable/explosive gasses, thus requiring very high demands on safety, and therefore strengthened health and safety features have been incorporated into RTO system designs.

19. In the 1990's, processing of VAM was approached by RTO system suppliers. Lengthy trials and adaptations were made. At the beginning of the 21st century the first large scale commercial installations were made and delivered, with long time successful operations.

How is the RTO used for destruction of VAM emissions at coal mines?

The basic function of RTO technology is to push the ventilation air through a bed of ceramic media, pre-heated to the normal oxidizing temperature for methane (850-900 degrees C), causing the latter to oxidize and adding its oxidizing energy to the bed media.

As the heat exchange of the RTO technology is extremely efficient, the VAM concentration of only 0.2% is required to maintain methane destruction (oxidizing) process. The energy value of concentrations above the said level can be retrieved in the form of heating, cooling, and/or electricity.

20. Due to design, many suppliers have a maximum concentration limit for VAM processing of around 0.7%. Special high concentration RTO designs can operate up to 1% or even 1.2% methane, but around this level, national safety legislations (securing adequate safety margin to the explosive range) applicable on most markets, become a limiting design factor.

21. Realizing the big market potential of VAM processing, a range of other technologies have been tested. This includes catalysts (that could lower the required oxidizing temperature, but it is difficult to catalyse methane), lean gas turbines (which so far have managed to be effective only with no less than 2-3% concentrations), concentrators (that are difficult to apply to the methane molecule) and more.

22. Struggling to process huge volumes of air with extremely low methane concentration, most VAM technologies other than RTO have not gone beyond the lab or pilot phase.

23. While there might be more VAM processing technologies suitable for commercial installations developed in the future, as of 2023 only RTO has proven successful and is readily available.

IV. Cost Effectiveness of Available Solutions

24. Full mitigation of VAM emissions requires equipment that can process the entire volume of ventilation air exiting the mine. The investment cost for VAM processing relates mainly to the (ventilation) air volume that is to be processed and is to a much smaller degree dependant on methane concentration. Therefore, higher concentration shafts not only produce more emissions, but are also characterized by lower mitigation cost per emission unit, and for that reason should be equipped with VAM processing installations in the first place.

25. The average life of a mine ventilation shaft varies from 5 years to 15 years, as the active mining domains progress away from the ventilation infrastructure on a different pace depending on the coal region where they are located. Mining companies progressively install new ventilation shafts over time.

26. The total investment cost (CAPEX) of a VAM processing plant for mitigating methane from a ventilation airflow of 500 thousand m3/h is around 14 million USD +/-15%, assuming uncomplicated conditions. While it might seem high, it is still very competitive when compared to other emissions reduction options.

27. The technical lifetime of a VAM mitigation plant is typically around 20 years, but given the nature of VAM processing, it depends on the lifetime of the ventilation shaft that it serves. However, if key elements of the VAM mitigation plant are designed in a modular way, they might be disassembled and relocated to a new location to operate there.

28. In addition, where feasible, utilization of the energy released as a by-product when mitigating VAM should be encouraged. The value of the energy, which can be used for heating or cooling, in industrial processes, or for power generation will improve the return on investment.

29. The cost of VAM processing (OPEX), evaluated on a 10 years of operation basis, is currently below 9 USD per tCO_2e using methane warming potential on a 100-year basis, and under 3 USD per tCO_2e using methane warming potential on a 20-year basis.

30. A VAM processing plant consists of multiple RTO units, each processing a portion of the air flow. The need to double the air processing capacity translates simply into the need to double the number of RTO units. The costs of some major items of an RTO VAM processing plant are more or less linear, so it can be assumed that processing half the volume discussed in the previous paragraph, i.e., 250 thousand m^3/h, is around USD 8 million (+/-15%) and that processing twice the volume, i.e., 1 million m^3/h, is around USD 25 million (+/-15%). Note, however, that these are just rough indications. For each specific site the particular conditions need to be carefully evaluated in order to accurately estimate the actual costs.

31. A third major cost element to consider, besides CAPEX and OPEX, is financing of the VAM processing installation. In order for VAM processing investments to take place, the cost must be offset by a value attributed to the greenhouse gas emission reduction achieved. This value can take the form of a cost that is avoided (e.g., tax/penalty), or a revenue (e.g., carbon emission reduction credit). Without any such mechanism, investment in VAM processing cannot be economically justified. Unfortunately, such financial drivers have been rare, which is the main reason why investments in VAM processing installations have not been more common.

32. An alternative option for reduction greenhouse gas emissions is Carbon Capture and Storage (CCS), which typically collects CO_2 from large emission sources, such as fossil-based power production facilities, cement factories, and steel plants, and pumps it down to subterranean storage. However, the cost of this technology is still very high and as of December 2023 amounts to 100-150 USD per ton of CO_2 (evaluated for a 25-year project life), which is significantly more than VAM processing technologies discussed above.

Overcoming Hurdles

33. Despite the effectiveness of VAM projects, the following main hurdles have been preventing many of them from scaling up: costs, lack of awareness, and safety concerns.

1. Costs

34. Scaling up of VAM projects requires investment and financing. To make it happen coal mining companies around the world need to start prioritizing investing in VAM processing that, however, is not directly related to coal production, which is their core business. What could solve the problem is making investments in VAM installations attractive to third parties and thus securing them as investors and project developers. Unfortunately, short of financial drivers discussed earlier, few coal companies and external parties have had incentives to steer their investments in that direction.

35. Another option for reducing VAM emissions is to improve gas drainage, thereby reducing the quantity of gas emitted from the mine ventilation system.

36. Methane drainage typically produces a sufficiently high methane concentration stream that can be directly used in gas engines for combined heat and power projects, industrial burners, boilers and other similar uses, or sold to be injected into natural gas distribution or transmission pipelines. Conducting drainage prior rather than during mining could lower the costs even further (as less methane is released and therefore the volume of ventilation air needed also decreases thus saving energy for operating the ventilation fan). Drainage of gas from the mine prior to coal extraction is not always possible because of certain geological conditions such as low permeability.

37. Considering the economic value of the energy produced from drained gas and the fact such projects contribute directly to increasing mine safety (as gas is typically extracted through a closed pipe network that keeps it separated from any personnel and ignition sources), they typically need less financial motivation than their VAM counterparts.

38. Short of any opportunities for gainful use of the drained gas, it can be, as a “last resort”, flared. This method, like VAM processing, pre-oxidizes methane (to become CO_2) prior to emitting it to the atmosphere, thus weakening its global warming potential (GWP) of the residual emissions.

39. However, gas drainage is not always possible. Furthermore, when it is, even with extensive drainage, VAM emissions will typically still remain the largest type of emission from the coal mine. Therefore, to effectively reduce methane emissions from a coal mine, it is necessary to address VAM.

40. As that conclusion becomes ever more apparent leading to a growing interest in mitigating VAM emissions, new suppliers with relevant experience from other industrial sectors begin to emerge, acquire necessary experience, and gain specific competency, further adding to the market’s diversity and competitiveness.

2. Awareness

41. Underground coal mines must remove methane from the workings to the surface for workers’ and operational safety. Since in many jurisdictions there are no incentives to limit the direct releases of methane to the atmosphere, oftentimes mine operators let mine gases freely escape from ventilation shafts and gas drainage systems, without undertaking any efforts to prevent or minimize them.

42. As mine operators have had no economic interest in addressing or even recognizing the problem, they are not only not aware of the existing mitigation solutions, but also not motivated to get informed. The existence of financial drivers (carrots/sticks) would help changing that attitude.

3. Safety

43. Due to the risk of accidents caused by methane in mine workings, safety is the top priority for coal mine operators. Adding a new feature (VAM processing) in the vicinity of the mine ventilation shaft is of major concern to many miners.

44. To avoid ignition and explosion, methane concentrations must always be kept safely away from its explosive range of 5-15% in the air. Typically, drainage gas is much above that range (usually higher than 25%) while VAM is kept far below it (0.5-1%).

45. For VAM processing installations, safety is the primary design criteria. It applies to all parts of the installation (ductwork and equipment) that are in contact with the flow of VAM. Safety concerns in mines are very similar to those related to the use of RTO technology for mitigating emissions of gasses from industrial processes, where there is a risk that the gas mix might reach the explosive range. Experienced RTO suppliers, having been exposed to those risks for decades, are well capable of handling them.

46. At the same time, each RTO application has its specific issues to address and particularities of processing VAM should not be easily disregarded. For example, a VAM processing plant cannot be allowed to impede the function of the mine ventilation fan and there must be sufficient precautions preventing flammable methane concentrations from reaching the VAM processing facility. Furthermore, the oxidation temperature of coal mine

methane can be higher than that of e.g., natural gas (requiring special design features in the RTO system). In addition, there can be dust of coal and other substances present in the ventilation air that need to be considered in the design of the duct work system and the interior design of the RTO's. These risks are real and unique for VAM processing, but far from unusual in many other industrial applications. Therefore, it is of crucial importance that they are tackled by the experienced suppliers, whose installations are designed to address them and have a proven record of long-term successful operation.

V. Steps preparing for development of a VAM project

47. The necessary steps cover three basic areas:

(a) Internal information on the essential basics: VAM concentration, plant location, and availability of drainage gas that can be allocated to the VAM plant;

(b) External information on potential value of the planned emission reduction and on newest developments in VAM technology;

(c) Potential partners that could be involved in financing the future project, such as project developers and VAM processing system suppliers.

48. There are 8 steps that need to be considered before successfully launching a VAM processing project:

(a) *Tracking VAM concentration*. Track relevant VAM concentrations over as long a period as possible. This simplifies decisions on actual design conditions for the forthcoming VAM plant;

(b) *Identifying the location.* Explore potential locations where the VAM processing plant could be located, aiming to have it in the vicinity of the evasé (the mine ventilation shaft being considered);

(c) *Assessing drainage gas situation.* Explore possibilities for drainage gas to be injected into the ventilation air prior to the point of processing to either balance the VAM concentration at a steady level (if power generation is considered) or sweeten the energy level of the system and the amount of methane that is to be mitigated;

(d) *Determining emission mitigation value*. Determine the value of methane emissions reduction (check opportunities for obtaining any sort of Carbon Credits or Carbon Offsets, or for avoiding penalties) that is to result from the VAM project;

(e) *Secure financing*. Identify potential investors, and secure financing for the project;

(f) *Select project developer*. Identify project developer (the mine, or a 3rd party);

(g) *Select VAM processing system supplier.* Identify VAM processing system supplier. Choose from the following options:

(i) an RTO supplier with successful, long term VAM processing experience;

(ii) an RTO supplier with experience from other relevant industrial applications, or;

(iii) a supplier venturing a technology under development, looking for a suitable site for large scale demonstration.

(h) *Stay updated*. Be familiar with the state of VAM technology and follow its developments.

VI. Conclusions

49. *Methane vs. CO_2*: Compared to efforts to reduce CO_2 emissions, reducing emissions of methane is an opportunity to achieve an immediate and powerful effect. From a climate perspective, it is a way to "buy time" needed until major reductions of CO2 come into effect.

50. *Size of emission source*: When taking a concrete action on reducing emissions of a given greenhouse gas, the size of its emission source is important. The ventilation shaft of a coal mine is a major single source of methane emissions. Therefore, mitigating VAM from a large ventilation shaft can have a very big positive impact on global warming (see Appendix I).

51. *Need to put value on emission reduction*: To trigger projects addressing VAM emissions, a value needs to be attributed to its mitigation. There needs to be a cost for emitting methane or an added value for reducing its emissions to incentivize investment in VAM abatement.

52. *Costs*: In terms of a cost of mitigation of a ton of CO_2e, VAM processing constitutes a fraction of other GHG reduction alternatives such as e.g., CCS.

Annex I.

Global Warming Effects of Emissions from Various Sources

1. VAM Emissions from a Major Coal Mine Ventilation Shaft

1. A large ventilation shaft, emitting 1 million m^3/h of air with 0.8% VAM concentration emits around 50,000 tons of methane annually. Assuming 98% cleaning efficiency, 96% availability, 0.71 in density, and 1.95 in resulting CO_2, the corresponding annual CO_2e emissions come to approx. 1,500,000 tons when compared on a 100-year basis (Global Warming Factor of 30) and around 4,100,000 tons when compared on a 20 year-basis (GWF of 82).

2. The resulting emission is linear, meaning that half the volume of air with the same VAM concentration yields half the emission and half the VAM concentration with the same volume also yields half the resulting emission.

2. Large Coal Mine Ventilation Shaft vs. Cows

3. According to the US Environmental Protection Agency (US EPA), a cow annually emits 60 to 120 kgs of methane. Therefore, 50 thousand tons of methane (an average annual VAM emission from a large coal mine ventilation shaft) corresponds to methane emissions generated by approx. 1 million cows.

3. Large Coal Mine Ventilation Shaft vs. Coal Fired Power Plant

4. According to the US Energy Information Administration (EIA), a coal fired power plant emits 2.3 lb of CO_2 per kWh (electricity). This equals 1.04 kg CO_2 per kWh.

5. According to IPCC (Assessment Report #6 dated 2023), compared on a 20-year basis, a ton of methane in the atmosphere has a negative environmental impact 82 times greater that a ton of CO_2.

6. An efficiently utilized power plant can be assumed to have 90% availability.

7. 50,000*82/1.04/(24*365*0.90) = 500 MW(e)

8. As a result, mitigating VAM emissions from a major coal mine ventilation shaft has an effect (compared on a 20-year basis) on global warming similar to that of closing down a coal fired power plant with a capacity of approx. 500 MW(e).

4. Large Coal Mine Ventilation Shaft vs. Cars

9 Combustion engine cars emit CO_2.

10. Assuming an average emission of 150g CO_2 per km and an average annual milage of 14,000 km, a passenger car with a combustion engine emits approx. 2.1 tons CO_2 per year.

11. According to IPCC (Assessment Report #6 dated 2023), compared on a 20-year basis, a ton of methane in the atmosphere has a negative environmental impact 82 times greater that a ton of CO_2.

12. 1 million m^3/h of ventilation air containing 1% of methane would, compared on a 20-year basis, emit 4.1 million tons of CO_2e annually. (On a 100-year basis, the corresponding emissions would be 1.5 million tons.).

13. Comparing VAM emissions equating to 4.1 million tons CO_2e with annual emissions of a single combustion engine car that amount to 2.1 tons CO_2, signifies that addressing the former corresponds, in terms of the environmental impact, with removing from the streets approx. 2 million cars (taken on a 20-year basis). (On a 100-year basis, the corresponding number of cars is approx. 720,000.).

Annex II.

Case Studies & Replication

1. The first successful on-site demonstrations of RTO technology for VAM processing took place in the 1990's.

2. The first three commercial VAM processing projects were commissioned in the first decade of the 21st century:

(a) 2007: In Australia, supplier MEGTEC (Sweden) commissioned a special power plant with 4 RTO units operating as boiler furnaces using VAM with around 1% methane concentration and generating steam for a conventional 6 MWe steam turbine. The installation processed around 20% (250,000 m^3/h) of the full ventilation air volume of a major ventilation shaft and operated for 10 years. The project was halted because the underground (longwall) mining was relocated (according to plan), causing the VAM concentration to drop;

(b) 2008: In China, supplier MEGTEC commissioned a single unit RTO installation processing a partial flow of around 60,000 m^3/h of ventilation air and generating hot water for local residential heating. The project was financed under the CDM program. The VAM Processing installation was operated for a few years, after which it was stopped due to lower than expected VAM concentration in the ventilation shaft;

(c) 2009: In the USA, supplier Biothermica (Canada) commissioned a single unit RTO installation processing around 50,000 m^3/h of ventilation air, which was operated for 4 years. The project was halted because the VAM concentration decreased, and the mine decided to close the ventilation shaft.

3. Other examples of successful VAM processing installations include:

(a) 2012: In the USA, supplier DÜRR (USA, Germany) commissioned three sets of RTOs, totalling 250,000 m3/h of ventilation air. After more than 10 years in operation, the VAM processing plant was shut down in 2023 due to low methane content. The plant is being prepared for relocation. This project highlights one of the benefits of RTO installations - a possibility of transferring the equipment to a new shaft when methane concentrations decrease below technical or economic feasibility limits;

(b) 2014: In China, supplier DÜRR (USA, Germany, China) commissioned a VAM processing installation with ten RTO units totalling 1,020,000 m^3/h of ventilation air. The inlet concentration to the processing plant is controlled to approx. 1.1% methane by the addition of drainage gas. Hotgas ducting is connected to a boiler that feeds a 30 MWe steam turbine. After 9 years, the plant is still in operation;

(c) 2016: In China, supplier Anguil (USA) commissioned an installation of 6 RTO units processing 540 thousand m^3/h, generating electricity with an installed capacity of 15 MWe. After 7 years, the plant is still in operation;

(d) 2022: In the USA, supplier Biothemica commissioned a VAM RTO installation processing 245 thousand m^3/h.

4. With decades of successful operation, VAM processing performed by RTO suppliers with relevant experience from other industrial applications is well proven. Multiple projects in different countries have demonstrated the viability of addressing VAM as a large-scale, effective mitigation strategy. Where suitable, energy recovery at the VAM processing plant can further extend climate change and energy production co-benefits.