

Ventilation Air Methane (VAM) Utilization Technologies

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Why is VAM Mitigation Important?

Methane, the principal component of natural gas, is often present in underground coal seams and is a safety hazard to miners because it is explosive in concentrations ranging from 5 to 15 percent in air. Gassy underground coal mines employ large-scale ventilation systems to move fresh air into the mine. These systems dilute methane released into the mine workings as coal is extracted and remove the gas from the mine, thereby maintaining safe working conditions. In-mine methane concentrations must be maintained well below the lower explosive limit, so ventilation air exhausts contain very dilute concentrations of methane (typically less than 1 percent and often less than 0.5 percent). However, because mine exhaust flow rates are so high, ventilation air methane (VAM) constitutes the largest source of methane emissions at most mines.

Releasing VAM to the atmosphere wastes a clean energy resource and produces significant global greenhouse gas emissions. Methane is a potent greenhouse gas with a global warming potential more than 25 times that of carbon dioxide. Deploying technologies that destroy VAM emissions or convert VAM into useful forms of energy (such as electricity and heat) can yield substantial greenhouse gas emission reductions.

Technologies Using VAM as Primary Fuel

Regenerative Oxidation and Catalytic Oxidation:

Regenerative Thermal Oxidation (RTO) is the only commercially operational technology capable of using VAM as a primary fuel at methane concentrations below

1.5 percent. RTO and Regenerative Catalytic Oxidation (RCO) have long been used as odor and pollution abatement equipment in manufacturing, printing and other industries, and have now been successfully adapted to oxidize methane in mine ventilation air. Demonstrations of RTO and RCO VAM abatement occurred in the 1990's and early 2000's, with implementation of the first commercial VAM RTO project in 2007. In total, at least six commercial RTO projects have operated in Australia, China, and the United States.

Available and Developing Options for VAM Utilization

- VAM used as the principal fuel
 - Oxidation, with or without energy recovery (Thermal or Catalytic)
 - Gas turbines – microturbines (e.g., 30 kW) and full sized turbines (>0.5 MW)
- VAM used as a supplemental fuel (i.e., combustion air)
 - Internal combustion engines
 - Turbines
 - Utility or industrial boilers
 - Hybrid rotary kiln/gas turbine

How does an RTO destroy VAM? Ducts direct a slip stream of exhaust air from the fan to the oxidizer. Air velocity is maintained in the ducting by use of a fan that creates vacuum pressure. This provides a steady flow of mine ventilation air into the oxidizer, and also ensures that there is not back pressure on the shaft fan. When entering an RTO, gas encounters a bed or column of heat exchange material, usually ceramic media that has been

preheated to the oxidation temperature of methane (1000° C). The VAM enters the oxidation chamber where it is oxidized and releases heat, which is absorbed by the second bed or column of heat exchange material, heating the bed to 1000° C. This heat sustains the auto-oxidation process without requiring additional fuel input. Valves and dampers repeatedly reverse the flow of incoming VAM to keep the hot zone in the center of the oxidizer. Catalytic and thermal systems both operate on this principal, although catalysts are intended to allow the reaction to occur at lower temperatures and also with reduced pressure drop across the bed of heat exchange material. When VAM concentrations are high enough, thermal oxidizers can provide excess heat energy for uses such as shaft heating and electricity generation. Examples of commercial VAM RTO projects include the West Cliff Colliery in New South Wales, Australia, Verdeo McElroy VAM Abatement Project at the Marshall County Mine in West Virginia, and the Gaohe Mine in China.



Verdeo McElroy VAM Abatement Project, Marshall County Mine, West Virginia, USA (courtesy of Sindicatum Sustainable Resources)

In addition to being the world's first commercial VAM project operating from 2007-2017, the West Cliff Ventilation Air Methane Project (WestVAMP) developed by BHP Billiton, was also the world's first commercial-scale VAM-to-power project. The plant consisted of VOCSIDIZER™ RTOs manufactured by B&W MEGTEC Systems. The plant generated 6 megawatts (MW) of electricity using a steam turbine generator, producing 300,000 MWh and reducing GHG

emissions by 2 million metric tonnes of CO₂ equivalent (tCO₂e) during its project life.



Fortman Clean Energy Technology Ltd VAM Abatement Project, Gaohe Mine, Shanxi Province, China (courtesy of Dürr Systems)

The Verdeo McElroy VAM Abatement Project commenced operation at the Marshall County Mine in West Virginia in May 2012. The project, developed by Sindicatum Sustainable Resources and now owned by NextEra Energy Marketing generates heat as methane is destroyed. The project consists of 3 RTOs manufactured by Dürr Systems. Each RTO has a capacity of 53,330 standard cubic feet per minute (scfm) for a total plant throughput capacity of 160,000 cfm (75 normal cubic meter per second [Nm³/s]), which is 80 percent of the shaft flow. As of December 31, 2017, the project has registered 1,045,923 tCO₂e in emission reductions.

As of September 2018, the world's largest operating VAM project is at the Gaohe Mine of the LuAn Mining Group in Shanxi Province, China. Developed by Fortman (Beijing) Clean Energy Technology Ltd. of China, the VAM-to-power project began operation in May 2015 with reported grid-connected power generation of 8000+ hours per year and a total throughput capacity of 700,000 cfm (300 Nm³/s), utilizing 12 RTOs manufactured by Dürr. Heat produced by the oxidation process is routed to a steam boiler which generates sufficient steam for a 30-MW power plant. In 2018, Fortman commissioned a second VAM-to-Power project at a mine in Yangquan, Shanxi Province, China. The

project contains 6 RTOs with a combined capacity of 350,000 cfm (150 Nm³/s) and includes a 15-MW steam turbine generator that will produce electricity. Heat produced by the VAM project will replace heating from coal-fired boilers during cold-weather months. In addition to these two projects, China has hosted several other VAM projects including one at the Datong Mine in Chongqing, which featured 6 MEGTEC Vocsidizers for a total throughput capacity of 210,000 cfm (104 Nm³/s).



Biothermica VAMOX™, Blue Creek Mine #4 Mine, Alabama, USA (courtesy of Biothermica Technologies Inc.)

In addition to Dürr and B&W MEGTEC, other manufacturers of VAM RTOs include:

- Biothermica, a Canadian air pollution control equipment supplier, manufactures an RTO called the VAMOX™. A VAMOX™ unit was fully operational at the Blue Creek No. 4 mine in Brookwood, Alabama USA from 2009 through 2012. The project employed a single unit capable of handling 30,000 cfm or 14 Nm³/s. The project was the first to operate at an active underground coal mine in the United States. Biothermica has reached an agreement to install two large-scale VAMOX™ units at the same mine in 2019, each capable of handling 140,000 cfm – which would make it the largest VAM project in North America.
- Gulf Coast Environmental Systems, LLC, supplies the CH₄ RTO™.

- HEL East Ltd. of the United Kingdom, which has tested a commercial-scale unit at an operating coal mine.
- The Commonwealth Scientific and Industrial Research Organisation (CSIRO) of Australia has developed the VAMMIT™, a VAM mitigator that is a compact flow reversal reactor with a newly-structured honeycomb regenerative bed, resulting in less pressure drop/energy consumption and a smaller footprint. CSIRO has field tested the VAMMIT™ at a mine in Australia. Site trial results at a mine site in Australia show that the operation of the VAMMIT unit is self-sustaining at VAM concentrations between 0.3 – 1.0 percent CH₄.

Catalytic technology for VAM abatement operates in a manner similar to RTOs but employs catalysts that enable it to operate at lower temperatures. The catalysts are placed with the heat exchange media in the bed increasing the total column of material. Although this lowered the oxidation temperature compared to a similar-sized RTO in early trials, it also resulted in lower VAM throughput. However, research and development have continued to address these issues, and commercial deployment of RCOs is expected in the near future.

- Canada's CANMET Energy and Technology Centre developed a prototype catalytic VAM RCO called the CH₄MIN™ using a proprietary catalyst. Following bench-scale and field demonstrations by CANMET, Sindicatum Sustainable Resources licensed the CH₄MIN™ technology in 2007, and from 2008-2009, built and successfully tested a 15 Nm³/s commercial-scale CH₄MIN™ in a laboratory setting.
- In 2015, Johnson Matthey, a United Kingdom-based global chemical manufacturer, introduced a new catalytic system, COMET™, developed in collaboration with Anglo Coal to address

VAM emissions. COMET™ is a “once through” system where the VAM stream is passed through a heat exchanger to raise the temperature of the gas to the desired inlet temperature and then passed through the oxidation reactor containing the oxidation catalyst. Johnson Matthey and Anglo Coal successfully tested the COMET™ system at an operating mine in Australia on VAM concentrations ranging from 0.1-0.8 percent CH₄.

- CSIRO has been developing emerging technologies for ultra-low concentration VAM abatement, including photocatalytic oxidation destruction under ambient temperature and pressure conditions. Lab scale tests have demonstrated successful destruction of VAM at concentrations less than 0.3 vol %CH₄.

Lean-fuel Turbines: Generation of electricity from VAM requires a rich and consistent CH₄ stream. For most shafts, this will require the addition of supplemental fuel such as drained gas that can be blended with VAM to increase the methane concentration to approximately 1 percent methane.

Lean-fuel gas turbines using VAM as the primary fuel are close to commercial deployment.

- CSIRO has developed a lean-fuel gas turbine, the VAMCAT™, which employs a catalytic combustor to run on VAM concentrations. CSIRO created a 25kWe power generator demonstration unit and field-tested it at an underground coal mine of the Huainan Coal Mining Group in China in November 2011. The demonstration unit operated at a CH₄ concentration of 0.8 percent.



Ener-Core Powerstation EC250, Attero Landfill, Schinnen, Holland (courtesy of Ener-Core, Inc.)

- Ener-Core produces the Powerstation EC250 which uses a Flex turbine microturbine to produce power directly from VAM. The operating range is from 100% to as low as 1.5% CH₄. The system can run directly on low pressure, low quality gases including VAM. A Power Oxidizer replaces the combustor, producing the heat to drive the turbine. With low-Btu fuels including VAM, the fuel is aspirated with air prior to the inlet and oxidation, eliminating external compression and accepting low pressure gas. Ener-Core also makes the Power Oxidizer 2 MW power station using a Dresser-Rand turbine.

Technologies Using VAM as Supplemental Fuel

Some technologies capable of using the energy content of ventilation air exhausts as a supplemental fuel in internal combustion engines, turbines, or industrial boilers are currently available.

One existing technology application entails using VAM as combustion air, supplying ancillary fuel to internal combustion (IC) engines, turbines, or industrial and utility boilers. In fact, use of VAM as combustion air in IC engines has been commercially

demonstrated. For example, the Appin Colliery in New South Wales, Australia implemented a project employing 54 VAM/coal mine methane driven internal combustion engines to power generators that produced 55.6 MW of electricity for the mine. Using ventilation exhaust as combustion air in large utility or industrial boilers has also been demonstrated on a pilot scale at the Vales Point Power Station in Australia. However, using VAM for combustion air is limited by geographic constraints: the facility must be sited near the mine.

Another approach to using VAM as a supplemental fuel involves an innovative rotary kiln system that burns waste coal with ventilation air methane or drained coal mine methane. The mixed fuel is combusted in the kiln, and the exhaust gases pass through a specially designed air-to-air heat exchanger. The heated clean air powers a turbine to produce electricity. The waste coal feed can be adjusted in response to variations in VAM flow or concentration, allowing for a constant energy feed to the turbine for electricity generation. By combusting waste coal and VAM, this technology offers the ability to mitigate methane emissions while also reducing acid runoff from (and spontaneous combustion of) waste coal piles. The technology was developed jointly by Australia's CSIRO and Liquatech Turbine Company Pty., and a 1.2 MW pilot plant was constructed at CSIRO's Queensland Centre for Advanced Technologies. EESTech Inc. acquired the rights to the technology and is standardizing designs for 10 MW and 30 MW systems while actively commercializing the technology in China and India. Because it avoids the water requirements of steam-cycle power generation, the hybrid coal and gas turbine is appropriate for remote locations where waste coal and methane are available but water is scarce.

Although not a direct use of VAM, advancements in concentrating or enriching VAM to increase the methane concentration are advancing. The Australian Coal

Association Research Program (ACARP) and CSIRO have developed the VAMCAP™, an enrichment technology that uses CSIRO-developed carbon composite adsorbents to capture and concentrate VAM into higher concentration levels. Through the ACARP project, the VAMCAP prototype was capable of enriching 0.30%, 0.60% and 0.98% VAM up to an average methane concentration of 3.49%, 6.09% and 9.46% respectively by one-step adsorption, and up to 19.28%, 24.24% and 36.92% methane respectively by two-step adsorption. This technology would have significant implications for VAM use, since there are more end-use options for higher-concentration VAM than typical drained gas.

For More Information...

To obtain more information about emerging VAM mitigation technologies, contact:

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Contact EPA's Coalbed Methane Outreach Program for more information about this and other profitable uses for coal mine methane:

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