Changing the Face of Mine Ventilation

Advances in smart controls, sensors and IoT-enabled devices are providing new tools for miners tackling the ever-increasing challenge of ventilating their underground operations

By Carly Leonida, European Editor

The ventilation control room at Boliden's Garpenberg mine. (Photo: ABB)

Ventilation systems are the largest consumers of power in underground mines, accounting for upward of 50% of energy use.

Saving on energy costs and ensuring personnel receive clean air where and when they need it is now a business imperative for mine operators, who are employing a new generation of smart digital technologies to monitor and optimize ventilation systems and ensure a safe working environment.

While digital tools are relatively new to the mining industry, the key components of mine ventilation systems have not changed significantly in the past 20-30 years, and their primary role remains unchanged: to remove build-up of harmful gases and contaminants from underground workings, and to provide and circulate a source of clean, breathable air to miners working deep underground.

"The ventilation system, as a primary system, is very similar to what you would find 20-30 years ago," said Kim Trapani, a ventilation engineer with Stantec based in Sudbury, Ontario. "That is, you still have large fans, usually on surface, driving the ventilation system underground.

"The main change has been the introduction of automation and control, which is the biggest driver for innovation. This has allowed ventilation on demand (VOD) to be implemented which can control of the speed of the main and secondary fans, and automated, regulated louvers/doors underground. The ventilation can be controlled through real-time monitoring of sensors underground, tags which detect equipment and worker movement, and also programmed events such as blast clearance ventilation, or emergency ventilation."

Prior to the use of digital communications networks, all ventilation adjustments were made manually with data from ventilation surveys, and often this led to the over or under ventilation of certain areas due to changes in production rate, doors that had changed position without feedback, or level breakthroughs. Adjusting the airflow rate on each level was done by adding or removing timbers at the return air raise.

Today, thanks to the advent of the Internet of Things (IoT), data can now flow freely back and forth from the inner workings of a mine to the surface control room, and the use of high-bandwidth networks allow controls to be applied to optimize each mine's ventilation system.

The use of IoT- enabled devices has also reduced the cost and complexity of both measuring and controlling applications in ventilation, as they can plug directly into any network switch on an underground communication network.

With digitalization, all components that move, direct and demand air can be connected and communicate. The analysis of real-time data from air quality monitoring, mining equipment locations and emissions allows a deeper understanding of workplace conditions so that informed decisions can be made for necessary adjustments and improvements. Digitalization allows mines to make predictions, increase their efficiency and reduce risk. From a transparency perspective, employees can also understand the state of their environment at all times.

Canada Leads the Way

"The biggest drivers for innovation in the past 20-30 years are, first and foremost, our ongoing efforts to improve worker health and safety," said Cheryl Allen, manager, ventilation and technical support for Vale. "In addition, reductions in the allowable occupational exposure limits, the cost of energy and environmental responsibility have been key drivers for continuous improvement. With the digital transformation currently occurring in our mines and the industry more broadly, it's a very exciting time as we explore solutions that we never would have imagined even 10 years ago."

Allen will be presenting at AusIMM's Mine Vent conference in Perth, Australia, later this year as one of the keynote speakers.

"I am honored to have been asked to be a keynote speaker at the conference and look forward to seeing discussion on topics such as: application of technology, mine design case studies that consider challenges and solutions, current research happening in Australia, methods of controlling airborne hazards in underground mines and safety initiatives," she told *E&MJ*.

"I am still developing my talk, but I'm planning to cover some of the exciting initiatives we are working on in our North Atlantic Mines which span across Manitoba, Ontario and Newfoundland/Labrador, as well as our approach to integrating new technology within our mines into ventilation design."

Canada, and specifically the Sudbury basin where both Allen and Trapani are based, is home to some of the world's deep-

est mines. The area has proved a hotbed for technological mine developments in recent years, especially in the field of ventilation.

Maestro Digital Mine, which specializes in providing mines with digital ventilation control solutions, also calls Sudbury home. Michael Gribbons, vice president sales and marketing, explained the area's draw.

"The Sudbury Basin has been a test ground for advanced mine ventilation concepts due to significant government-backed funding since 2010," he said. "This C$8.5 million ventilation project was made possible by a C$4.25 million contribution from the federal government's Community Adjustment Fund, and a matching amount was funded by Vale and Xstrata Nickel (now Glencore).

"The goal was to reduce the energy footprint of two mines by controlling the amount of air to different locations based upon the current requirements, instead of sending the same amount to all areas.

A view over Vale's Coppercliff nickel mine in Sudbury, Canada. The Sudbury area has become a hotbed for mine technology development in recent years. (Photo: Vale Agency)

One of Maestro's air quality monitoring systems in action. (Photo: Maestro Digital Mine)

The project ultimately provided data to support ventilation controls at many of the mines within the basin."

These mines were getting deeper and hotter, so the energy intensity required to ventilate them increased rapidly, and this made ventilation an important factor in mine sustainability.

"In fact, some of the projects were not economically feasible due to the ventilation requirements," Gribbons added.

"Maestro Digital Mine participated in this program, and quickly understood both the benefits and challenges around controlling ventilation in an underground mine.

"Environmental sensors needed to be both accurate and repeatable in order to take advantage of automatically controlling the ventilation. However, at the time, all the sensors on the market were designed for use in surface applications and not meant for measurement at depth. Our research concluded that many of the sensors were highly inaccurate, and some didn't even work in the high-heat and high-pressure applications seen underground.

"Maestro then developed digital sensors that were accurate, repeatable and economical for underground mining applications. They compensate for changes in barometric pressure and temperature to assure accuracy at all levels in the mine. Since the sensors are all digital, additional information could then be logged and retrieved enabling advanced diagnostic functions and early predictive analysis. We also learned that the older legacy analog sensors required a programmable logic controller (PLC) in place to get the data back to surface."

Maestro's Vigilante AQS air quality station was born out of this research. The system eliminates the requirement for an expensive and complex PLC.

"As a result of our research and product development, Maestro Digital Mine has provided ventilation solutions to over 128 mines globally," Gribbons added proudly.

Indeed, Maestro's systems manage air requirements at many of the world's deepest and most technologically advanced mines, including: Goldcorp's Borden and Hoyle Pond mines; Agnico Eagle's Goldex mine; McEwen's Black Fox mine; Glencore's Onaping Depth and Raglan operations; and Rio Tinto's Resolution mine. Maestro's systems also measure conditions in many Vale mines and have the capability to transmit data to be used by Vale's ventilation control systems. International projects include two MATSA mines in Spain, Randgold's Kibali mine, De Beer's Venetia mine and Rio Tinto's Oyu Tolgoi.

"Along with these high-profile projects, we continue to supply equipment to all of Barrick and Newmont's mines in Nevada, and every potash mine in Saskatchewan," added Gribbons.

The company launched its newest IoT-enabled product, the Zephyr AQS air quality station at the CIM conference that was held in Montreal at the start of May.

"Whereas the Vigilante AQS will handle 100% of mine ventilation applications, this comes with an added cost," Gribbons explained. "The Zephyr AQS was made to satisfy 80% of all the air monitoring requirements of a modern mine. Airflow rate, airflow direction, gas levels, barometric pressure and wet/dry bulb temperatures can be measured in real time and now affordably."

The company has already pre-sold 100 units to three existing hard-rock mining customers in Canada, the US and Spain.

The digitalization of mine ventilation controls means that mine employees can understand the state of their environment at all times. (Photo: Vale)

Deeper Innovation

Increasing depths are one of the main challenges that miners are facing when ventilating their operations today.

"At Creighton mine in Sudbury, we are currently developing 8,300 ft underground with plans to go deeper," Allen said. "As we expand deeper, we must create designs that can provide air to the new mining areas. This air must provide a climate where employees can safely and comfortably work. All of this must be done using existing raises and fans as much as possible, supplementing with new raises and/or fans only when necessary to minimize the large capital costs associated with new infrastructure. We must always be respectful of our surrounding communities as well to keep noise levels low and emissions clean."

Allen explained that these challenges have also led to opportunities, and Vale is investigating applications where low-emission vehicles can replace diesel-powered vehicles to reduce heat, gases and diesel particulate. These, in turn, have the potential to reduce the air volumes required otherwise.

"Technology that can automatically support the efficient use and management of the air (i.e. VOD) is another opportunity available to us," Allen said. "We have already installed VOD at some of our mines, with plans to expand to all of our mines in the coming years."

She added that the ability to monitor contaminants such as silica and diesel particulate in real-time will also be beneficial, as will wireless communication technology that is cost efficient and easily brought to the workplace.

Reliable communication is the backbone of many technologies underground, including autonomous mining systems that reduce worker exposure to heat and lower ventilation requirements. Equipment designs that assist the worker and remove manual tasks also reduce exposure to heat stress.

Dedusting and Coal Mining

Ventilation is especially important in coal mines which generate high concentrations of dust and are susceptible to build ups of methane gas.

German vendor, CFT, specialises in ventilation and dedusting solutions. Markus Thomeczek, Executive Vice President – Sales, explained the risks: "The explosive methane gas and dangerous coal dust which are released by coal mining can be found in the whole mine area. An increased concentration of these two components can lead to an explosive mixture," he said.

"The consequences of methane fire damp in mining are devastating. The effect can be multiplied by the presence of coal dust which is ignited by sparks or hot surfaces in combination with the methane gas.

"The danger of coal dust explosions is that the explosion spreads throughout the whole mine until the mine is completely destroyed. However, most of these mine disasters and casualties as well as production losses can be prevented successfully thanks to clean air technologies, especially dedusting and ventilation."

Another application of CFT dedusting plants is in combatting industrial diseases such as black lung.

"The incidence of black lung, which requires a legal compensation payment in Europe, could be reduced with modern de-dusting applications," Thomeczek said. "However, this industrial disease is still a key topic in underground mining worldwide.

"Besides the health problems associated with black lung, this lung disease is also a high economic risk for mining nations; in 1953, after black lung was accepted as an industrial disease, coal production costs rose more than 10% due to compensative retirement payments in Germany.

"In the following decades and, thanks to newly developed de-dusting technologies, there was a successive reduction of acceptable dust limits in order to combat black lung diseases," Thomeczek said.

Dedusting equipment is just one area of CFT's portfolio, the company also offers semi-mobile, container-based ventilation solutions for mines, and also cooling and heating systems — both permanent and temporary.

Thomeczek explained: "These solutions are used for medium-term applications and can be moved easily after finishing the project. For example, we recently delivered an integrated ventilation, heating and cooling system for the Slavkali shaft sinking project in Belarus."

In 2019, CFT is also delivering four containerized ventilation systems, two with integrated cooling and two dust collection systems for the Woodsmith polyhalite mine in the UK. These are for use in shaft sinking ventilation and for use with Herrenknecht shaft boring machines.

In addition to designing for electric and battery-powered mobile equipment, the team at Vale is working on a couple of projects to expand the use of natural cooling systems by taking advantage of Canadian winters, as well as installing automated ventilation control systems to maximize the efficiency of air distribution underground. This is made possible by building on the digital project of LTE (a 4G mobile communications standard) for wireless communication.

Allen adds that Vale has a few mine development projects where ventilation is a significant component. One of these is a current study where two mining companies are working together to mine a deep orebody that has a shared boundary between the two operations.

"It will have a challenging ventilation design that will require alignment on criteria for the design, which sets the foundation for key decisions," she added.

Natural Heating and Cooling

Stantec's Kim Trapani has also been researching the heating and cooling of mines in sub-arctic climates using an ice stope storage system. The project was the subject of her paper given at the North American Ventilation Symposium in Montreal in late April.

"The system uses a mined-out stope or opening close to the mine surface through which the surface ambient air passes before going underground," she explains. "In winter, when the air goes through this opening, return service water (which is relatively warm) is sprayed onto the freezing cold air. This results in the water freezing and depositing as ice in the opening, and the air warming up to be used underground. In the summer this ice is melted, again by spraying.

"The service water, and the chilled water from the melted ice, is gathered and sprayed in another chamber onto the incoming air to cool it before transfer underground (similar to a regular bulk air-cooler used for cooling ventilation air with the water coming from a chiller).

"A techno-economic study for such a system shows that it is often less expensive to implement than a conventional system."

Stantec also has a number of other ventilation projects underway, including developing the ventilation plan and infrastructure for the Kakula project in the Congo which has a significant ventilation and refrigeration infrastructure component.

"A lot more operators are choosing to implement smart ventilation infrastructure," Trapani adds. "This is primarily to allow them to monitor the conditions underground. There are also significant cost savings from reduced ventilation that can be gained from implementing VOD. The level of savings will depend on the mine's design and operation."

Another company with an interest in VOD is vendor ABB. VOD plays a large role in the company's Ability package of digital solutions. The system employs a series of sensors throughout the mine that transmit real-time information regarding air quality, diesel-vehicle use and personnel to an Ability System 800xA operator for analysis.

"VOD is a relatively new innovation, and the idea is to more efficiently distribute air where it is needed by only ventilating when and where people or machines are working," explained Jan Nyqvist, ABB Product Manager for Automation Under-

ground Mining. "There is no need to ventilate the entire mine because production may only be concentrated in, say, 20% of the facility at any one time.

"By controlling mine ventilation in this way, annual energy savings of up to 50% are possible."

The Ability package also includes Ventilation Optimizer, a complete mine ventilation control solution that operates equipment according to actual ventilation demands. These are dynamically calculated from mine production schedules and events, and event equipment status and location, ensuring optimum performance.

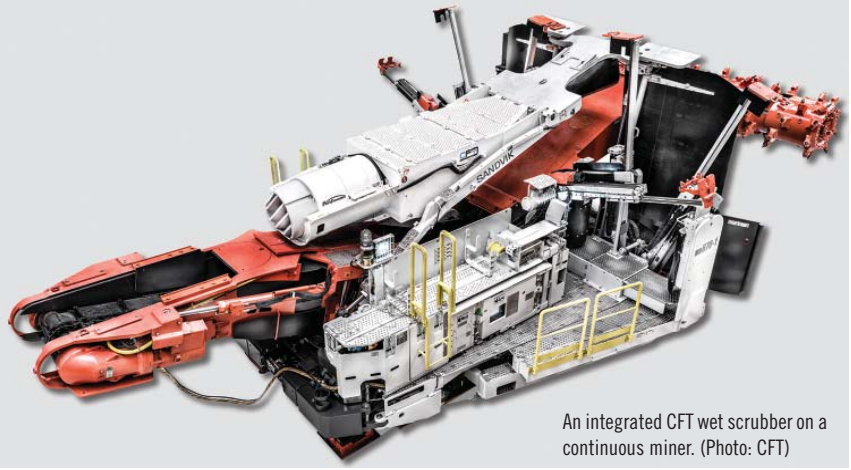
"There are three levels to ABB Ability Ventilation Optimizer," says Nyqvist. "The first involves basic control, such as remotely starting and stopping equipment from the control room, meaning personnel do not have to venture into hundreds of kilometers of underground tunnels to start a fan.

"The second level is the VOD functionality and finally, in level three, we employ an algorithm, sensor feedback and advanced multivariable control technology to run all the fans in optimal operational mode, distributing the air supply more efficiently and minimizing energy consumption in real time."

A CFT dry deduster for underground mining. (Photo: CFT)

The implementation of Ventilation Optimizer at the Garpenberg mine in Sweden meant that energy consumption by fans fell by approximately 600 kW. This equated to a 40% reduction in energy costs for the owner Boliden.

"Using ABB Ability Ventilation Optimizer level 3 with model-based control, we are able to run the ventilation system at Garpenberg completely automatically, or autonomously," said Nyqvist. "Using feedback control from sensors, we can update the operational set points on the system every 15 seconds, meaning that



An integrated CFT wet scrubber on a continuous miner. (Photo: CFT)

we are continually running the system in an optimal way."

Digital Optimization

ABB has been using digital twins — digital replicas of physical assets such as fans — in its ventilation systems for a decade now but has taken the concept to a new level with Ventilation Optimizer.

"As part of level 3, we apply a more model-based algorithm to control all the fans underground, using a patented optimizer method. This creates a digital model of the ventilation system that is then able to control all fans in an optimized way," Nyqvist said. "In the future, we hope to develop low-cost IoT sensors for fire scenarios or toxic source detection that will make the system even smarter."

In ventilation, digital twins take the form of a model that replicates (if calibrated properly) the ventilation operating parameters underground. These models also have the ability to input real-time data from sensors underground to provide an updated ventilation model of the underground mine.

"Mines have used ventilation modelling software for decades, but the new twist is to tie the model with live sensors and find ways to optimize the ventilation," Gribbons said.

"The challenge to this thinking is around the mine being a dynamic model. There is a continuous trade off for seeking optimal ventilation versus optimal production rates, and there is a constant effort required to maintain and advance a ventilation control system in an underground mine. This remains one of the challenges in advancing digital twins or VOD."

Enter Electrification

CO_2, dust, humidity and toxic gases such as methane all constitute air-quality concerns for mining companies, but it is still chiefly nitrogen dioxide emissions from diesel vehicles that drives the need for ventilation systems in underground mines. However, increased electrification could change that.

"Increased electrification in mines, particularly the transition to electric vehicles, will get rid of many diesel machines, which will help air quality a lot, but there will still be a need for ventilation systems in mines to keep them free from dust," Nyqvist said. "Also, as mines go deeper, we need to regulate temperature. Some mines today have a temperature of 35°C, meaning that a lot of air is still required to maintain a healthy working environment."

With the improvement in the capabilities of next-generation batteries, there has been a huge increase in interest surrounding electric vehicles and the benefits that electric fleets can deliver for underground mines.

"Electric fleets will be a great benefit to reduce emissions of gas, diesel particulate and heat, which will have tremendous benefits in terms of the health and safety of our people," Allen said. "The use of electric machinery will also change the criteria of ventilation design in comparison to that of diesel equipment."

Ventilation systems typically consume 50%-70% of the energy used by a mine site. The use of electric equipment offers the potential to employ smaller raises and fans which reduces mine capital costs, a reduction in operating costs through lower demands on ventilation systems, and less refrigeration and heating, all of which lead to a smaller environmental footprint.

"Without electric vehicles some orebodies are not economically feasible to mine due to the energy intensity required to ventilate the workings," Gribbons explained. "Kirkland Lake Gold's Macassa mine and Glencore's Onaping Depth are two excellent examples of the economic reason to use much more expensive electric vehicles instead of a conventional diesel fleet."

German manufacturer, SMT Scharf, was one of a number of companies that introduced battery-electric mine vehicles at the bauma 2019 tradeshow in Munich in April.

Scharf's new E-Cruiser is available in various body variants from pick-up to station wagon, with a 1-metric ton (mt) payload and all-wheel drive capabilities. The larger of two available batteries allows a range of 120 km and can be recharged in just two hours.

"The underground test of several units shows that the range is sufficient for a complete shift, and that charging can take place during the shift change," said Jens Steinberg, director of sales and marketing at SMT Scharf.

While enthusiastic about the new product, Steinberg is realistic about the impact of electrification on mine ventilation. "The electrification of fleets or improvement of mine ventilation is certainly not an end to itself," he said. "Mine operators will need to implement both measures to achieve the primary goal, which is to minimize employee exposure to exhaust gases, and to reduce overall CO_2 emissions from their operations."

With modern lithium-ion chemistries and the use of integrated battery management systems, off-gassing is no longer an issue with next-generation batteries, as was the case with older lead-acid formulations.

"Local regulations for the ventilation of mines prescribe certain amounts of fresh air per kilowatt of diesel power which, in principle, are no longer required for electric vehicles," Steinberg explained. "Especially in deeper mines, ventilation must not only ensure that the exhaust gases are purified, but also that

the mine is cooled down to acceptable working conditions. Here, electric vehicles have another advantage to offer, as they produce much less waste heat than a diesel vehicle due to the much higher overall efficiency of the drive train.

"When driving downhill on ramps with an electric vehicle, the braking energy is electrically fed back into the battery instead of being converted into heat by the brakes or the engine, as is the case with a diesel vehicle. This results in a further relief of the mine ventilation system."

Steinberg expects that, in the future, we will see a combination of different alternative powertrains used underground. "It will very much depend on the local conditions of the mine and on the requirements of the machine as to which type of propulsion achieves the best performance with minimum emissions," he said.

"Our various battery-electric LHDs up to 11-mt payload and matching haul trucks operate very efficiently — several units already for eight years. If more power is required for larger payloads, a diesel-electric hybrid variant, or electric drives with a cable or overhead conductor will probably be used initially. As soon as new battery technologies enable higher energy content and shorter charging times, battery-electric drives will be able to succeed, even with high power requirements."

Reducing Energy Intensity

There is no avoiding the fact that the energy intensity of mines is increasing due to several factors: firstly, mines are getting deeper and, as a result, require more energy to circulate the air (increased pressure drop, and increased air density requires more power to circulate the air). Secondly, as mines increase their depth, the rock temperature increases the temperature of the ventilation air.

As a result, many deep mines now require the pre-chilling of air which is a significant drain on energy costs. In colder climates, the air may also need to be heated in winter months to allow miners to work in a comfortable temperature range.

"There will be some relief in the energy intensity of mines when full electrification takes place," Gribbons said. "Electric motors are far more efficient than internal combustion motors so the heat that is given off is less and there are no noxious gas emissions to deal with. As a result, less ventilation will be required in these types of mines. At the moment, we are at the start of this cycle since electric mobile vehicles are much more expensive than diesel vehicles.

"It may take another 20 years to fully change the current fleet of equipment, but for those that can afford this technology, it will reduce their demand on ventilation and energy."

Ensuring adequate ventilation at the mine face is another omnipresent challenge.

"By appropriately designing and maintaining the auxiliary ventilation system this could be mitigated," Trapani said. She added that an exhausting ventilation system, with the air being exhausted from the face rather then pushed towards it is one way of tackling high temperatures as this limits exposure of the air to heat sources. However, when the heat is too high, such a preventive measure would not be sufficient and some type of cooling would be required.

Gribbons hits the nail on the head when it comes to implementing mine ventilation solutions.

"Many of these challenges revolve around budget and integration time," he explained. "Clients are looking for solutions that can be integrated quickly, with a quick return on investment (ROI) and low CAPEX spend."

He explained that integrating a simple mine monitoring system, for example, one that enables miners to return to the face more quickly and safely after blasting, is relatively easy and inexpensive.

"Projects such optimizing re-entry time based upon blast clearance typically have an ROI of 1-4 weeks which is a great starting point," he said. "However, integrating ventilation control and monitoring requires a much higher CAPEX spend which, in turn, will slow the process due to the requirement for multiple approvals from mine management, and sometimes even the board.

"Ventilation doors and air regulators need to be installed in order to control the airflow at each level, and these can take months to deliver and install in an underground mine," he said.

"Next, the client will have to select either a mine-made human-machine interface (HMI) solution or a ventilation control package from a software supplier, so this type of [advanced monitoring] solution is normally only attempted by operations with a long life of mine, and a rich, deep orebody."

SMT Scharf's new E-Cruiser. Fleet electrification will help to significantly reduce the energy intensity of underground mines in the coming years. (Photo: SMT Scharf)

The short of the long is that there are no quick (or cheap) fixes when it comes to ventilating a mine. And every underground operation, no matter how big or small, will face these challenges in the future. However, there are some innovative solutions available to help overcome the situations outlined above and, with some clever planning as early as possible in the mine design process, both operating and capital costs for ventilation can be kept to a minimum.