REAL-TIME AIR QUALITY MONITORING: CHALLENGES AND CONSIDERATIONS

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ABSTRACT

The ability to continuously monitor the air quality within a mine has become instrumental in becoming a low cost producer. The many considerations involved in monitoring air quality include sensor type, hardware placement, as well as data storage medium. BESTECH has had the opportunity to gain insight into these air quality monitoring considerations through deployments of NRG1-ECO™, a mine-wide energy consumption optimization system. This paper explores the particular challenges overcome through these installations, and provides a set of guidelines for mines that want to maximize data capture while minimizing costs. It provides a view of additional benefits of air quality monitoring, such as ventilation control, reporting and trending.

KEYWORDS

Environmental Sensors, Air Quality, Data Collection, Energy Management

INTRODUCTION

The mining industry has always faced many challenges related to ventilation and air quality. Ventilation infrastructure is capital cost intensive and operating costs can be quite high. Mine ventilation models can be created, simulating air quantity and quality conditions; however, without real-time air quality information, only a part of the picture is provided. As sensor technology has advanced and costs have decreased, mines have increasingly been deploying sensors in strategic areas to monitor real-time air quality conditions in an effort to enhance worker safety, achieve ventilation optimization, and lower operating costs.

BESTECH, a Canadian firm that specializes in the areas of engineering, automation, software development and environmental monitoring, has developed a mine-wide energy consumption optimization system, NRG1-ECO, which employs multiple complimentary control strategies in order to achieve energy savings, increased productivity and improved worker safety. It also offers AQM or Air Quality Monitoring, a complete hardware and software solution for 24/7 surface environmental monitoring. This system monitors and logs the level gases and particulates in the ambient air, and presents the data via a centralized server to the user’s browser.

As part of NRG1-ECO, an environmental control strategy was developed. This strategy provides a means of automatically adjusting ventilation equipment based on changing environmental conditions. Fans and louvers are adjusted according to real-time data such as airflow, temperature, and contaminant concentrations.

Combined, these systems have provided considerable experience in the use of different sensor technologies. This paper explores the many considerations involved in selecting, deploying and maintaining sensors in underground mines. It provides information on selecting a data collection and storage medium, how it can be best presented to an end user, and how air quality sensors have been used to optimize mine energy consumption.

SENSOR CONSIDERATIONS

Through the multiple deployments of NRG1-ECO, experience has been gained into the use of a wide variety of sensor types and technologies from a variety of large and small companies including Accutron Instruments Inc., Armstrong Monitoring, Dräger, Endress & Hauser, Maestro Mine Ventilation,
Meglab Inc., Mine Safety Appliances (MSA), Scott Safety, as well as Vaisala. The numerous types of sensors that have been deployed include airflow, CO, NO, NO₂, NOx, temperature, barometric pressure, relative humidity, differential pressure sensors, amongst others. The considerations involved for each type of sensor is subsequently examined.

These sensors have been utilized in systems as part of an environmental control strategy in underground mines, controlling fans and louvers in order to optimize the energy costs associated with mine ventilation. In this scheme, environmental variables, such as gas concentrations and temperature, are continually monitored. If these values cross a given threshold, the airflow process variable is increased in consequence via a PID (proportional, integral, derivative) loop. When more airflow is required, fans are ramped up (or started) and/or louvers are opened in order to meet both required demands and environmental regulations. If less airflow is required, the fans are ramped down and/or louvers are closed.

The following sections introduce and discuss some of the more common sensors used. Not included but part of some NRG1-ECO installations are differential pressure measurement and fan vibration.

**Airflow Sensors**

Airflow sensors in mining environments typically come in two types: single-point and time-of-flight. One common design for single-point anemometers is mechanical vane. It consists of a propeller which is turned by the airflow in the drift and internally calculates the airflow at a given point. However, airflow in a drift is rarely consistent throughout a single cross-section of the drift. These types of sensors are susceptible to eddy currents and swirls in the airflow. To control costs, such systems as NRG1-ECO, rely on airflow monitoring in order to optimize ventilation and as such, require a greater deal of accuracy. For these reasons, to determine the flow in main airways, time-of-flight airflow sensors have been exclusively used. These sensors require two ultrasonic airflow sensors which are directed at one another. They do not have any moving parts and do not require periodic cleaning. In their setup, one sensor is placed upstream from the other across the drift in such a way that when acoustic pulses are directed at one another, the difference in time between the reception of acoustic pulses can be measured, providing a means of calculating the average velocity across the path and thereby a true volume. Identical times-of-flight between the two targets indicate a lack of airflow. The sensors are initially calibrated with the drift dimensions, which gives the sensors the information necessary to calculate the airflow. These types of sensors have the maximum fidelity when placed in a straight uniform drift free from eddy currents caused by rock cavities, junctions and variations in the rock surface. Placing sensors near bends, close to fan discharges or regulators is also discouraged for non-uniform flow conditions. It is typically recommended to perform monthly calibrations on these types of sensors in order to ensure accurate readings, however it is not uncommon for these units to read higher than conventional anemometry traverses due to the latter being more biased to the central higher flow region. In practice, calibrations are done on a priority basis with main drifts being calibrated more frequently than secondary blocks. Ideally, the calibrations should be done with a detailed multi-point traverse, and the more routine anemometer measurements used to check sensor performance and highlight any anomalous variance. Airflow sensor coverage depends on the mine, but in our typical deployments, the main ventilation circuits are monitored as well as the area near the fresh air and return air raises in order to determine the amount of airflow utilized throughout the mine.

Single-point sensors are generally less expensive than time-of-flight sensors and can be used where the velocity profile can be guaranteed and any calibration correction (for point versus area) is consistent throughout its operational range, or where the measurement is less critical. One such application would be in the more confined spaces of ducts where time-of-flight sensors are not appropriate. However it should be noted, that some of these units, those based upon thermal principles, are air density dependant and would need to be compensated for non-standard atmospheres in deep mines.

**Gas and Particulate Sensors**
Depending on the type of environmental contaminants, gas or particulate sensors can be installed in order to measure the concentration of gases produced by blasts and diesel vehicles. To date, AQM and NRG1-ECO installations have included CO, CO₂, NO, NO₂, NOₓ, SO₂ sensors.

Gas sensors are being used as a part of the NRG1-ECO’s environmental control strategy. They help ensure worker safety while maximizing ventilation energy efficiency. If a gas concentration is detected above a certain threshold, the airflow through the given area is increased in order to expel the gas. In active working headings, sometimes a lack of ventilation can allow gases to pocket in areas that will not be monitored directly by the sensors. For this reason, occasional purges can be initiated in order to ensure that otherwise undetected gases are not allowed to accumulate. It is generally recommended that these gas sensors be calibrated twice a year in order to ensure accuracy, but it is also advised that the frequency be increased for key monitoring areas.

In terms of their function, CO₂, CO, NO and NOₓ monitors can show diesel activity to the point where the movement and timing of individual vehicles in and out of an area is clearly evident during in-shift activity. NO₂ and SO₂ are less informative due to their lower ambient levels in relation to the accuracy, sensitivity and resolution of the sensors. All the gas sensors, except for SO₂, to varying degrees will show blast activity, especially between shifts when the concentrations are well in excess of exposure limits. The monitoring of SO₂ underground is typically only warranted when there is a risk of a sulphide dust explosion, or significant oxidation of sulphide ores, that would impact the re-entry of personnel. However, SO₂ sensors can be an integral part of surface emissions monitoring from processing plants.

Particulate sensors, are currently only part of our surface based AQM environmental stations. The BAM-1020 by Met One Instruments, Inc. uses filter tape to measure the mass of particulates suspended in air. For every measurement taken, the filter tape is advanced and a new measured amount of outside air is pulled through the section of filter tape. The sensor then measures the amount of particulate on the section of tape in order to get a reading. These sensors are also self-calibrating. Every hour, a zero reading is taken where no air is pulled in order to calibrate the sensor. To date, no continuous monitoring of dust or diesel particulate matter has been included in any of our underground installations.

The AQM product has been mainly deployed in areas where legislation has required a constant monitoring of the ambient air. Stations are installed in strategic areas in or around a mine or source of contaminants. In surface applications, gas and particulate concentrations are collected and monitored 24/7 by operators and production is either increased or decreased depending on the wind direction and quality of air surrounding populated areas. The calibration of these sensors is therefore extremely important. Automated daily bump tests are done by injecting a known concentration of gas into the sensor and calibrating it in consequence. These sensors, although they are self-calibrating, require occasional maintenance, such as replacement of gas canisters used for bump tests.

While gas and particulate sensors have historically been used for to provide an alarm, to enhance worker safety, ensure public safety and compliance with legislative requirements, their main function has been retroactive rather than being proactive. Today’s sensors, as being installed in mines include PID loops and PLCs that can manage airflow distribution to potentially reduce a mine’s operating costs.

**Environmental Sensors**

The selection of environmental sensors again depends on the application. The most common inclusions in AQM deployments are ambient temperature, relative humidity and barometric pressure.

Temperature sensors for industrial applications are sold by a wide variety of manufacturers. In areas of extreme heat or cold, they can be used to modulate heating and cooling equipment in order to ensure outside air intake will not damage infrastructure or affect worker safety. They are also used to monitor equipment health. For example, fan bearings can be monitored for overheating with interlocks that stop the fan in order to protect it.
Similarly, relative humidity and barometric pressure sensors for industrial environments are again sold by a wide variety of manufacturers who supply similar products. Here, the selection of a specific manufacturer is more related to customer preference than to performance.

Early installations in underground mines only considered ambient temperature (dry bulb) sensors for inclusion in NRG1-ECO’s environmental strategy as a decision point to modulate airflow to a workplace for heat management. However, unless sources of cooling were present the energy savings were limited. This is because it is difficult to significantly affect the temperature of the air entering an area that is more dictated by the surface environment, the depth to which the air descends, and rock temperatures. However, in the workplace local ambient temperature conditions are affected by local heat sources, such as auxiliary fans and mobile equipment, and the use and/or presence of water. Here, it has become necessary to use sensors which quantify and aggregate a combination of measurements, namely ambient temperature, relative humidity and barometric pressure. Together these can provide a wet bulb temperature, an indication of the evaporative cooling potential and provide the ability to control ventilation via heat-stress index. This allows for a more accurate assessment of worker safety in areas of higher temperature and humidity and an increase of the delivery of fans and air velocity in the area if required.

**Technological Shifts**

Today, technology is commonly applied in various aspects of mining operations and as a result, the price of technology is constantly decreasing. Manufacturers are therefore incorporating more and more technology into their sensors, as opposed to providing them as options or add-ons. The “smart” calibration capacities of gas sensors would be one example that is becoming a norm, others being introduced would be the determination of a wet bulb temperature mentioned above, as would including air density compensation where applicable.

Sensors typically functioned via a single analog 4-20mA electrical signal. These sensors were usually configurable by means of the HART communication protocol. In order to configure or perform diagnostics on a sensor, the device must be directly connected to the equipment by a HART modem. The communication is realized through a digital signal which is generated by creating slight sinusoidal variations in the analog process variable signal. Due to its sinusoidal qualities, the process variable is not affected by these variations. Without this physical connection to the device, sensor configuration and diagnostics cannot be performed. Increasingly, digital sensors are replacing analog sensors in industrial settings. Utilizing internet-based protocols, web interfaces are substituting HART modems for configuration and diagnostics, allowing for remote configuration and monitoring of sensors. As an example, a digital airflow sensor allows the configuration of the sensor’s IP address, the drift dimensions between the sensors, the output units, etc. remotely via a web interface. Additionally, more information can be retrieved from sensors than simply the process variable; communication status and device failure status can be queried via the control network, providing a basis for alarms and interlocks.

Communication technology is progressively being bundled with sensors. In the past, communication modules for sensors could be purchased separately. As the price of these modules has decreased, it is not uncommon to see sensors that support multiple communication protocols without the need to purchase and install a separate communication module.

Furthermore, sensor probes have become more interchangeable. This is becoming a standard for electrochemical gas sensors. Such functionality also allows probes to be easily replaced in the case of failure, or changed to a different type of probe in the case that a different measurement is required. These probes can now serve multiple functions, such as probes that measure multiple environmental parameters.

Evidently, sensor technology has become more accessible and configurable, and has made tremendous progress in terms of ease of installation and diagnostics.
Sensors for Real-time Control

Once sensor real-time values are available for given levels or blocks within a mine, some interesting possibilities emerge. One such possibility is the ability to control devices using the sensor information. The operator sets a setpoint for an environmental sensor value and the fans/louvers are adjusted in consequence when that setpoint is reached.

Figure 1 shows an example of a discrete fan reacting to a spike in CO concentration. As the graph shows, the fan is initially stopped. The setpoint for the CO was set by an operator as 10ppm. This means that any CO concentration above 10ppm would cause the fan to start. Since the CO concentration could hover around the setpoint, the PLC has a configurable delay before starting the fan. The CO concentration must be consistently above the setpoint for the fan to start. This policy avoids unneeded wear on the fan and the starter. The same delay is applied when stopping the fan. In this way any transition between running states is warranted.

Figure 1 - Discrete Fan Reaction to CO Spike

Figure 2 shows a CO spike with a VFD fan. VFD fans have the luxury of being able to slowly increase the fan setpoint in order to meet demand. For this reason, the reaction to an increase in CO is more subtle. A PID loop is used in order to have the fan setpoint increase in response to higher CO concentrations. In this case, the CO setpoint is 5ppm. At the start of the sequence, the CO concentration is below the setpoint and the fan setpoint is below 90%. This indicates that another strategy such as tagging (RFID) is controlling the fan. Once the concentration consistently breaches the setpoint, the environmental strategy takes control and makes the fan setpoint climb to near 100%. Once the CO is cleared, control is released and the fan tracks down to the level set by the tagging strategy.
As you can see, using real-time sensor information for control of devices can be of great value in terms of worker safety. Decisions are made with up-to-date information and limit the potential for mistakes. It also ensures that purges after blasts are done for only the required amount of time. There is no longer a need to estimate the amount of time necessary to clear a pocket of gas, as the PLCs ensure that it is done only as required.

**DATA HISTORIAN**

Air quality data can be collected and stored in a data historian in order to observe and compare long-term trends in air quality. With the popularization of digital sensors, more information can be collected and trended than simply the process variable; therefore, having a record of this information has become more prevalent.

Data historians can be grouped into two main functions: data collection, and data presentation. Some vendors, such as BESTECH, provide both of these functions as an integrated product. There are also companies that provide strictly data collection and some that provide specialized interfaces for data presentation that can work with any data historian.

**Data Collection**

Most data historians provide an OPC (OLE for process control) interface (or client) which communicates to equipment via an OPC server. The time series data can then be compressed in order to remove redundant data or data that is similar within a configured deadband. The data storage medium depends on the historian. Most historians store the data in specially designed compressed binary files which can store a large quantity of historical data in a small amount of space. Relational databases can also be used as data historians, but due to the nature of relational databases, these solutions are not as scalable and require more hard drive space.

Most of NRG1-ECO’s deployments to date, have been at larger sites where an enterprise historian is present to collect all process data in the mine. However, in order to support smaller sites which do not have their own data historian, such systems can include a “light” data historian which stores the data into a database so that it can be used by the software’s built-in reporting user interfaces.

**Interface between Data Collection and Data Presentation**
Some data historians provide built in data presentation tools to display data, using their own proprietary communication technologies. Yet, in order to provide interoperability between historians and presentation technologies from different vendors, specific communication technologies have been created.

OPC-HDA is a group of standards created by the OPC Foundation for communicating historical data. It provides a standard way for presentation layers to retrieve information from data historians. For instance, a specialized application can query the data historian and manipulate the data in specific ways before presenting the information to the user. The advent of this technology has allowed applications to be created for specialized purposes, without the need to integrate with all the various data historian providers.

Some data historians provide a SQL interface in order to allow software developers to query the data stores in a way to which they are accustomed. The SQL interfaces are not standardized across vendors, and thus need to be rewritten for each vendor if support for more than one data historian is required.

Our AQM product is built for scenarios where it is imperative to collect data. They have been deployed in areas where a failure to collect air quality data results in the temporary closure of a plant or fines from government bodies. Consequently, such systems provide the ability to keep data at the source for an indeterminate amount of time in the case of a communication loss, and to later back collect the data to the data store.

**Data Presentation**

Data presentation interfaces have varied uses. They vary from interfaces which take a specified amount of inputs to produce a specialized report, to generic trends which merely display raw data, to user configurable reports where report authors are given the ability to drag and drop certain data onto interfaces and customize how the data is shown.

Data historians were originally criticised for merely providing flat data sources without much intelligence. Increasingly, functions that were previously reserved for relational databases have been added to data historians. Data can be categorized by physical location, type of information and even equipment type. This categorization allows a data presentation layer to take advantage of these features by asking questions such as “How do average temperatures in this part of the mine compare to that part of the mine on a given day?” or “How many times have X sensors failed compared to Y sensors?” As a result, a new level of discoverability is introduced to the data which was not possible previously, except with much more work and at a greater risk of human error.

Systems such as NRG1-ECO can have a specialized reporting interface which displays information like communications up-time, energy savings information, among others key performance indicators. As is the case with our reporting software, the built-in data historian can be used for smaller sites or OSIsoft’s PI system in order to retrieve historical data. Support for OPC-HDA may be added in the future pending customer needs.

The question of which data historian to use is one that depends greatly on the needs of the individual site. An integrated solution that provides both the data historian and the presentation software provides a full-featured option for larger sites which can incur the added expense, whereas a simple data historian with OPC-HDA support and some generic trending at a significantly lower cost may be adequate in other cases.

**CONCLUSION**

In order to set up an air quality monitoring system, many factors need to be considered in the planning phase. Decisions regarding sensor choices, data collection mediums and presentation technology are necessary in order to minimize capital costs while ensuring that required functionality and accuracy are
met. Not all sensors are well suited to mining applications and may not consider such factors as the need for air density compensation.

Sensors range in terms of price, accuracy and functionality. Analog sensors simply provide a process variable and require physical access to configure. Digital sensors provide a rich view of sensor functionality. They are often equipped with a web interface for configuration and some provide built-in support for different communication protocols. Some sensors with even higher accuracy requirements provide daily automated calibrations.

In order to perform real-time control of devices according to environmental conditions, many considerations have to be made. Among them, density of data, wear on ventilation equipment, as well as types of environmental values to be collected need to be considered.

Some enterprise data historians can provide full functionality from data collection and storage, to data organization and presentation. They are typically quite high in cost and are used primarily by larger sites. For smaller sites, a simple data historian that supports OPC-HDA and provides a simple trending interface may be adequate.

Whether using sensors to validate model simulations, improve worker safety or optimize energy usage, potential system integrators must choose the best suited components for accuracy, maintainability, functionality, as well as cost.