

Remote gob gas venthole monitoring and cellular telephone-based real-time data transmission system

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ABSTRACT: Many longwall mines rely on methane drainage to supplement traditional fan-based ventilation systems. However, the surface production facilities for methane drainage systems, including gob gas ventholes, are commonly located in remote locations, sometimes without convenient access to electrical power, and they may be monitored infrequently. The first evidence that a methane drainage system may not be operating efficiently, or not operating at all, can be an increase in methane concentrations at a return air shaft or underground where the workforce is exposed to the risk of a methane explosion. A solar powered, remote gob gas venthole monitoring and cellular telephone-based real-time data transmission system has been developed and successfully field tested by the National Institute for Occupational Safety and Health (NIOSH) to address this problem. With this system, individual methane drainage boreholes can be monitored from the mine office to determine current operational performance parameters, as well as review past data to anticipate maintenance needs and troubleshoot operational problems.

1 INTRODUCTION

The control of methane emissions in the underground workplace has long been a safety problem facing the coal mining industry. Fan-based mine ventilation systems using dilution as a means to keep methane concentrations below maximum statutory levels have long been the primary method for methane control in underground coal mines. However, with the mining of deeper and gassier coalbeds, and the increased use of higher productivity advanced mining technologies, it becomes more difficult to adequately control increasingly higher methane emissions with ventilation alone. As mine ventilation systems generally reached their maximum practical potential, methane control technologies were developed to capture and exhaust methane contained in the mined coalbed before it could enter the underground environment, where it would then have to be diluted with ventilation air (Diamond 1994).

The control of methane associated with longwall mining is a particular challenge because not only does the gas present in the mined coalbed have to be addressed, but gas commonly released from the overlying and underlying strata as the panel is extracted must also be controlled (Diamond et al. 1992, Mucho et al. 2000). Generally, little effort is made to extract gas from underlying strata in the United States, therefore any gas from this source that migrates to the mine atmosphere is controlled by the ventilation

system. Vertical boreholes drilled from the surface are the most common control technology used in the United States to extract methane from the collapsed overburden (gob) before it can migrate to the low pressure sink of the mine ventilation system (Diamond 1994). However, to do this, the ventholes must not only be adequately designed and located for site-specific conditions, they must also be monitored and serviced to ensure that they are in operation to extract gas from the gob when needed (Mucho et al. 2000).

Unfortunately, many gob gas ventholes are located in remote areas, and due to the cost of providing electrical power to the sites, some of the produced methane is used to fuel the internal combustion engines that power the exhausters. The methane-fueled engines are generally more prone to service problems than electric motors and may be adversely affected by varying methane concentrations in the produced gob gas. If the holes are infrequently visited by maintenance personnel, the first indication that a venthole is not operating efficiently or is off-line completely may be an unexpected increase in methane concentrations at a return air shaft or in the underground air courses. This potentially hazardous scenario can largely be eliminated by adequate venthole performance monitoring and real-time data retrieval at the mine office or other designated location.

National Institute for Occupational Safety and Health (NIOSH) personnel designed and constructed a gob gas venthole monitoring system in the mid 1990's. This early system was capable of monitoring the gas flow volume and methane concentration of the produced gas stream, and included a hard-wired data telemetry system (Garcia et al. 1995). However, this monitoring system required ac power, and the system components were relatively expensive. To facilitate NIOSH's current research efforts in the area of optimizing methane control technologies for advanced mining systems and practices, in particular those associated with longwall mining, a new gob gas venthole monitoring system was developed that is capable of operating and transmitting real-time data from remote locations where ac power is not available.

The new gob gas venthole monitoring system utilizes lower cost, current state-of-the-art components with sufficiently low power requirements so that a rechargeable battery instead of ac power can be used. The system battery is recharged by a solar panel. The other significant upgrade to the previous monitoring system is that the new system utilizes cellular telephone technology as the communication link to view and retrieve performance data from the ventholes. As a test, the system was installed and operated on a number of gob gas ventholes at a cooperating mine operating in the Pittsburgh Coalbed in southwestern Pennsylvania. This paper describes the system components, operational characteristics, and ancillary applications for the acquired data.

2 SYSTEM COMPONENTS

2.1 Gas production system

A general schematic of the surface production facility for a gob gas venthole at the test site is shown in Figure 1. Gas production from gob gas ventholes is usually facilitated by the use of exhausters (also commonly referred to as blowers or vacuum pumps) to efficiently extract methane from the longwall gob. The dominant low-pressure sink created in the gob by the exhauster induces the flow of gob gas to the venthole instead of the competing pressure sink of the mine ventilation system (Diamond et al. 1999, Mucho et al. 2000). Electric motor driven exhausters are preferred for their reliability when electricity is available. However, when longwall panels are located in remote areas where providing electric power is very difficult and/or expensive, methane-fueled internal combustion engines are often used to power the exhausters. The exhausters commonly used at the test site where the new monitoring system was tested are a skid-mounted, self-contained unit (engine and exhauster) with a capability of moving up to $45 \times 10^3 \text{ m}^3/\text{d}$ (1.6 MMcfd) of gas while maintaining a vacuum pressure of 15.2 kPa (61 in w.g.)

2.2 Gob gas analyzer system

2.2.1 Data storage and system control

A Campbell CR23X micrologger¹ with storage module is the data collection and control component of the gob gas analyzer system (Figure 2). The micrologger can read and record dc voltage outputs from the pressure transducers, barometer, linear temperature devices,

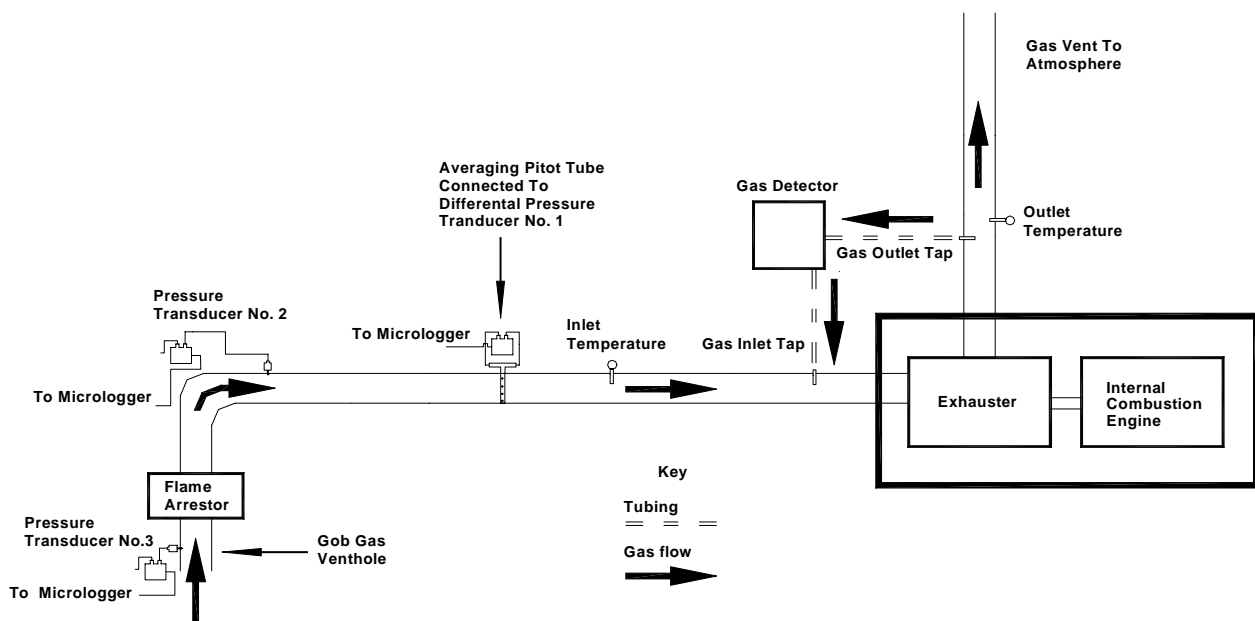


Figure 1. Schematic of gob gas venthole monitoring and data transmission system.

¹Reference to specific products does not imply endorsement by NIOSH.

and the thermal conductivity gas detector (with the addition of the Campbell Curs100 shunt terminal input module). The micrologger is also used to control power distribution to the system components.

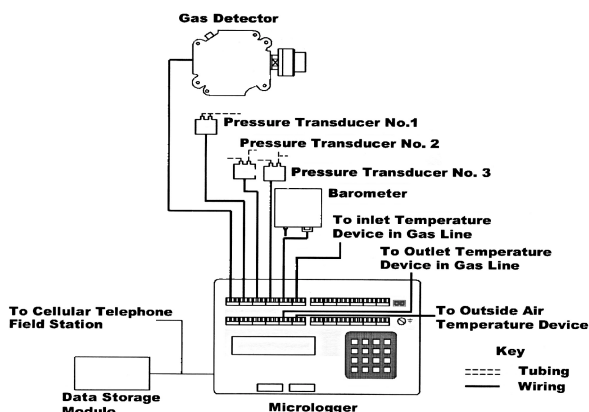


Figure 2. Schematic of gob gas analyzer system component.

The micrologger was programmed to collect data every 15 seconds from all input devices and to average these readings over a 15-minute time period. Only the 15-minute averages are sent to the data storage module (Figure 2) for on-demand downloading to a Windows-based computer, either on-site to a laptop computer, or remotely to the mine office. An important feature of the micrologger is that it uses an external transistor-transistor logic (TTL) level trigger voltage to activate system input devices only at the instant when a measurement is taken to conserve battery power. The micrologger was also programmed to calculate and record the total gas and associated methane flow rates from the appropriate measured parameters. In addition, the micrologger's program corrected these parameters to the American Gas Association's STP conditions, which are 16 deg C at 760 mm mercury atmospheric pressure (60 deg F at 30 in mercury). The micrologger is powered directly from a 12-V, 95-amp hr battery.

The optional Campbell Com100 cellular telephone package and associated support software allows the micrologger to be contacted remotely from an off-site location to observe real-time or stored gas production system performance data. The micrologger can also be programmed to alert the mine whenever the gob gas venthole production system goes off-line or when any measured or calculated parameter falls outside of a predetermined acceptable range.

2.2.2 Total gas stream flow rate determination

The total gas stream flow rate is calculated from the differential pressure measured across the averaging Pitot tube's pressure taps and gas stream density calculated from measured gas temperature and flowing pressure data. In this application, a 15.24 cm (6 in) averaging Pitot tube with an accuracy of $\pm 2\%$ of actual flow was installed on the inlet side of the exhauster (Figure 1). The Pitot tube's output pressure

taps were connected across the differential pressure transducer's pressure ports to measure the velocity pressure, which is used to calculate the gas stream velocity. The transducer used with the Pitot tube has a pressure range of 0.0 to 1.0 kPa (0 to 4 in w.g.). The pressure transducer provides an accuracy of $\pm 1.2\%$ full scale (FS), comparable to a pressure measurement of ± 0.01 kPa (.05 in w.g.); therefore, the lower the flow rate, the less accurate the resultant reading. Measurements taken in low-flow gas streams would require a different equipment configuration or a lower range differential pressure transducer to maintain system accuracy. An error of $< 3.2\%$ in the calculated gas flow rates resulted from the use of the Pitot tube/differential pressure transducer component in the system installed on the gob gas ventholes monitored at the test site [total gas flow rate range of 11 to 45×10^3 m³/d (0.4 - 1.6 MMcfd)].

2.2.3 Methane flow rate determination

The methane flow rate is determined by multiplying the calculated total gas flow rate by the percentage of methane in the gas stream. The methane concentration monitoring component of the gob gas analyzer system (Figure 2) consists of a thermal conductivity gas detector housed in a container constructed from a section of 0.3-m (12-in) diameter Polyvinyl Chloride (PVC) pipe (Figure 3). The gas detector used in the system has a range of 0 to 100% methane. Typically, methane concentration values determined by the thermal conductivity gas detector were within $\pm 5\%$ FS compared to periodic gas stream samples analyzed by gas chromatography methods. The vacuum supplied by the exhauster is used to circulate a portion of the produced gas stream through the housing containing the gas detector (Figures 1 and 3).

2.2.4 Pressure measurement instrumentation

The absolute pressure of the gas stream is required by the averaging Pitot tube equation (based on the Bernoulli energy balance equation and the continuity equation) to calculate the gas flow rate. Two differential pressure transducers (Nos. 2 and 3, Figure 1) with a range of 0 to 35 kPa (0 to 139 in w.g.) were placed into the gas stream. The differential pressure sensors consist of two pressure ports where pipeline pressure is measured relative to the atmospheric (gauge) pressure. The absolute pressure of the gas stream is calculated by adding the gauge pressure (from transducer No. 2, Figure 1) to the barometric pressure measurement.

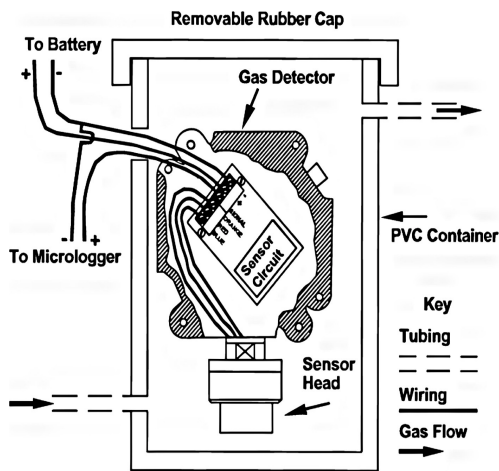


Figure 3. Schematic of gas detector system component.

2.2.5 Temperature measurement instrumentation

A linear temperature sensor is used to measure the outside temperature and the gas stream temperature on the inlet and outlet sides of the exhauster, as shown in Figure 1. The gas temperature measurement taken on the inlet side of the exhauster near the averaging Pitot tube/differential pressure transducer location (No. 1, Figure 1) was an important parameter needed to calculate the gas flow rate at STP conditions. Generally, the gas stream temperature on the outlet side of the exhauster is not used for this purpose since the gas stream temperature increases substantially as it passes through the exhauster. However, the gas stream outlet temperature is a parameter that can assist in the evaluation of the vacuum pump's performance. A significant temperature increase on the outlet side of the exhauster may indicate that insufficient gas is available from the gob for the level of applied suction, thus causing the exhauster to run inefficiently. This situation can be remedied by adjusting the engine speed to reduce the suction applied by the exhauster.

2.3 Cellular telephone data transmission system

Cellular telephone technology is a convenient means of communication for data transmission and system control purposes from remote locations. The Campbell Com100 cellular telephone hardware and support software used in the NIOSH gob gas venthole monitoring system allows the micrologger to communicate with a Windows-based computer located at a remote location, such as the mine office. The mine operator can monitor and display real-time gas production system performance data in tabular or graphical form or download previously collected data to evaluate longer term production trends for individual ventholes. The communication system can also be used to alert the mine operator whenever the gob gas venthole shuts down or if any measured or calculated parameter falls outside of a predetermined operational range.

The major components of the cellular telephone field station are connected to the micrologger for system control, as shown in Figure 4. The Motorola M6000 cellular transceiver requires an external Motorola RJ11C telephone interface to connect the Campbell COM200 field modem to the transceiver. The cellular transceiver transmits a signal at a much higher capacity and can receive a much weaker signal than a typical cellular telephone. If necessary, the transceiver can be used in combination with a directional (Yagi) antenna placed on a high pole and pointed toward a cellular telephone tower to increase signal strength.

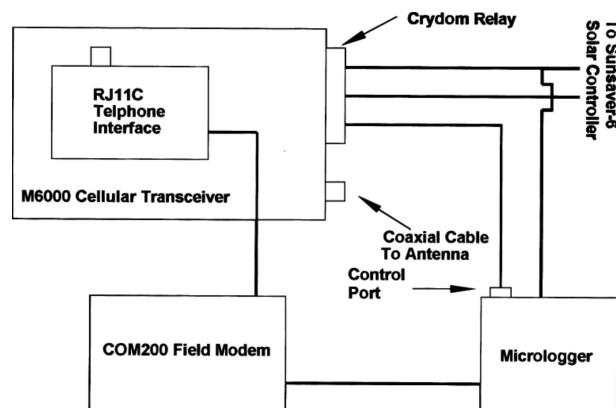


Figure 4. Schematic of cellular telephone based data transmission system component.

The Crydom relay (Figure 4) allows the micrologger to apply power to turn on the transceiver (standby mode). Since power consumption in the standby mode is less than 0.2 amp hr, the transceiver was left on standby continuously so that the monitoring system could be accessed remotely at any time. However, because of the relatively high power consumption of the transceiver when transmitting and receiving data (1.8 amp hr), a solar panel was used to maintain a charge on the system's 12-V battery.

2.4 Battery/solar-powered charging system

The major components of the battery and solar-powered charging system used to power the remote gob gas venthole monitoring and communication system are shown in Figure 5. A Solarex SX-50 photovoltaic solar panel, which generates a peak power of 50 watts, keeps the system's 12-V, 95-amp hr battery charged. The output from the solar panel is connected to the input of a SunSaver-6 solar controller. Whenever sunlight is available, the controller provides a precise charging voltage to protect the battery from overcharging. The controller also prevents current leakage at night that would discharge the battery. The dc output voltage to power the cellular transceiver is regulated by the controller.

The controller will automatically disconnect the power to operate the transceiver whenever the battery capacity falls below 11.5 volts to prevent damage to the battery. If the transceiver is disconnected due to low battery voltage, the communication system cannot transmit data or send an alarm to the mine office until the battery is recharged. However, all other system components and data storage and device control functions can continue to operate normally with less than 11.5 volts of battery capacity. The transceiver is automatically reconnected once the battery is recharged. In extended tests of the system through all seasonal weather conditions and usage demands, the 50 watt solar panel and 12-volt, 95-amp hr battery were sufficient to keep the cellular telephone communication system on-line.

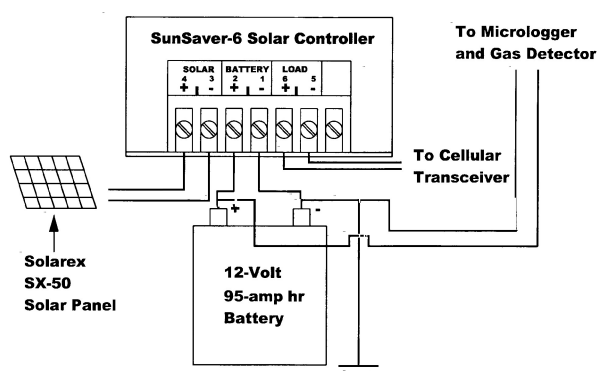


Figure 5. Schematic of battery/charging system component.

3 ANCILLARY SYSTEM APPLICATIONS

3.1 Troubleshooting gas production system performance problems

In addition to providing real-time gas production data, a major advantage of the gob gas venthole monitoring system is that historical data can be reviewed to diagnose production problems, in some cases before they become acute. It was common practice at the test site that when a venthole was found off-line by maintenance personnel, they try to restart the methane-fueled engine using propane. In some cases the engine would restart and run normally. Typically, the maintenance personnel would only remain on-site long enough to complete their routine servicing of the system and then leave, assuming that the gas production system was running properly. However, it was not uncommon for some trouble-prone production systems to go off-line again shortly after the maintenance personnel had left the site. With the gob gas venthole monitoring and communication system in place, the operational status of the ventholes can be checked more frequently from the mine office than the sometimes weekly on-site visits by the maintenance crew to ensure that all holes are running properly.

Because of the possibility of variable methane concentrations in the produced gas stream powering the methane-fueled engines, the mine operator

sometimes incorrectly assumed that trouble-prone gas production systems were going off-line frequently due to methane concentrations being outside of the optimum range for the engines. Thus, the gob gas production system would sometimes remain off-line for long periods of time due to an incorrect assumption as to the reason for the problem. Once the gob gas venthole monitoring system was in place on holes that developed operational problems, it was quite obvious that the methane concentration in the produced gas stream was not varying significantly and was within the operational range for the engine. The problem with these holes was then determined to be mechanical, not fuel-quality-related. By having access to historical gas quality data from the monitoring system, the time required to diagnose the cause of gas production system failures can be significantly reduced. Thus, the venthole can be put back on production in a timely manner to avoid adversely affecting the methane concentration levels in the underground workplace.

An operational problem that sometimes occurs with the gob gas venthole production system is that the flame arrestor becomes clogged with particulate matter (probably drill cuttings) entrained in the gas stream soon after a venthole is completed and put on production. With pressure transducers installed on both sides of the flame arrestor (Nos. 2 and 3, Figure 1), a comparison of the pressure readings from the two sensors enables the mine operator to evaluate the potential of a clogged flame arrestor being responsible for an unexpected decline in gas production. Under normal operating conditions (gas flowing freely through the flame arrestor), the pressure differential between the two transducers will be minimal. However, as the flame arrestor becomes clogged, the pressure will increase above the flame arrestor (transducer No. 2, Figure 1) and decrease below (transducer No. 3, Figure 1), resulting in an increasingly larger pressure differential between the two monitoring points.

3.2 Control of gas production rate

Methane concentrations in the produced gas stream typically vary over the life of a gob gas venthole (Diamond 1994). Once the methane in the produced gas stream reaches ~ 45 to 55%, the methane-fueled internal combustion engines operate less reliably. At 25% methane, the gob gas production system is usually de-energized for safety reasons, and the holes are either shut-in or allowed to free flow. The extraction rate of gas from the longwall gob depends on the amount of suction applied to the individual gob gas ventholes. When the recharge rate of methane to the gob is less than the production capacity of the venthole, mine air is pulled into the gob gas production system, thereby reducing the methane concentration in the produced gas stream (Mucho et al. 2000).

It is desirable to keep the methane concentration in the produced gas stream within the optimal range of the engine powering the gas extraction system. Keeping the gob gas ventholes operating is a key safety issue for many longwall mines. Additionally, for gob gas production systems that capture and sell the produced methane, it is desirable to maintain the methane concentration at contractual quality levels. The amount of suction applied to the gob gas venthole by the exhaustor can be controlled by adjusting the engine speed. This is currently done at the test site when the gob gas production system is periodically serviced by manually adjusting the engine throttle setting for optimum performance for the current methane concentration in the produced gas stream. However, the gob gas analyzer system could be configured and the micrologger programmed to monitor engine RPM and to activate a control circuit to adjust the engine speed to accommodate varying gas production conditions. A similar system (but using electric motors and a hard-wired communication link) has been used by a mine operator in Virginia to monitor and control their gob gas production system performance (Smallwood et al. 1993).

4 SUMMARY

A remote gob gas venthole monitoring and cellular telephone based real-time data transmission system has been designed and successfully field tested under varying seasonal conditions by NIOSH. This system can provide an additional margin of safety for the underground workforce by continuously monitoring the operational status and critical production parameters associated with longwall gob gas ventholes. By including an alarm capability in the system, the mine operator can automatically be notified that the gas production system is off-line or a critical production parameter is outside its optimal range. Thus, the first evidence of a malfunction in the gob gas venthole production system is not an increase in methane concentrations at a return air shaft or in the underground environment.

By taking advantage of the real-time data transmission capability of the cellular telephone-based communication system and historical gas production data for a particular venthole, the mine operator can evaluate and spot potential operational problems or maintenance needs before they result in a shut-down of the gas production system. The historical data can also be of use in diagnosing the cause of production

problems after they have occurred, which can significantly impact the amount of time required to correct the problem. When this system is fully deployed at a mine site, the mine operator will have the necessary data to make timely decisions to more efficiently control methane gas in the underground environment.

Modifications to this system, such as controlling the gas extraction rate by automatically adjusting the engine speed powering the exhaustor to keep the methane concentration in an optimal range, may provide additional benefits to the mining industry. The gob gas venthole monitoring system can also be used for other mine-site methane drainage applications where accurately determining the total gas and methane flow rates is desirable. This includes monitoring other surface gas production facilities such as those associated with cross-measure, horizontal, or vertical borehole gas drainage systems.

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