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MINE ENVIRONMENT MONITORING SYSTEM AND SENSOR PERFORMANCE EVALUATIONS

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# Chapter 24

## MINE ENVIRONMENT MONITORING SYSTEM AND SENSOR PERFORMANCE EVALUATIONS

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ABSTRACT

The paper describes the capabilities of a micro-computer-based real time data acquisition system for monitoring and control of mine environments. Applications of such a system for monitoring the ventilation and air quality of a mine is outlined.

The paper discusses the results of running a monitoring system with various environmental sensors in a simulated mine environment. The sensors used in this study are: carbon monoxide (CO), carbon dioxide ($CO_2$), nitric oxide (NO), nitrogen dioxide ($NO_2$), sulphur dioxide ($SO_2$), methane ($CH_4$), air flow, absolute pressure, temperature and relative humidity. A performance evaluation of the monitoring system and sensors is presented.

### INTRODUCTION

The main objective of a continuous monitoring system is to receive data from a series of remote sensing devices, and to store and display the data automatically. Depending on the requirements, the system can be used to monitor aspects of production, maintenance, communication, fire and environment. Such a monitoring system can, therefore, provide management with needed up-to-date information. There are various systems with different options commercially available. However, all systems monitor some parameters via sensing devices, which produce electric signals. The telemetry devices of the system transmit the data to the computer, where the signals are analysed and displayed on video terminals and/or printers. The computers may have specially designed software to analyze and interpret the data in a special fashion.

The parameters commonly used for mine environment monitoring are: temperature, relative humidity, pressure, air flow, methane ($CH_4$), carbon monoxide (CO), carbon dioxide ($CO_2$), nitric oxide (NO), nitrogen dioxide ($NO_2$), sulphur dioxide ($SO_2$), dust, smoke, radiation, etc. Continuous monitoring of the required parameters in underground mines can be utilized to better control the quality of the mine environment, perhaps involving a cost saving. Research projects have been proposed in the past to provide economical ventilation. These projects include 'closed loop control' where ventilation-related parameters are monitored continuously and the air flows are controlled (reduced or increased) based on the operational requirement at that time. Another application is the controlled recirculation of ventilation in mines to reduce mine air heating and ventilation costs. Also, a system can be developed to automate the ventilation system for a dieselized mine based on the $CO_2$ concentrations as a control parameter. It has been observed in the past that $CO_2$ is a good indicator for air quality control for a single diesel machine operating in a mine. If this is also true for multiple machine operations, then the ventilation of dieselized mines can be controlled by $CO_2$ measurements alone.

All such projects require a dependable continuous monitoring and control system with reliable sensors. To assess the performance of such an array of equipment, CANMET installed a monitoring system with various environmental sensors in the laboratory. The system was evaluated in a simulated mine environment produced by diluting the exhaust flow of a diesel engine by fresh air from the test cell ventilation system. This paper describes the results of the evaluations performed.

### MONITORING SYSTEM

The system employed was a Senturion-200, manufactured by Conspec Controls Ltd. located in Downsview, Ontario. It is a microcomputer based real-time data acquisition monitoring and control system. The central control station, as shown in figure 1, consists of a central processing unit, an operator's video display terminal (CRT) with keyboard and a printer.

The central processing unit of the Senturion-200 system contains the following component functions: Z-80 microprocessor, 64 x 8-bit random access memory (RAM), 8-full duplex serial I/O


Figure 1. Senturion-200 Continuous monitoring and control system

ports, real time clock, 7K x 8-bit read only memory (EPROM) and floppy diskette controller. The system disk uses 8-inch single-sided floppy disks with storage capacity of 256 kilobytes of data. The floppy disk is used to load the computer with system program memory, record the sensor accessor data, and store data for shift reports and/or historical logs for later retrieval. The system contains a power supply unit to provide the necessary direct current voltage to the microcomputer.

The televideo terminal (CRT) provides the operator a means of monitoring the system. All entries to the system are done through the terminal, and it provides continuous data on preselected sensing parameters along with alarm conditions. The terminal screen has 24 rows, each with an 80-character width. A split-screen format (figure 2) is used, which allows the operator to display data on one portion of the screen while entering and accessing information on another portion. The left top of the screen displays up to 12 alarms and return to normal conditions simultaneously. The top right side has a continuous display of time and date, the central space is reserved for operator data

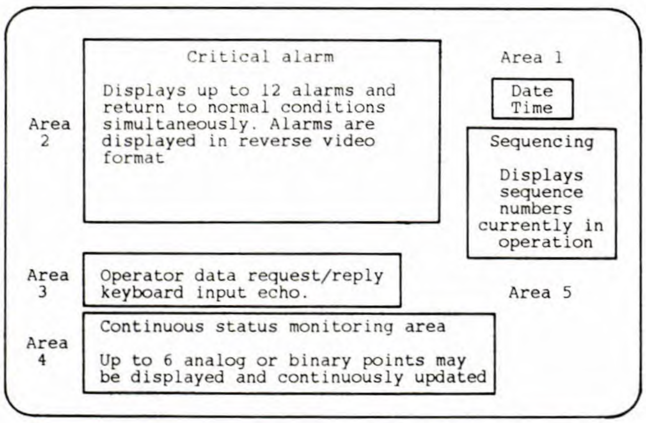


Figure 2. CRT display areas

request and/or reply, and the bottom space is reserved for up to six analog or binary continuous data status.

The hard copy logs, reports and alarm status are printed on a printer. The monitoring system has the ability to support either one or two printers. When two printers are used, one is designated as the event printer while the second is designated as the data printer. The data printer is used to log and generate shift reports, listings, trend logs etc. as requested by the operator for informational and planning purposes. The event printer will log all the events as they occur in the system, providing a log of all field activities as seen by the processor.

Data Gathering Network

The Senturion-200 uses a unique data multiplexing system which allows a common four wire communications trunk cable to be shared by up to 128 field devices. Unlike other systems which use remote multi-point devices, each field device is monitored and/or controlled by a point multiplexer called an 'Accessor'. The Senturion system is manufactured with up to four accessor trunks. The trunk is connected to the central station via an RS-232 interface and to the accessor via a shielded four-wire cable. Two of the wires are used to provide 24VDC power to the Accessors and the remaining two wires are used to transmit and receive digital signals. The messages to and from the Accessors are comprised of 22 bits of data in each direction at a rate of 4800 bits/sec. The maximum limit of 128 field devices on a single trunk cable is determined by the power available to drive the Accessors and field devices.

Each field device is interfaced with an Accessor. Each Accessor has its own unique dip switch selectable address variable from 0 to 127. Therefore, each field device is identified by its own identity number. All the field devices on a trunk will have different addresses. The Accessors are classified as either analog or binary. Binary Accessors control and/or report status from field devices. There are many kinds of binary Accessors which are used for various functions such as turning on or off fans, warning lights or alarms. Analog Accessors are used to accept an analog input from a field device, which is converted to an 8-bit binary (digital) number for transmission to central station. The 8-bit number is then used by the central station to check for alarm condition and other status.

Software Description

The Senturion-200 system uses three types of software packages: system monitor, control program for microcomputer (CP/M) operating and, application software. The system monitor software is used to load the CP/M operating system and to perform diagnostic tests on the hardware. The CP/M operating system is used to provide the unit with the ability to load the application software.

The application programs including main scan, command service, alarm printer service, terminal display service, and specialized programs, are written by Conspec Limited.

The shift report software provides up to 5 daily shift reports for up to 64 field devices, including the average values, lowest and highest values attained with the corresponding time during the shift. The reports can automatically be printed on the printer and/or stored on the floppy disk for later retrieval. Only the 3 latest shift reports are stored at any time. The trend log software provides continuous printout of up to 10 points at regular intervals from 1 to 99 minutes as desired. The historical log software is used to store and recall past status of up to 50 points for the last 60 minutes.

## DESCRIPTION OF SENSING UNITS

Only those sensing units which were used in this work are described below. Most of the sensors used were obtained from Conspec Ltd. All these sensing units use Conspec designed A-type Accessors. The analog signals produced by the sensors are digitized and transmitted by the Accessors in an asynchronous serial baseband format to the central station for processing.

### Temperature and Relative Humidity (T and RH)

A single channel Humi-Temp signal conditioner developed by the Phys-Chemical Research Corp. was used for monitoring of ambient temperature and relative humidity. It provides a linear analog signal of 0-10VDC corresponding to 0-100°C temperature and 0-100% RH. The temperature and RH accuracy is stated as $\pm$ 0.5°C and $\pm$ 2.5% respectively. Both humidity and temperature sensors are housed in a special hi-strength plastic probe assembly (figure 3).

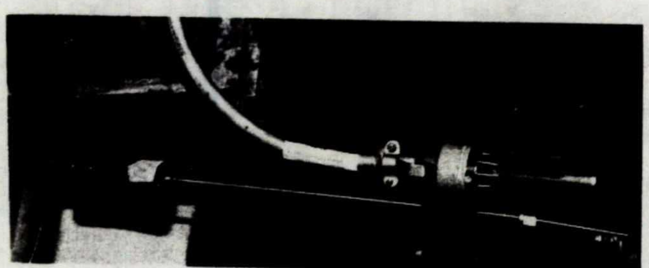

Figure 3. Temperataure and relative humidity probe for humi-temp sensing unit

The humidity sensor used was an electric hygrometric circuit element which senses changes in humidity by change in impedance. The sensors are susceptible to contamination by sulphur gases and sulphur compounds. Excessive exposure to oil and oil vapors may produce a calibration shift, loss of response time and sensor deterioration. The sensor probe can be located up to 75m away from the electronic circuit board box. The electronic circuit board requires 115VAC power supply.

Also, a Conspec RTD temperature sensor was used, which has a measurement range of -35°C to 65°C. It uses an A-63 Accessor, and a power supply of 24VDC is supplied by the trunk cable.

### Air Flow (V/Q)

The air flow sensor used was a J-Tech model VA216B air draft sensor. The sensor employs a patented ultrasonic technique to measure a form of turbulence created in the air. This turbulence is related to the velocity of air. The input voltage required is 8-21VDC; the unit has a power consumption of 30mA at 15VDC. The instrument measuring range is given as 0.25-15.25 m/s (50-3000 fpm). The stated accuracy is $\pm$ 2% of full scale (FS). The operating requirement is 0-50°C for temperature and 10-80% for relative humidity.

The airflow through the sensor head may not be the average velocity of the airway. For this purpose the span adjustment provided on the instrument can be used to indicate the average flow. If it is required to read the output as an air volume rate, then the correction factor (CF) is adjusted accordingly when the sensor information is supplied to the central computer.

### Pressure (P)

The absolute pressure sensor consisted of a Micro Gauge pressure transducer and Conspec A84 Accessor enclosed in a stainless steel enclosure. The input voltage required is 24VDC supplied by a Accessor trunk cable. It provides a linear analog signal of 0-200mA corresponding to 86-107 kPa.

### Carbon Monoxide (CO)

Two diffusion type sensor heads and one sampling analyzer for CO monitoring were used. All of these instruments have electrochemical cells for the analysis of CO gas. An interference filter is included in the gas input port to trap particulate matter and to eliminate interference gases and vapors.

The first diffusion-type sensor consists of an Ecolyzer CO sensing head model 5001-DGFR (figure 4) with Conspec A60 Accessor enclosed in a NEMA 4 Enclosure. The CO measuring range is 0-50 ppm. It can also be used for 0-500 ppm range by

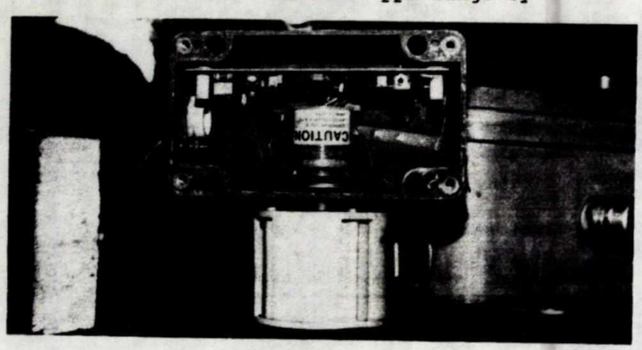

Figure 4. CO sensor unit with Ecolyzer sensing head

altering the dip-switch setting in the sensing head electronics. The input voltage required is 8.5-28VDC; it has a power consumption of 30mA at 15VDC. However, 21VDC is the maximum for intrinsically safe applications. The specified accuracy is ± 2% of FS with a rise time of 60 seconds to 90% of final value. The operating requirement is 0-50°C for temperature and 10-85% for relative humidity.

The second diffusion type sensing unit consists of a CO sensor head model 2TS/2E developed by City Technology Ltd. with a Conspec CO monitor card enclosed in a stainless steel corrosion resistant case that meets the NEMA 4 rating (figure 5). The measuring range is 0-50 ppm of CO. An interference filter is used to remove trace quantities of sulphur dioxide, oxides of nitrogen, and hydrogen sulphide. The voltage requirement is similar to the first type except that the power consumption is 20mA at 15VDC. The stated accuracy of the instrument is ±2% of full scale with a rise time of 30-45 seconds for 10-90% of final value.

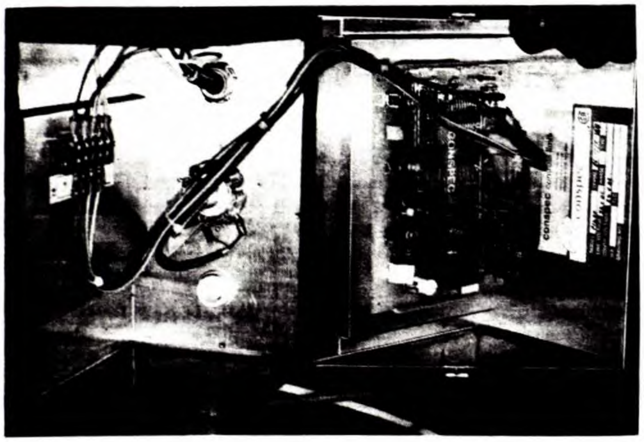

Figure 5. CO Sensor unit with CTL sensor head (left) and PA board (right)

The sampling analyzer used was an Ecolyzer model 2000 with Conspec A60 Accessor. The instrument provides dual ranges of 0-50 ppm and 0-100 ppm for CO monitoring. The stated accuracy is ± 1% of full scale. The instrument requires 115VAC or can also be run on it's rechargeable batteries which are good for 8 hours of continuous operation.

Carbon Dioxide ($CO_2$)

Two types of $CO_2$ sensing units were used. The first one is a diffusion type Fuji Electric Co. Ltd. model ZFP1YAZ1 based on the non-dispersive infrared ray (NDIR) principle, with a Conspec A69 Accessor enclosed in a NEMA 4 enclosure. In this model, ambient air diffuses into the analyzer where the sample is analyzed for its $CO_2$ concentration. The operating requirement is 5-40°C for temperature and 0-90% for relative humidity. The instrument measuring range is 0-3000 ppm and the accuracy is stated as ±100 ppm at 1000 ppm point. It requires 115VAC to run and consumes 130mA. It provides a non-linear analog signal of 0-100mV for CO2 concentration of 0-3000 ppm. Because of this non-linearity, the output in the Senturion system is provided in volts and converted to the corresponding $CO_2$ concentration manually using a calibration chart.

The second $CO_2$ sensing unit used is a Fuji model ZFP5 NDIR sampling analyzer with Conspec A69 Accessor. This instrument has a dual range of 0-2000 ppm and 0-5000 ppm with accuracy of ± 5% of full scale on the low range and ± 10% of the indication on the high range. The other specifications are similar to the diffusion type model.

Nitric Oxide (NO) and Nitrogen Dioxide ($NO_2$)

The nitric oxide sensing unit used was an Ecolyzer sensing head model 5002-PGF-50 with Conspec A60 Accessor. The sensing head is housed in a rugged, plastic corrosion-resistant enclosure that meets the NEMA 4 rating. It contains an electrochemical sensor, a pump assembly, a printed circuit board and remote calibration printed circuit board. The sensor assembly contains an interference filter and an external particulate filter. The instrument measuring range is 0-50 ppm with accuracy of ± 1%. The response time is stated as 30 seconds to 90% of final value. The input power required is 120mA at 15-28VDC. The analog voltage output is 0-1VDC. The operating requirement is 0-40°C for temperature and 10-90% for relative humidity.

The nitrogen dioxide sensing unit used is also manufactured by Ecolyzer and employs sensing head model 5003-PGF-10 having a measuring range of 0-10ppm. The other specifications are the same as for the nitric oxide sensor.

Sulphur Dioxide ($SO_2$)

The sulphur dioxide sensing unit used was an Interscan corporation model LD-24 $SO_2$ continuous monitoring analyzer with Conspec A69 Accessor

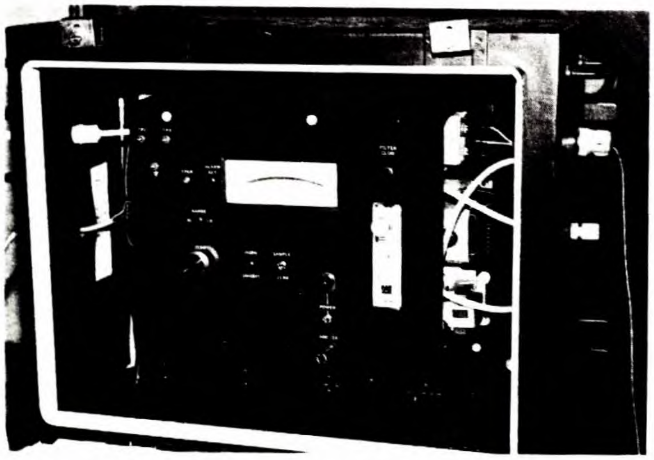

Figure 6. $SO_2$ sensor unit

housed in a fibre glass enclosure that meets the NEMA 4 requirements (figure 6). The system uses a patented electrochemical Voltammetric sensor for $SO_2$ detection. The system consists of diaphragm pump, rotameter, refillable Voltammetric sensor, and electronic circuit board. The instrument requires 115VAC to run and provides a linear analog output of 0-100mV corresponding to 0-5 ppm of $SO_2$ concentration. The accuracy is stated as ± 2% of full scale.

Methane ($CH_4$)

The methane sensing unit used was a J-Tec model VM101B sensor with a Conspec A61 Accessor enclosed in a stainless steel enclosure (figure 7). The VM101B is a catalytic type fitted with a flame arrestor containing a plug-in sensor. The input voltage required is 9-21VDC with a power consumption of 80mA. The maximum supply voltage is 21VDC for an intrinsically safe environment. It produces a linear analog output of 0.5-1.5VDC corresponding to 0-5% $CH_4$. The accuracy is stated as ± 2% of the indication. The operating requirement is 0-50°C for temperature and 10-80% for relative humidity.

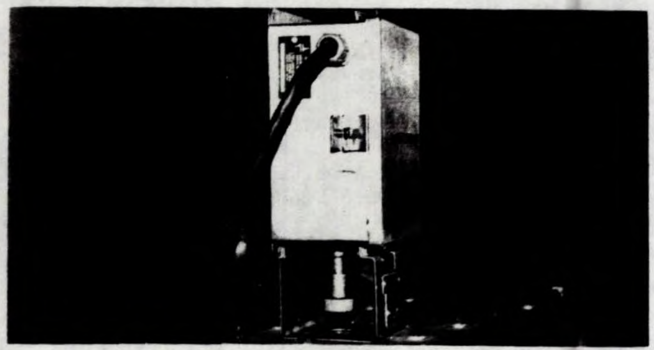

Figure 7. Methane sensor unit

DESCRIPTION OF THE TEST AREA

Figure 8 shows a schematic of the test area and the arrangement of the equipment used for the Senturion 200 monitoring system. All the sensors and the engine were located in the test cell, where a diesel environment was simulated by running a Deutz F6L 912W air-cooled, nominal 67

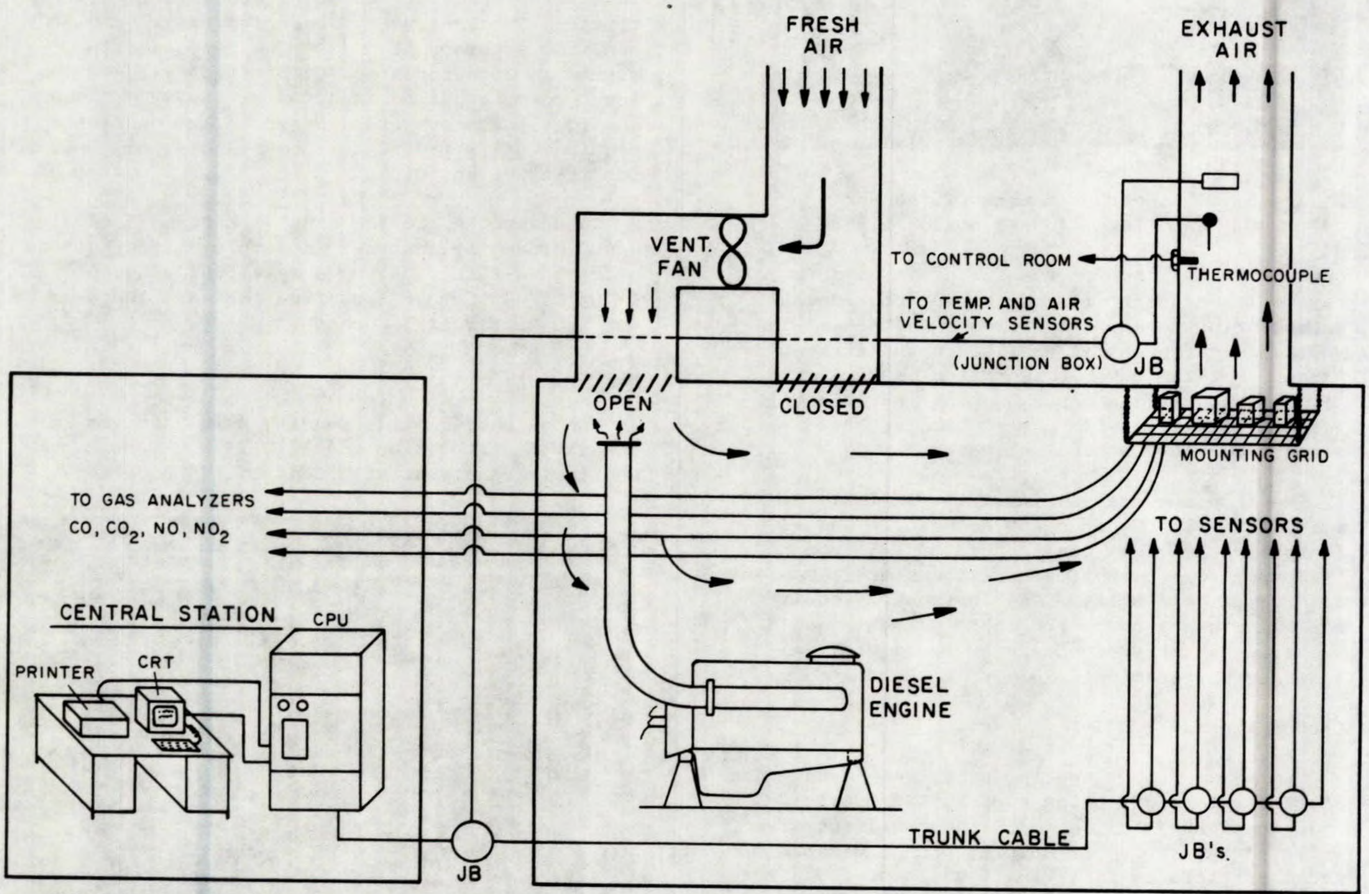


Figure 8. Schematic of the test area for continuous monitoring of simulated mine environment

kW (90 bhp) diesel engine. The air was drawn into the test cell by a ventilation fan. The distribution of air flow is shown by arrows. The fan had two speeds which provided average air velocities of 3.81 m/s and 6.15 m/s respectively in the exhaust ventilation duct. The engine was operated at 2100 rpm and at output torques of 81 N.m (60 lb.ft), 162 N.m (119 lb.ft) and 243 N.m. (180 lb.ft) which were called 1/3, 2/3 and full loads respectively. The engine was run for a four week period using these different engine loads and ventilation rates.

The engine exhaust was emitted directly into the intake ventilation (see top left in the test cell area of the figure 8) in order to facilitate the mixing of the pollutants before they reached the sensor locations. This was confirmed separately by measuring the gaseous pollutants at the grid point and in the vertical exhaust duct. The mounting grid, as shown in the figure, was suspended by chains about 0.7m below the exhaust opening. The side openings were closed by a plastic sheet so that the pollutants were exhausted through the bottom of the grid, passing over the sensors before exhausting to the outside atmosphere. The sensing units for CO, $CO_2$, NO, $NO_2$ and $CH_4$ were placed on the grid underneath the vertical exhaust duct, while the sensing units for $SO_2$, pressure, temperature and relative humidity were placed on the test cell floor with a sampling tube connection to the grid location. Also, an air flow sensor and an RTD temperature device were placed in the center of the exhaust duct as shown in figure 8. The sensors were connected to the trunk of the Senturion-200 via trunk cables. The circles denoted by 'JB' are the junction boxes which were used to connect up to four trunk cables.

Two thermocouples were installed close to the temperature sensors and were connected to the gauges in the control room for temperature measurements. The figure 8 shows various tygon lines from the grid location to the control room, which were used to take samples for gas analysis. This was necessary to compare the gas concentrations analysed by sensors with other independent and reliable instruments.

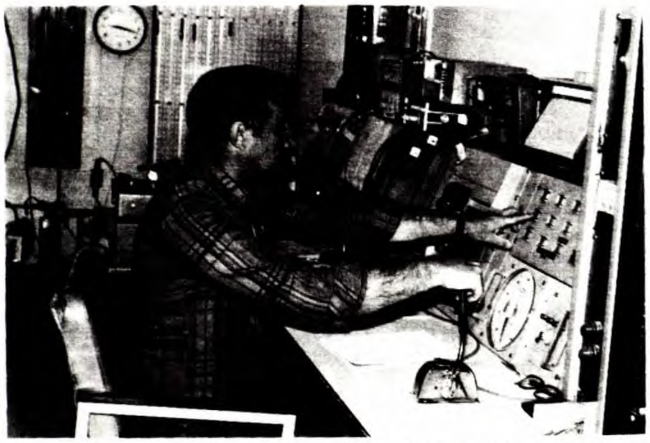

Figure 9. View of engine control room with gas analyzers (top right)

The Senturion-200 monitoring system located in the control room is shown in figure 8. The CRT was used to input all the necessary data on the sensing units into the computer. Figure 9 shows the control board for running the engine with gas analyzers located on the upper right side of the photograph. The instruments used for independent gas analysis were; CO Ecolyzer, $CO_2$ Fuji, NO Chemiluminescent, $NO_2$ Ecolyzer, Methane infrared. The Gas concentrations were recorded on chart recorders, while the concentrations transmitted by the sensors were recorded for every minute on a floppy disk and later retrieved for printing on the printer. Figure 10 shows the location of some sensing units on the mounting grid underneath the exhaust duct (plastic side removed).

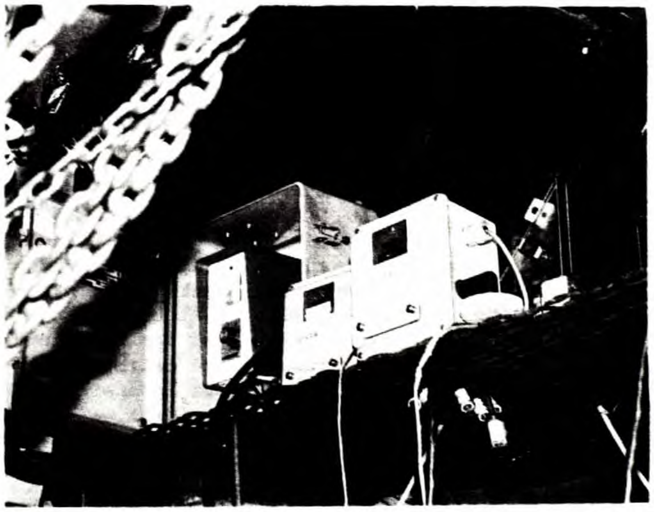

Figure 10. $CO_2$, NO and $NO_2$ sensors unit (from left to right) on the mounting grid

## EXPERIMENTAL PROCEDURE

Initially the monitoring system was installed only with temperature and humidity sensing units to permit familiarization with the operation of the system. After the system was debugged, each sensor was calibrated while on line without running the diesel engine. Problems with the sensors were corrected separately and are discussed later. This procedure was continued until all the sensors produced satisfactory results. The calibration was performed on the complete sensing device which included sensor, sensor electronics and Accessor.

The calibration of the sensors was done using two methods. In the first method the sensor reading was displayed on the CRT and adjusted to the true reading until the CRT displayed it on its screen. This method is suitable only if the sensor is located close to the CRT or if two way communication is available between the CRT and sensor locations. This method is not suitable for calibrating sensors located far away from the CRT such as in mines. In the second method, calibration is possible with remotely located sensors. This requires the use of a portable test unit called 'Accessor Checker' manufactured by Conspec Ltd. The Accessor Checker is connected between the sensor's Accessor and it's four-wire Accessor stub cable, and the Checker's address switch and command is set to agree with those on the Accessor. The sensor's output is provided by the status response on the Checker. Therefore the sensor's response can be read by the Checker, and the sensor can be adjusted accordingly.

After the initial system ran satisfactorily, the diesel mine environment was simulated in the test cell by running the diesel engine at different loads and ventilation fan speeds in order to test the sensing units at different pollutant concentrations. It was not possible to run the engine at full load and low fan speed for longer than 30 minutes because of high test cell temperatures and excessive engine oil temperature. However, these tests were useful to study sensor response at high temperatures and low relative humidity. For many days steady state conditions were utilized for the whole day operation.

The system was run in this simulated mine environment for a period of four weeks with three to four hours of daily operation. At the end of the day all the sensors were checked for zero and span drift. Only those sensors were calibrated which had drifted significantly. Daily operation activities were recorded, such as: start and stop of ventilation fan, time for the change of duty loads, calibration sheets, etc. The computer was programmed to provide shift reports every hour, which included average values, minimum and maximum values achieved during the hour. Figure 11 shows a typical output of a shift report. The historical log trend software was used to produce a printout of all the sensor readings every minute. For comparison purposes the comparable gas concentration results by other instruments were recorded on chart record papers. ~~During the operation, temperatures at the grid point, in the test cell~~. The CRT was programmed for continuous display of six sensors, and was watched for any unusual conditions.

During this work a large body of data was obtained, both from the computer-linked sensors and from the various analytical systems against which the sensor data was compared. This large body of data required time-consuming analysis, but such was considered necessary to gain experience with this type of system.

## DISCUSSION OF THE RESULTS

The experience gained while running the system with the various environmental sensing units in a simulated mine environment is described below.

### Central Monitoring System

Initially there were problems with the communication system. The system would stop monitoring from time to time without apparent reason producing meaningless messages (such as ATTEMPT FAILED). These problems were reported to the manufacturer and a representative of the company modified the SIO/processor card, and added a new data buffer/processor interface card in the processor drawer of the unit. From that point, the system ran continuously for over four months without a single problem of this kind. Another problem experienced was with the restarting of the system. This was due to a broken power on/off switch, and loose connections at the terminal blocks in the power supply. The problems were resolved after a considerable passage of time. Also, the real clock time display on the CRT lost about 40 seconds in 24 hours, requiring an adjustment to the clock time every day.

May 11, 1987 14:00:00 Shift Report

Report No. 2 Day=11

| | Description | AVERAGE | UNITS | HIGH | TIME | LOW | TIME |
|---|---|---|---|---|---|---|---|
| 1 | TEMP-HUMITEMP | 23.520000 | DEG. C | 25.088000 | 13:40 | 18.032000 | 13:00 |
| 2 | RELATIVE HUMIDITY | 38.808000 | % | 50.176000 | 13:00 | 36.4456000 | 13:49 |
| 3 | TEMP-RID | 24.760000 | DEG. C | 26.328000 | 13:43 | 18.096000 | 13:00 |
| 4 | AIR VEOLOCITY #1 | 1026.6000 | F.P.M. | 1132.8000 | 13:14 | 955.80000 | 13:10 |
| 5 | CO #3 PORTABLE | 4.1160000 | PPM | 6.4680000 | 13:00 | 3.3320000 | 13:11 |
| 6 | CO #1 ECOLYZER | 6.0760000 | PPM | 6.6640000 | 13:00 | 5.4880000 | 13:09 |
| 8 | $CO_2$ #1 CONTROLLER | 0.0623280 | VOLTS | 0.0670320 | 13:00 | 0.0576240 | 13:00 |
| 9 | NO | 5.4880000 | PPM | 6.8600000 | 13:03 | 4.1160000 | 13:53 |
| 10 | $NO_2$ | 1.2936000 | PPM | 1.8816000 | 13:01 | 1.0976000 | 13.12 |
| 13 | PRESSURE | 100506.40 | PASCALS | 100668.80 | 13:00 | 100344.00 | 13:45 |

NO. SAMPLES USED 60

Figure 11. Shift report output

The uninterruptable power supply (UPS) provided with the system kept the CPU active when power was switched off. Unfortunately the CRT and printer were not connected to the UPS and no information could be obtained during the period the power was off. After talking to the company representative it was understood that it is possible to connect the CRT and printer to UPS to permit system reporting during main power failure.

Sensors

All the analogs in the system are read as 8-bit binary numbers with a range of 000 to 255. These values are scaled to receive meaningful readings. This scaling factor is called the correction factor (CF). It may also be necessary to offset this scaling value by adding or subtracting a fixed constant value from it. This fixed constant is called the offset. For example if the measuring range of a temperature sensor is from 0 to 100°C, then CF = (100 - 0)/ 255 = 0.39, i.e. the temperature range is divided in 255 equal parts of 0.39°C each. The sensor output will therefore be in the multiples of 0.39. In general it was found that sensor readings fluctuated by one or two values of CF defining the sensor resolution. The value of CF will depend on the measuring range of each sensing unit. If the sensor values are consistently different from the true value by a fixed constant for the complete range, then the sensor output can be adjusted by offsetting the entire range by this fixed constant. This offsetting was useful in calibrating some sensors like the RTD temperature sensor and the absolute pressure sensor, neither of which required any calibration.

The RTD temperature and Humi-Temp sensors were checked and calibrated in a temperature/humidity control chamber before connecting to the monitoring system. The relative humidity (RH) sensor was checked at a fixed temperature of 25°C over a RH range of 15% to 90%. Both the temperature sensors were checked at a fixed RH value of 50% for a temperature range of 10°C to 30°C.

Figure 12 shows some of the sensor readings for one complete day of operation of the system. The top of the figure shows the length of time at each engine load shown. The ventilation fan was run at low speed from 12:59 hours to 16:06 hours. The bottom two curves on the top drawing show temperature readings obtained by the Humi-Temp temperature sensor (curve A) and the RTD sensor (curve B). The corresponding temperatures taken by thermocouples located at the sensor locations are marked by the sign 'X'. It should be noted from the figure that RTD readings are about 2°C higher than those provided by the thermocouple for the complete range. This deviation can be compensated by offsetting the RTD measuring range by 2°C in the computer input data. Therefore, it can be said that both temperature sensors provided very accurate measurements and are suitable for mine use.

The relative humidity sensor readings were also very close to the readings taken by the RH meter during the test. After some use, the RH sensor did not provide accurate results when the humidity was less than 30% in the test cell. It was suspected that this was due to some problems in the electronic circuit board which could occur due to the excessive movement of this instrument in the laboratory. The Humi-Temp sensors could only be calibrated in a temperature/humidity control chamber.

The pressure sensor readings are shown by solid lines. Simultaneous pressure readings were not taken by other instruments, but spot readings were taken at the end of each day by a precise Negrette/Zambra aneroid barometer. During this time the sensor readings deviated by an average of ± 0.7% in comparison to the aneroid readings. The pressure sensor head is robust and requires no calibration.

The air flow sensor was calibrated to provide the average air velocity in the vertical exhaust duct in the test cell. This was done by measuring the average velocity in the duct by anemometers and adjusting the sensor span. The volume flow rate in cu m/s monitored in the exhaust duct is shown in the figure. ~~This was anemometers and adjusting the sensor span.~~ The volume flow rate in cu m/s monitored in the exhaust duct is shown in the figure. This was obtained by multiplying the sensor air velocity readings by the cross-sectional area of the flow opening where sensor was located. The stated accuracy of ± 0.3 m/s for the sensor may require an additional 0.12 m/s due to the fluctuations of CRT readings by one or two correction factors as mentioned above. The response time is less than a minute as can be seen from the time fan was turned on or off. After three weeks of operation it was noticed that the sensor was reading about 0.56 m/s (110 fpm) when the fan was off. This was due to the accumulation of dust/oil vapors on the sensor head. However, the flow read close to zero when the sensor head was cleaned with a tissue paper. Therefore, it is necessary to clean the sensor head whenever the flow readings deviate from the true flow readings before recalibrating the instrument.

The trunk cable supplied 24VDC to the sensors but the airflow sensor requires only 8-21VDC. For this purpose, a 781T 1Amp., 3-terminal regulator was installed between A50 Accessor and the sensor electronic board in order to provide the unit an input voltage of 15.3VDC. Also, false air flow readings may appear on the CRT when the velocity at the sensor location is below 0.25 m/s, as the sensor's minimum detection limit is 0.25 m/s.

The bottom two curves in the lower graph of figure 12 show the CO readings. The solid line is for the CO sensor fitted with an Ecolyzer diffusion type cell. The dotted line is for the sampling analyzer which was connected to the monitoring system by using a A-type Accessor. The readings provided by this analyzer are similar to those determined in earlier experiments with other laboratory analyzers during operation of the same

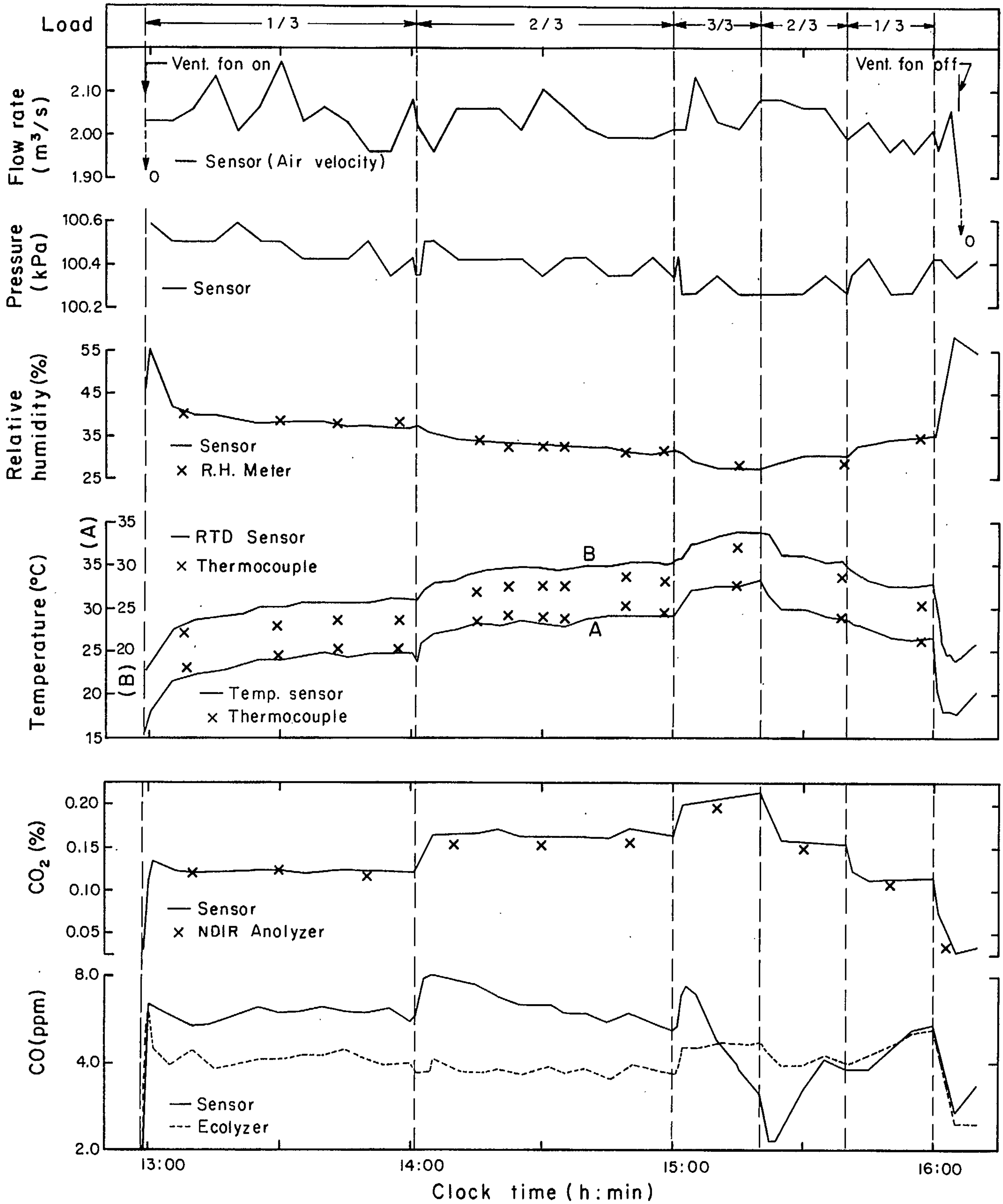


Figure 12. Monitoring of environmental parameters by the continuous monitoring sensors

engine loads and ventilation. The CO sensor concentrations were much higher than those of the analyzer when the engine was running. Also the sensor readings dropped when the test cell temperature was above 30°C, as seen from the temperature graph for the higher engine loads. Data for other days revealed that the sensor did not work when the test cell temperature was above 30°C or the relative humidity was below 25%.

The higher CO sensor values may be due in part to interference by other diesel produced gases, in spite of the sensor being equipped with an interference filter. The sensor's calibration drifted from 6% to 25% over five days when exposed to diesel engine exhaust. No significant zero drift was found. In summary, this type of sensor provided higher CO concentrations than those from a calibrated analyzer. It does not appear suitable for temperatures above 30°C or humidity below 25%, and requires calibration every fourth or fifth day. The response of the sensor was found to be within a minute.

The CO sensing unit fitted with a CO head manufactured by City Technology Laboratory (CTL), was also studied. Unfortunately, the sensor did not work on the day pertaining to figure 12. The cable in its enclosure was pinched by the cover when it was closed in the morning after it's calibration. However, analysis of other days data suggested that it functioned similarly to the sensor with Ecolyzer head mentioned earlier, except that high temperatures and low humidity did not affect its operation.

The $CO_2$ concentrations by a diffusion type sensor are shown by solid lines along with readings taken continuously by a $CO_2$ analyzer. This sensor provided trouble-free accurate readings. It is worth mentioning that this sensor did not need any calibration during the entire duration of the test period. The response time is also good as seen on the graph when the engine load is changed. The only problem with the instrument is that it provides output in DC volts which has to be converted manually from a nonlinear calibration graph to obtain $CO_2$ in ppm.

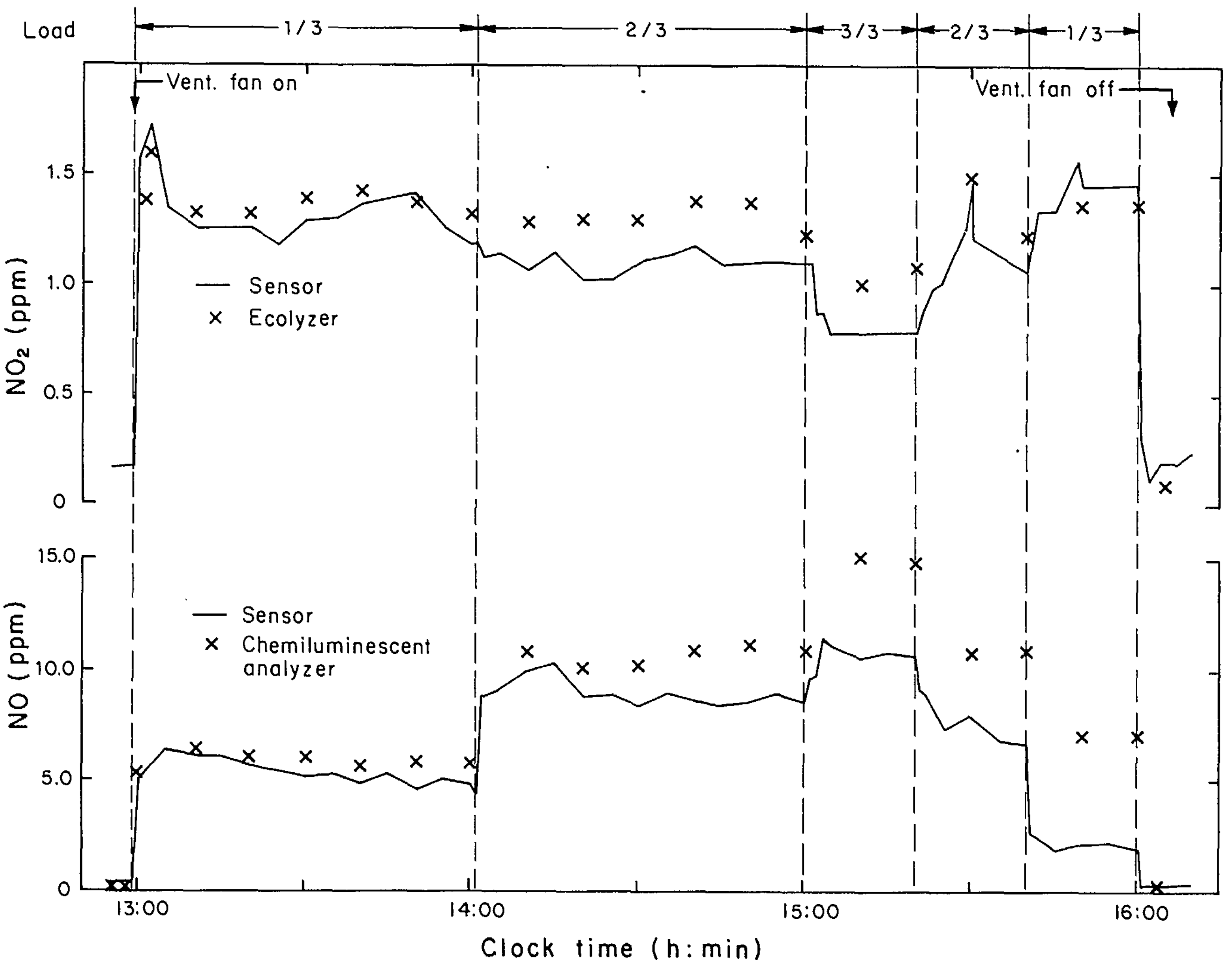


Figure 13. NO and $NO_2$ concentrations by the continuous monitoring sensors

However, this can be solved by changing the electronics of the instrument or providing a software for conversion in the computer system.

The NO measurements taken by the sensing unit and the chemiluminescent analyzer are shown in figure 13. It should be noted that the NO concentrations given by the sensor started drifting after about 1.5 hours, and in 3 hours the drift was significant - from 7 ppm to 2 ppm. The next day calibration with a standard span gas showed the drift to be 25% of the reading while no zero drift was observed.

The $NO_2$ measurements are also shown in figure 13 which shows a good correlation between the readings taken by the sensor and the Ecolyzer analyzer. The next day calibration did not show any drift in zero and span. The response time was good for both sensors. Unfortunately, these sensors were used only for two days of operation because of a 3 months delay in receiving electrochemical cells and a further 3 months delay in the delivery of the repaired sensing units.

The daily drift in the $SO_2$ sensor was found to be high, from 10% to 30% of the reading. It was necessary to calibrate the unit with a standard span gas on every day of operation. Therefore, the unit does not appear to be suitable for underground use. Also, in the beginning it was observed that the electrolyte from the voltammetric cell reached the rotameter. This was due to excessive pressure built up in the sensor. On the recommendation of the supplier some changes were made in the plumbing system of the instrument and a pressure release valve was added to the system.

The functioning of the methane sensing unit was checked in the test cell by injecting methane into the inlet of the ventilation fan and measuring it's concentration continuously both by the sensor located on the grid and by an infrared analyzer. For this test the outlet of the exhaust ventilation duct was covered with a plastic sheet with about 0.15m diameter hole in the centre of the plastic sheet to allow only small quantity of flow in the test cell. During this test methane at constant flow rate was continuously injected into the intake side of the fan and louvers located at the bottom of intake ventilation duct (see Figure 8) were opened to allow for recirculation of mixed air in the test cell. The mixing of the gas was confirmed by analyzing the samples drawn from a point close to the ventilation supply duct in the test cell and from the grid location. The analysis was done using an infrared analyzer.

The methane readings at the grid location taken by the sensor and the analyzer are shown in figure 14. As seen in the figure initially methane was injected at a flow rate of 1 L/s and later increased to 1.6 L/s to get a concentration of about 1.5%. At which time the methane supply was shut off. The figure shows a very good correlation between readings. The response time of the sensing unit is less than a minute. An attempt to repeat this experiment with the diesel engine running was not successful because the restricted airflow in the exhaust duct, required for reasonable methane flow rates and sufficiently high methane concentrations, resulted in very high pollutant concentrations and overheating of the test cell (50°C).

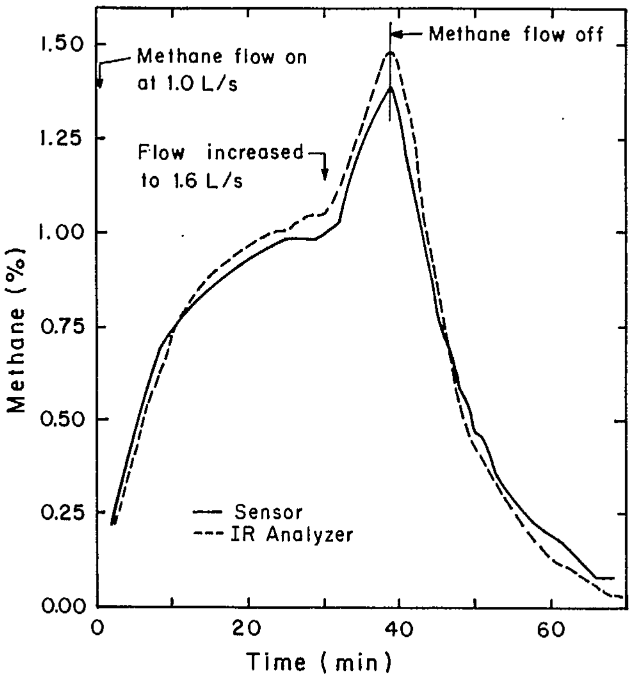


Figure 14. Methane concentrations by the continuous monitoring sensor

CONCLUSIONS

The Senturion-200 system performed satisfactorily after making changes in it's hardware.

All the non-gaseous sensing units and $CO_2$ sensor worked very well during the test runs. The $SO_2$ sensing unit lost calibration too quickly during the tests and is, therefore, not considerd suitable for underground use without improvements.

The air flow sensor's head required cleaning occasionally to remove accumulated dust/oil vapors. The sensor may provide false readings when the flow is less than 0.25 m/s.

The delivery of electrochemical cells used in some of the units and repair, may each take up to 3 months.

A suitable frequency of calibration and maintenance of sensing units is essential to produce reliable results from such a system.

## RECOMMENDATIONS

The CRT and printer should be connected to the UPS to monitor the environment continuously in case of power failure.

Sensing units should be designed to draw a minimum possible current from the trunk line cables, as the number of sensors used on a line depends on the amount of current drawn.

The sensors requiring 110VAC to operate should be modified to run on the trunk power supply. The $CO_2$ sensing unit should be modified to provide it's output directly in ppm of $CO_2$.

The complete monitoring system, with the array of sensing units should be installed in an underground mine for final evaluation if environmental control by such a system is contemplated.

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