Chapter 87

CONTINUOUS MONITORING OF NATURAL VENTILATION PRESSURE AT THE WASTE ISOLATION PILOT PLANT

Ian M. Loomis

Westinghouse Electric Corporation

Keith G. Wallace

Mine Ventilation Services, Inc.

The Waste Isolation Pilot Plant (WIPP) is a U.S. Department of Energy research and development facility designed to demonstrate the permanent, safe disposal of U.S. defense-generated transuranic waste. The waste storage horizon is 655 m (2150 ft) below surface in bedded salt. To date the WIPP project has not emplaced any waste.

There are three intake shafts used to supply air to the underground. All air is exhausted though a single return shaft. The total design airflow during normal operations is 200 m^3/s (424,000 cfm). The ventilation system is designed to provide separate air splits to construction, experimental, and storage activities. Separation is achieved by isolating the storage circuit from the construction or experimental circuits with bulkheads. Any air leakage must be towards the storage area of the facility. Field studies have shown that the pressure differential necessary to maintain the correct leakage direction is susceptible to the effects of natural ventilation; therefore, extensive studies and analyses have been conducted to quantify the natural ventilation effects on the WIPP underground airflow system. A component of this work is a monitoring system designed to measure the air properties necessary for calculation of the natural ventilation pressure (NVP). This monitoring system consists of measuring dry bulb temperature, relative humidity, and barometric pressure at strategic locations on surface and underground. The psychrometric parameters of the air are measured every fifteen minutes. From these data, trends can be determined showing the impact of NVP on the ventilation system during diurnal variations in surface climate. Both summer and winter conditions have been studied. To the author's knowledge this is the first reported instance of automatic and continuous production of time and temperature variant NVPs. This paper describes the results of the initial monitoring study.

INTRODUCTION

The ventilation system at the Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico, is designed to perform two distinct functions. First, it supports normal mine ventilation requirements complying with all state and federal mine regulations. Second, the system is designed to prevent an uncontrolled release of radioactive contaminants from the storage and transportation areas of the facility. Although a nuclear radiation release in the facility is considered unlikely, many special features are implemented in the ventilation system to prevent the possible spread of contamination.

The facility is constructed with the waste transportation and storage areas separated from the mining and non-radioactive experimental areas. The ventilation system is designed such that air leakage is from the mining and experimental areas to the storage areas. Furthermore, radiation detectors are located throughout the storage and waste transportation areas underground and an exhaust filtration building is installed on surface to prevent the possible release of radiation to the environment.

For over two years the underground ventilation system has been rigorously tested and balanced. It was during this period that the adverse effects of NVP were noticed and subsequently quantified. From extensive field studies and computer models, several mitigating features were designed and constructed and special operational procedures were implemented to control the impacts of NVP.

To quantify more accurately the NVP at the WIPP, a continuous monitoring system was installed. This monitoring system consists of measuring dry bulb temperature, relative humidity, and barometric pressure every fifteen minutes at strategic locations on surface and underground. From this psychrometric data, the NVP is calculated. Fan operating pressures and flows and strategic differential pressures are recorded from the site Continuous Monitoring System (CMS). The monitoring system provides a means of evaluating how the ventilation system behaves in regard to climatic conditions and to judge the efficacy of the mitigating features and operational procedures.

To the author's knowledge, continuous calculation of NVP as a function of time and surface temperature has not been previously reported.

Overview of the Waste Isolation Pilot Plant

The U.S. Department of Energy determined that the plastic nature of bedded salt may provide the best solution to isolate transuranic (TRU) waste from the biosphere. Initial evaluations at the WIPP site began in 1974. In 1979, the United States Congress enacted Public Law 96-164 for the construction and development of the WIPP project. The mission of the WIPP is to demonstrate the safe, long-term disposal of TRU waste generated by the national defense programs of the United States. TRU waste is classified as a low to medium level waste. The waste is stored in drums and does not produce significant heat (not greater than 1 W per drum).

The WIPP site is located approximately 47 km (29 miles) east of Carlsbad, New Mexico in the Chihuahuan Desert. The repository is located in the 630 m (2000 ft) thick Salado Formation. This Permian Basin salt deposit is about 225 million years old and appears to have been minimally disturbed by earthquake, faulting, and ground water activity since it was deposited. The underground facility is 660 m

(2150 ft) below surface approximately half way through the Salado Formation. Since 1984, non-radioactive experiments have been performed underground to determine rock behavior and fluid and gas transport. These experiments are important to determine the long-term performance of the repository. Experiments with nuclear waste, which have not yet been initiated, will evaluate the reactions between materials contained in the waste and the repository environment.

The facility is designed to accommodate eight panels, each with seven storage rooms. At present, only the first of these panels has been constructed.

Description of the Ventilation System

The repository is accessed by three intake shafts and one return shaft. There are three main areas to the facility; experimental, mining and storage. The three intake shafts at WIPP are the salt handling, waste handling, and air intake shaft (AIS). The exhaust shaft is the only return airway for the facility. During normal operation, most of the intake air enters the underground through the AIS. The salt handling shaft, which provides men and material access to the mining side of the facility and is used for the removal of the mined salt, is a secondary intake shaft. The waste shaft is equipped with an enclosed headframe, and is used for lowering the waste to the repository horizon. A controlled amount of intake air enters this shaft. The waste shaft air is immediately exhausted to return after ventilating the shaft station area. The waste shaft also provides access for men and materials to the waste storage area (see Figure 1). Air entering the AIS splits to the north and south ends of the facility at N300/E0 (see Figure 1). Air passing north circulates clockwise through the non-waste experimental area. Air passing south combines with the salt handling shaft intake air. At S1000 the air splits to either the storage area or continues south to the mining area. Air moves clockwise through the mining area and joins the experimental exhaust in E140 north of the waste shaft station. Storage area airflow is counter-clockwise from E140 through the panel and returns through E300. The return air combines with the mining, experimental, and waste shaft station exhaust at S400/E300. There are four main regulators which control the airflow through the facility, as shown on Figure 1. These are the mining regulator, located at the return end of the mining circuit, the experimental regulator, located at the return end of the experimental circuit, the storage supply regulator, located at the intake end of the storage circuit, and the waste shaft station regulator located at the return end of the waste shaft station.

The WIPP ventilation system operates under two normal configurations. The first configuration is called waste handling mode. During waste handling mode two main 450 kW (600 hp) centrifugal main fans operate in parallel to provide 200 m^3/s (424,000 cfm). In the second configuration, called waste storage mode, one or two main fans operate. With only one main fan operating a total flow of 120 m^3/s (250,000 cfm) is achieved.

To prevent the possible spread of contaminated air to the non-waste areas of the facility, the storage area is kept at a pressure below the mining and experimental areas. The differential pressure is typically 500 Pa (2 in. w.g.) and is influenced by the main fan configuration and NVP. The waste tower is also maintained under a negative pressure to ensure this shaft is always an intake.

In the event that detectable quantities of radioactive material are found in the exhaust air stream, the ventilation system is automatically shifted to filtration mode. In filtration mode, the storage supply regulator and a door in the common return drift from the experimental and mining areas (in E300) are closed (see figure 2). The main fans are turned off and a single 175 kW (235 hp) centrifugal fan is started.

The total facility airflow is reduced to a maximum of 28.3 m^3/s (60,000 cfm). All the air is routed through banks of air filters, including high efficiency particulate filters, before discharge to the atmosphere. The filtration capability is 99.95% removal of sub 0.3 micron particles.

EFFECTS OF NATURAL VENTILATION ON THE WIPP VENTILATION SYSTEM

At the WIPP facility, NVP arises from an imbalance in air density between the salt handling shaft, AIS, waste shaft, and exhaust shaft. During cool surface conditions, the density of the air entering the AIS and salt handling shaft is greater than that of the return air at the exhaust shaft. Reduced surface temperatures result in NVPs that assist in the direction of airflow.

During higher surface temperatures the opposite occurs. That is, the density of the air in the two open intake shafts is less than that in the waste or exhaust shaft. This results in a NVP opposing the normal direction of flow.

For both cold and warm conditions, the density of the air in the waste and exhaust shafts remain relatively constant. This is because the waste shaft collar is enclosed with a headframe that conditions the air before it enters the shaft. Hence, the NVP developed between the waste and exhaust shafts is small.

The airflow through the surface fans is maintained at a constant rate. Airflow sensors, located in the exhaust duct leading to the fans, monitor the flow and are used, via a computer, to adjust automatically the inlet vanes to the centrifugal fans. This is advantageous in maintaining an accurate, constant airflow to the underground. Maintaining a fixed flow fan results in the pressure developed by the fan system (which is a combination of the fan and inlet vanes) varying with the NVP. Hence, during cool surface conditions the fan system pressure is lowered by an amount equal to the NVP, and during warm surface conditions the opposite occurs. An equivalent pressure/quantity curve for the fan system is a vertical line (constant quantity), and any variation in NVP simply adds or subtracts from the fan system pressure to maintain the constant flow (assuming a constant airflow resistance underground).

As noted previously, the WIPP facility must meet certain differential pressure criteria across the waste tower and between the mining and storage areas. Additionally, minimum air quantities are required in specific underground areas for the activities planned in those areas.

Effects of Low Surface Temperature

During periods of low surface temperatures, the fan system pressure is reduced by the NVP. Because the NVP assists in the direction of airflow (which is equivalent to applying a forcing fan on the intake shafts), the pressure differential between the mining and storage sides of the facility are maintained in the correct direction. However, as the surface temperature falls, the intake air is redistributed among the intake shafts. More air enters the facility through the AIS and less through and salt handling shaft and waste shaft as the surface temperature falls. The reduced airflow through the waste shaft, and resulting decrease in waste shaft tower pressure, is not considered a problem when both main fans are operating. During stored waste mode with only one main fan operating, a decrease in airflow down the waste shaft as the surface temperature falls can result in significant reductions of airflow, and in some instances, even reversal of air up the waste shaft.

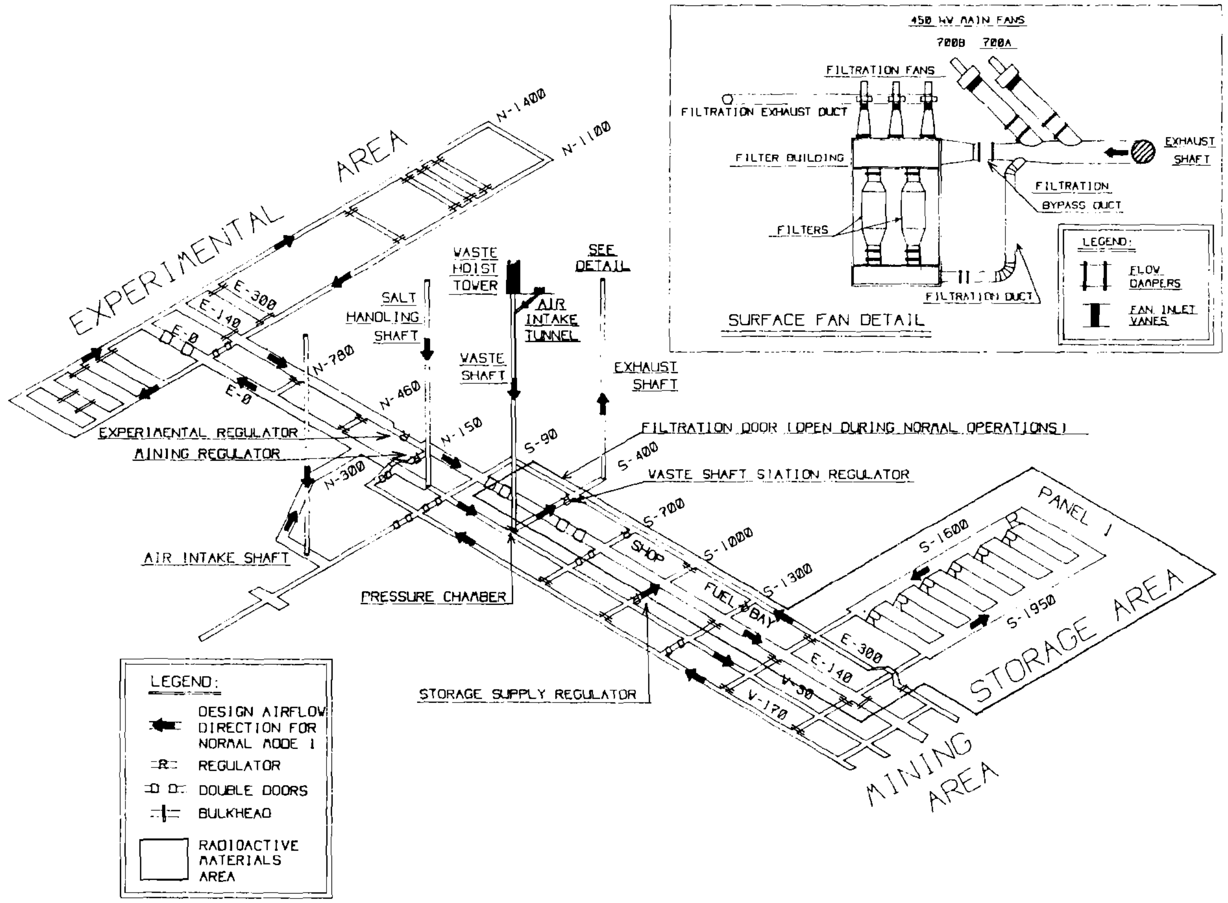

Figure 1. DETAILED DRAWING OF THE WIPP FACILITY, INCLUDING SURFACE FAN ARRANGEMENT

This is because the fan system pressure generated by one fan to maintain a constant flow (approximately 60% of the two fan system) is less than that for a two fan system. Hence, a large NVP can reduce the fan system pressure below the value necessary to maintain a negative pressure on the waste tower. To prevent this from occurring, procedures are in place that close the underground regulators at the return ends of the mining and experimental areas. By increasing the system resistance between the open intake shafts and return shaft, the fan system pressure is increased (because of the constant flow fans) and the waste shaft is maintained as a downcast.

Effects of Higher Surface Temperatures

During higher surface temperatures the NVP opposes the direction of airflow. This results in an increase the fan system pressure to maintain a constant airflow through the facility. For the normal configurations with one or two main fans operating, the airflow through the waste shaft is maintained constant by the regulators at the return end of the waste shaft station. The remaining intake air enters the facility through the AIS and the salt handling shaft. Because the waste shaft airflow is nearly constant for various higher surface temperatures, the intake air is not redistributed among the intake shafts similarly to that noticed during low surface temperatures. The tower pressure (top of the Waste Shaft) is maintained at a negative 500 Pa (2 in. w.g.). To prevent the tower from realizing a significantly larger negative pressure, special relief dampers were installed. These prevent the excessive pressures that could arise if the underground regulators were breached during high negative NVPs generated from warm surface conditions.

A reversed NVP applied to the intake shafts can result in a reduced pressure differential between the mining and storage areas. Such a reduction is particularly noticeable in the S400 cross-cut connecting the waste shaft station with the mining intake airway W30 (see Figure 1). The pressure differential at this location is dependent on the magnitude of the NVP between the open intakes, the waste shaft and the exhaust shaft, the frictional pressure drops in the airways, and the fan system pressure.

Variations in NVP between the waste shaft, the intake shafts and the exhaust shaft, obstructions (such as a work deck) in the intake shafts, adjustments to the underground regulators, and changes in the resistance to the waste shaft headframe enclosure can cause the airflow to reverse at this intersection. To prevent this from occurring, a pressure chamber was constructed in S400.

The pressure chamber consists of two bulkheads built in the S400 drift between the waste shaft and the W30 drift. The bulkheads are approximately 3 m (10 ft) apart and have two, interlocking airlock doors for access through the chamber from either side of the cross-cut. A compressed air line is supplied to the chamber. When the differential pressure between the W30 drift and waste shaft station falls below a set point, a valve is opened that allows compressed air into the chamber. A second differential pressure sensor is used to determine when the chamber has become pressurized to a sufficient value and the compressed air valve is closed. The process is repeated, as necessary, until the natural differential pressure across the chamber exceeds the set point. Additional engineering studies are presently being performed to install small, non-stall vane axial fans on the W30 bulkhead to pressurize the chamber continuously. If the fans are installed, compressed air would be maintained as a redundant system.

The NVP does not impact filtration mode. This is because the open intake shafts are isolated from the return shaft. Most of the air exhausting through the filtration fan enters the facility through the waste shaft. This configuration ensures that the differential pressure across the tower and between the mining and storage sides of the facility are maintained in the correct direction regardless of NVP.

MONITORING PLAN

In late 1990, a continuous NVP monitoring plan was developed for the WIPP facility. The plan consisted of installing independent monitoring stations located strategically on surface and underground to measure barometric pressure, dry bulb temperature, and relative humidity. The Central Monitoring System (CMS) was used to obtain continuous data on fan operating flows and pressures, differential pressures between the mining and storage areas and across the waste tower, and backup surface climatic conditions.

Calculation of the NVP is achieved by measuring the barometric pressure and computing the specific volume at the top and bottom of each shaft. From this information, a barometric pressure against specific volume graph can be produced. A linear relationship is assumed between the top and bottom of each shaft. A linear relationship is also assumed between the intake and return surface stations and between the intake and return underground stations. The area enclosed by the graph gives the natural ventilation energy (accounting for the work of the exhaust fan(s)). Multiplying the natural ventilation energy by the mean density of the intake and return shafts yields a value for NVP. To facilitate the calculations, a computer program was written for calculation of the NVP from the psychrometric data. Calculation of NVP at the WIPP site has been reported by Brunner, et. al., 1991.

Psychrometric Monitoring Stations

Each of the psychrometric monitoring stations consist of three main elements, the programmable controller, the barometer, and the relative humidity/temperature probe. The stations are powered by a 12 volt battery pack. Battery operated stations were selected because of the lack of power at some of the desired measurement locations, and to minimize dependence on the site electrical system. Provided the batteries are replaced regularly (every two months, or so), the system is reliable. The cost of each station was approximately U.S. $3,200 including equipment casing, interface hardware, and software for an IBM PC compatible computer. Figure 2 shows a typical underground monitoring station with the main components of the station labeled.

Site Continuous Monitoring System

Through a series of Local Processing Units (LPUs), the CMS monitors over one hundred site parameters each second. The parameters extracted from the CMS for the NVP studies are the mode of operation (waste emplacement, waste storage or filtration mode), the flow and pressure of each main or filtration fan, differential pressure between the mining and storage circuits underground (at two locations), and the differential pressure across the waste hoist tower.

In addition, the WIPP site is equipped with a site atmospheric monitoring station. This station monitors and reports to the CMS a large number of climatic parameters, including dry bulb temperature and dew point at 3 m (10 ft) above the surface and the barometric pressure (adjusted to sea level). This information is used as back up to the surface psychrometric monitoring stations.

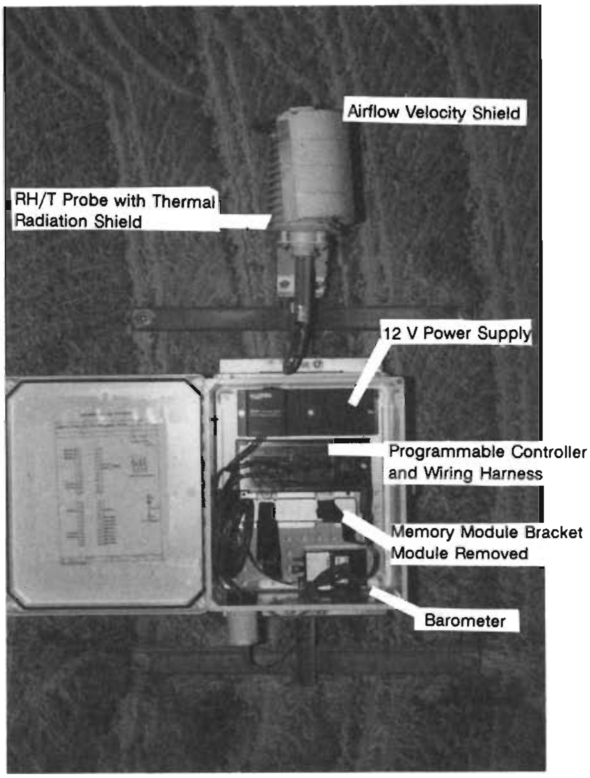

Figure 2. DETAILS OF TYPICAL PSYCHROMETRIC MONITORING STATION NOTE RELATIVE HUMIDITY/TEMPERATURE PROBE WITH PROTECTIVE COVER

Location of Psychrometric Monitoring Stations

As noted earlier, the NVP is calculated by measuring the air psychrometric properties at the top and bottom of each shaft. Psychrometric monitoring stations were installed at each of these locations except at the top of the AIS. Surface conditions for this shaft were extracted from the stations at the exhaust shaft and on the collar of the salt handling shaft.

To protect the RH/T probe, radiation shields were installed around the sensor heads. In high velocity airways, the RH/T probe was also protected by a metal shield (see Figure 2).

INITIAL RESULTS OF NVP MONITORING PROGRAM

There are eight psychrometric monitoring stations distributed throughout the facility. Data has been collected nearly continuously since January of 1991. Each station is programmed to collect data in fifteen minute intervals. This translates to 96 data sets per station per day. During the testing period, both cool and warm surface conditions and various modes of operation have been observed. To date, the monitoring stations have operated reliably. The only problem encountered was after initial installation when it was noticed that the batteries were losing their charge too quickly. This was overcome by modifying the wiring to the barometers and changes to the program software. Figures 4 and 5 show typical data obtained for a 24 hour period during the 20th May, 1991. Figure 3 illustrates the NVP and surface dry bulb temperature against time.

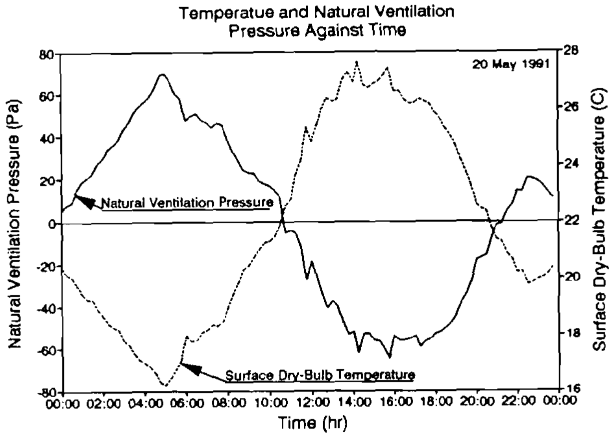

Figure 3. GRAPH OF SURFACE DRY-BULB TEMPERATURE AND NATURAL VENTILATION PRESSURE AGAINST TIME

This figure confirms that as the temperature increases, the NVP decreases, and vice versa. Furthermore, the results show that there is very little time lag between changes in surface temperature and changes in NVP. Figure 4 illustrates a plot of surface dry bulb temperature against NVP. A linear relationship can be seen between the temperature and the NVP. The hystereses shown on the to develop operating procedures and to test the installed mitigating infrastructure against the expected maximum

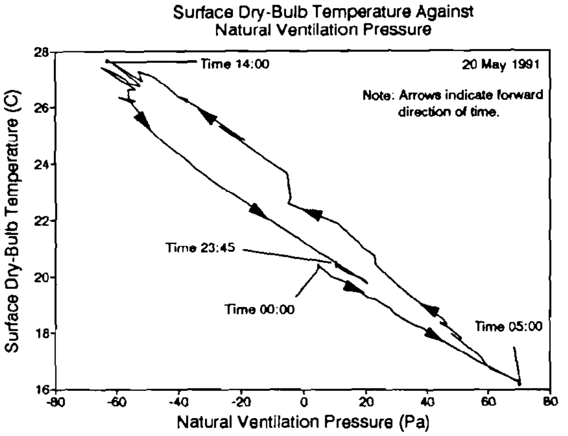

Figure 4. GRAPH OF SURFACE DRY-BULB TEMPERATURE AGAINST NATURAL VENTILATION PRESSURE

Figure is thought to be caused by heat retention in the main AIS liner.

Linear regression analyses were performed on several days of warm and cool surface conditions. Figure 5 shows the results of plotting the NVP against surface dry-bulb temperature using the average linear regression for these measurements. The R-squared value was about 98 percent for both the summer and winter data, indicating a good correlation. The average slope for winter measurements was more negative than for summer measurements with the y-intercept being greater for cool conditions. This is indicative of the increased heat transfer from the strata to the air during the winter months.

By extrapolating the summer and winter data, the maximum positive and negative NVP were estimated using the summer and winter 99% design dry-bulb surface NVPs. The monitoring program has been a valuable asset in evaluating the performance of the ventilation system. temperatures for the WIPP site (see Figure 5). These extreme NVP values were input to a ventilation model and the system behavior analyzed. This has allowed engineers

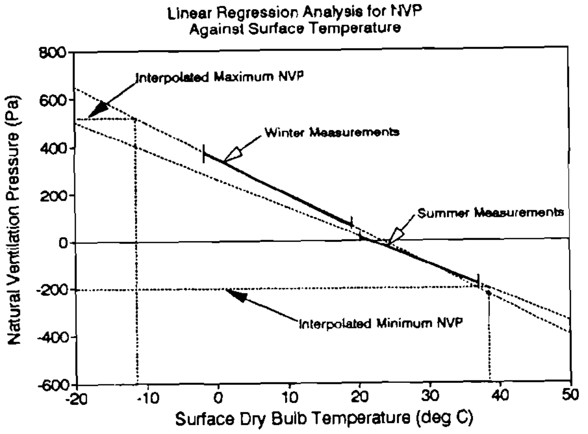

Figure 5. LINEAR REGRESSION ANALYSIS FOR NATURAL VENTILATION PRESSURE AGAINST SURFACE DRY-BULB TEMPERATURE FOR BOTH WINTER AND SUMMER MEASUREMENTS. INTERPOLATED MAXIMUM AND MINIMUM NVP VALUES BASED ON ASHRAE 99% DESIGN DRY-BULB TEMPERATURE

FUTURE APPLICATION OF MONITORING SYSTEM

The installed psychrometric monitoring stations provide a means by which dynamic control of the ventilation system may be possible. As discussed, the NVP can affect the airflow and pressure distribution at the WIPP facility. Any plan that provides dynamic control of the ventilation system must consider the effects of NVP. By connecting the monitoring stations to a central computer and developing a comprehensive expert system, control of the ventilation system could be enhanced.

Continuous psychrometric monitoring of all four mine shafts would provide the data necessary to calculate all NVP cycles by the central computer. These NVP cycles could then be directly input to the WIPP ventilation model and the model output used to prompt the operator on the optimum regulator settings. The operator could compare the current settings with the computer generated settings and decide whether an adjustment is warranted. The operator would keep the ventilation controls within a setting range specified by the expert system.

The programmable controller within the psychrometric monitoring stations is able to measure and record any signal from a transducer. For instance, it is planned to install a differential pressure transducer in the station at the base of the AIS. This transducer will be connected to a small diameter polyethylene tube that will extend the entire length of the shaft. The measured pressure drop will be used to determine the resistance of the AIS. This technique of differential pressure measurement in a shaft has been proven to give good results (McPherson, 1988; Deen, 1991). The purpose of measuring the shaft resistance continuously is because of the work deck that operates in the shaft. The work deck has been shown to vary the shaft resistance, depending on equipment on the deck and its position within the shaft. The variable resistance impacts the effects of the NVP on the ventilation system.

Use of the continuous monitoring program coupled with an expert system would provide a valuable tool for controlling ventilation operation. The monitoring system could be enhanced to provide information such as regulator settings, airflow and pressure differentials at strategic locations, fan operating duties, and air quality parameters. The monitoring program, combined with the expert system, would provide the operator with unparalleled monitoring capability, and direct control of the ventilation system. Long term trends in ventilation response could be recorded from such a program.

Additional capabilities of a complete monitoring system would be to measure the "thermal flywheel" effect caused by the retention and rejection of heat in the walls of the main intake shaft. Additional instrumentation within the shaft would be necessary but all the data could be recorded by the present monitoring stations. The central computer could analyze the data and evaluate the effects on the NVP.

CONCLUSIONS

During ventilation testing and balancing at the WIPP facility it was noticed that NVPs could impact system operation. During higher surface temperatures, it was possible to reverse the airflow and pressure differential between the waste shaft station and the mining intake airway. It was also possible to create an excessive negative pressure on the waste tower. Cool surface conditions, combined with only one main fan operating, could result in airflow reversing up the waste shaft. These effects on the ventilation system violate permissible criteria. To prevent these adverse effects, operational procedures were revised and new ventilation infrastructure constructed.

The new infrastructure included a pressure chamber between the mining intake and the waste shaft to prevent air leakage from the shaft to the intake and a pressure relief system installed on the air intake tunnel to the waste shaft to prevent a negative over-pressurization of the tower. To quantify further and evaluate the impacts caused by the NVP, a unique continuous monitoring plan was developed in late 1990. Continuous monitoring of NVP has not, to the author's knowledge, been previously reported.

Over six months of data has been collected by psychrometric monitoring stations. Preliminary analysis of this data shows that the NVP varies inversely with the surface temperature. Furthermore, a NVP against surface temperature graph is approximately linear with an obvious hystereses. The hystereses is thought to be caused by the heat retention of the liner in the main AIS. Regression analyses suggest that a linear relationship exists between NVP and surface dry-bulb temperature. The analyses showed that the cool weather linear relationship has a more negative slope and greater y-intercept than warm surface temperatures. Extrapolation of data has allowed the maximum positive and negative NVP to be estimated for both the summer and winter 99% design dry-bulb surface temperatures. Applying the extreme NVPs to a ventilation model has allowed engineers to evaluate the system performance and develop appropriate operating procedures.

Future applications of the monitoring system may include continuous calculation of NVP through a central computer. The computer also would retrieve data about the regulator settings, airflow and pressure differentials at strategic underground locations, fan operating duties, differential pressure on the tower, and air quality parameters. From this information, the computer would prompt an operator that an adjustment to a regulator or fan is necessary. The operator could then send a signal from the computer to adjust automatically the ventilation control.

The NVP monitoring program established at the WIPP has been a valuable asset in evaluating the underground ventilation system. The program will continue to provide useful information as the facility begins to receive waste and may become the foundation for a comprehensive ventilation monitoring system.

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