Measured Values of Coal Mine Stopping Resistance

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Abstract:

As coal mines age and become more developed, ventilation modeling becomes more important for the planning and continued operation of the system. Numerous studies have been performed and presented that address the collection of data and measurement of airway friction factor and resistance per unit length values. However, a quantitative analysis of the resistance for stoppings in coal mines for different construction materials and methodologies has not been adequately addressed. In order to develop an accurate/realistic ventilation model both airway resistances and stopping resistance values need to be determined. Over the course of the past two decades Mine Ventilation Services, Inc (MVS) has measured the resistance of stoppings of various construction types in mines throughout the world. An analysis of this data is presented in this paper along with a discussion of measurement methodology.

Introduction

The need to provide accurate ventilation models for subsurface coal mines has increased over the years with the expansion of existing operations. As mines have expanded, the working areas have become further from portal and shaft locations. Due to the extent and distance covered by some mines, the need to provide adequate engineering support to the ventilation system is increased. As the coal mines become larger the number of stoppings in the ventilation system increases. Each of these stoppings represents a potential leakage path. If these leakage paths are not adequately represented in the ventilation model, then the accuracy of the model will be questionable. The reliability of a ventilation model with inaccurate stopping resistances is jeopardized even if the airway resistances are correctly determined and modeled. There is little literature available concerning average resistances of stoppings in use at current facilities. The purpose of this paper is to present these resistance values so that they can be used and incorporated into ventilation models to provide a more accurate and useful tool for the ventilation engineer to use.

Methodology of Measurements

The resistance of a stopping can be measured in two different ways. One defines a single stopping and was described by the former United State Bureau of Mines (USBM). The other method, which MVS employs, measures the stopping resistance over many stoppings and then calculates an average stopping resistance per stopping. These two methods are described in the following sections.

Single Stopping Resistance (USBM)

The former United States Bureau of Mines described a technique where the leakage through an individual stopping could be defined (Weiss 1993). To measure the leakage through a single stopping, a temporary brattice is constructed on the low pressure side of the stopping. By leaving a small orifice in the brattice, the leakage can be measured accurately due to the consolidation of the airflow. At the time of the airflow measurement, a pressure differential across the stopping, or seal, should be quantified. The leakage and the pressure loss together will quantify the resistance of that particular stopping using the Square Law which is described later in this paper.
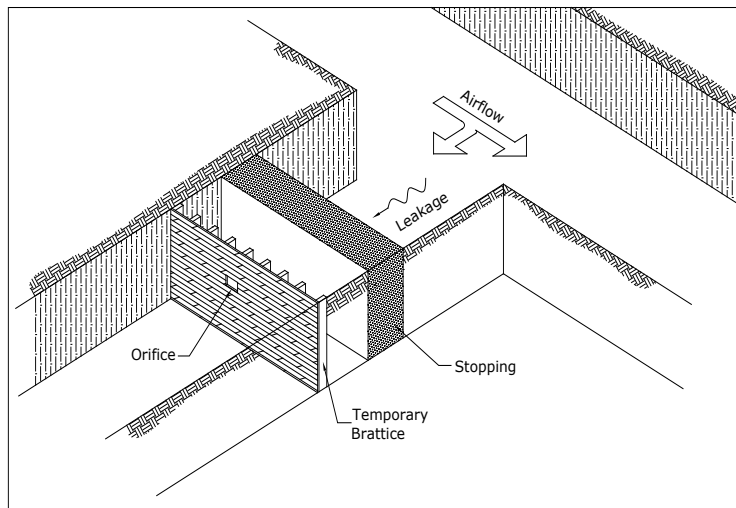

Figure 1: USBM method of measuring single stopping resistance.

This method is good for measuring one stopping, however if numerous stopping resistances are to be determined, this method becomes time consuming. In most cases a single stopping resistance is not reliable enough. It is better to have an average of numerous stopping resistances for the purpose of ventilation modeling due to the high variance of stopping resistances found in an average mine.

Average Stopping Resistance (MVS)

In ventilation modeling, stoppings are normally modeled in groups. Modeling each stopping individually can clutter a ventilation model making it hard, if not impossible, to utilize. In order to model several stoppings, the average value of several stopping resistances should be used rather than relying on a single stopping resistance value. Additionally, man doors are required to be built into stoppings periodically for means of egress and access. These doors lower the resistance of the stopping they are built in; therefore, the average resistance value for the all the stoppings in a mine can be substantially lower than the resistance of a single well built stopping. Mine Ventilation Services, Inc (MVS) has been measuring average stopping resistance in active mines for more than two decades using the averaging technique described below.

The basic concept is identical to the USBM technique, however rather than measuring the airflow and pressure through a single stopping, these measurements are taken though the mine over many stoppings. For example, Figure 2 shows a simple illustration of a three entry coal mine heading. The three entries are separated by two stopping lines, which include doors periodically (symbolized by a D). Two airflow measurements are taken at points A and B. The difference in these airflows is the total amount of air leaking though the stoppings from entry 2 into entry 1 between points A and B. In the case of Figure 2, five stoppings are averaged between points A and B from entry 2 to entry 1.
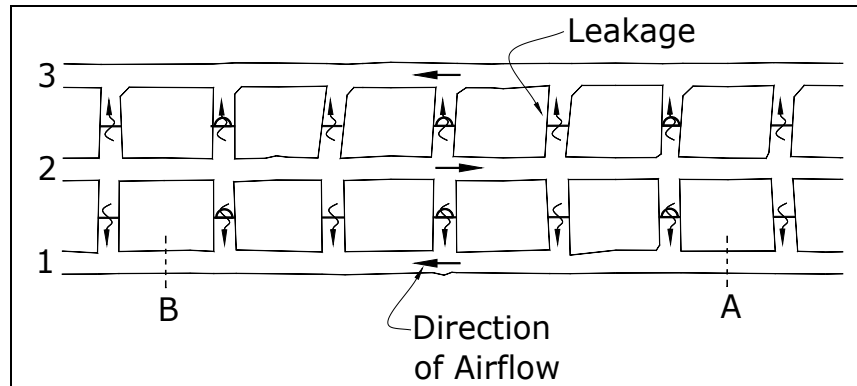

Figure 2: **Example of quantifying average stopping resistance.**

To quantify the resistance according to the Square Law, the pressure differential between entries 1 and 2 is also needed. The stoppings that have doors provide good access for measuring pressure differential. In Figure 2, three stoppings have doors between points A and B. These three pressure differential measurements are averaged to determine the average pressure differential from entry 2 to entry 1 between points A and B.

After calculating the total leakage and the average pressure differential per stopping between points A and B, then the Square Law (Equation 1) is used to calculate the resistance to leakage between points A and B.

Equation 1: $R = \dfrac{P}{Q^2}$

Where: R = resistance to leakage (Ns^2/m^8)
        P = average pressure differential (Pa)
        Q = leakage (m^3/s)

The resistance to leakage between points A and B is then equated to an average resistance per stopping by resolving for the number of parallel leakage paths between the two entries (Equation 2). The number of parallel leakage paths between the two entries is equal to the number of stoppings between the two entries; in this case there are 5 parallel leakage paths.

Equation 2: $R_S = R \times n^2$

Where: R_S = average resistance of a single stopping (Ns^2/m^8)
   R = resistance of leakage (Ns^2/m^8)
   n = number of separate parallel leakage paths

Using this method to determine the average stopping resistances at a mine is useful for various reasons. When compiling data for use in ventilation modeling, often the measurements taken in older areas of a mine are kept separated from newly developed areas. By taking averages though out the mine, different average stopping resistance values can be used to model different ages of construction. Additionally, different average stopping resistance values can be determined for different types of stoppings.

Measured Values

The MVS approach to determining average stopping resistance has been used by the company since they started performing full system ventilation surveys. The following section summarizes average stopping resistances that MVS has measured over the years. The two types of stoppings investigated are Kennedy panel stoppings and concrete block stoppings. The block stoppings can be wet stacked blocks or sprayed blocks.

The data presented below was gathered using the MVS average stopping resistance technique. Therefore these values include various conditions of stoppings including doors, layers of dust, settling, and new construction. All data has been standardized to an air density of 1.2 kg/m³. Figure 3 compares the average stopping resistance values for Kennedy and concrete block stoppings.

The four condition types listed are based on what MVS has observed most often in mines. Poor condition stoppings generally are old with several gaps or cracks that are allowing significant leakage. These stoppings are often in need of repair or are located in non-active areas of the mine that are projected to be sealed in the near future. Average condition stoppings are the most common in underground coal mines. These, along with good condition stoppings, represent the highest number of measurements. Good condition stoppings are well established with minimal noticeable leakage. Often these stoppings are well sealed with layers of dust and the doors shut tightly with no gaps. Excellent condition stoppings are highly resistive stoppings that have been sprayed with a sealant to reduce leakage. These stoppings have minimal leakage.

The average resistance per stopping for the Kennedy stoppings is lower than the average resistance per stopping for the concrete block stoppings for each condition. A good condition Kennedy stopping, however is comparable to an average condition block stopping. The sprayed block stoppings (excellent condition) are substantially more resistant than any of the other conditions of stopping.
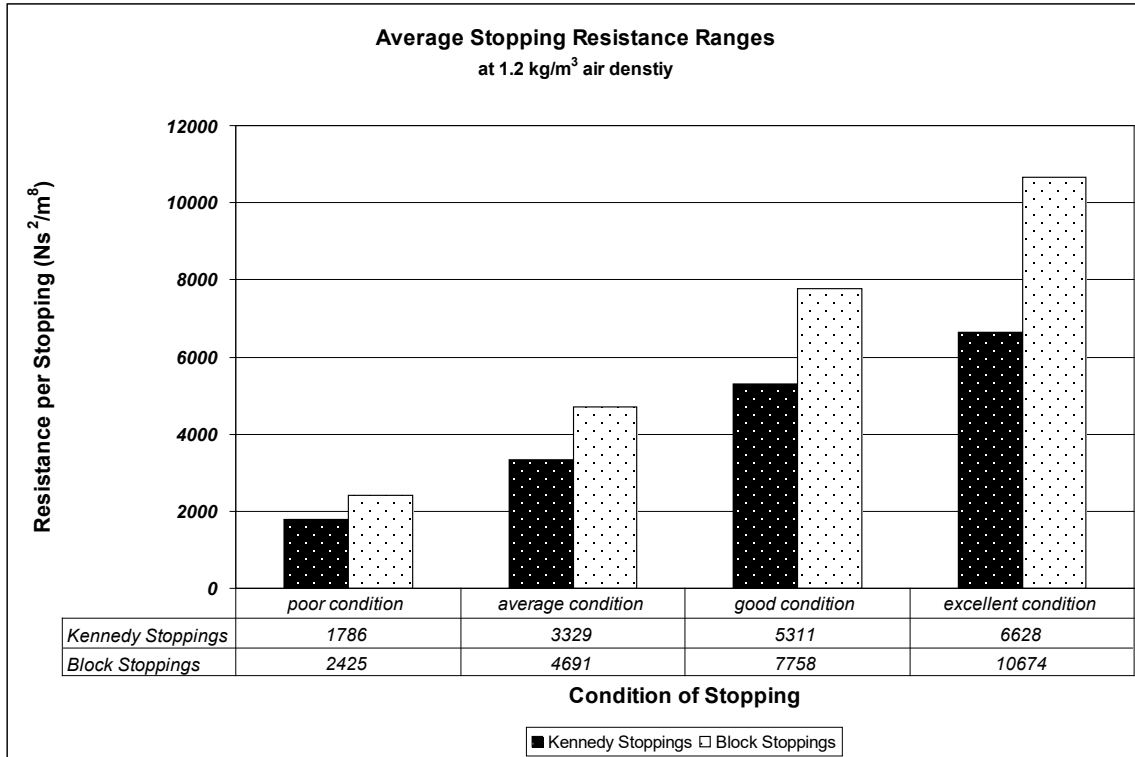
Average Stopping Resistance Ranges

at 1.2 kg/m^3 air denstiy

Resistance per Stopping (Ns^2/m^8) vs Condition of Stopping

	poor condition	average condition	good condition	excellent condition
Kennedy Stoppings	1786	3329	5311	6628
Block Stoppings	2425	4691	7758	10674

■ Kennedy Stoppings ☐ Block Stoppings

Figure 3: Average stopping resistance ranges based on type and condition.

Also noted were average measurements taken from a newly constructed concrete block stopping line which was sprayed with a sealant. These stopping resistances, taken from two separate mines, averaged to 51,696 Ns^2/m^8 per stopping. This show what resistance to leakage can be achieved with an ideally constructed sealed stopping. These types of values however, should not be used in modeling the average coal mine.

Applicable Use of the MVS Data

Ventilation systems can be modeled using the average stopping resistances calculated by the MVS method. To model ventilation systems with the MVS method a calculated average resistance for a single stopping must be chosen. This stopping resistance used for the ventilation modeling should be realistic. The resistance calculated for stoppings in average conditions illustrates stoppings which have been generally constructed properly and have adhered to normal deterioration from the surrounding environment. MVS has observed using the average condition resistance to develop ventilation models will provide a more realistic approximation of leakage through stoppings. Leakage paths modeled in ventilation system can be sufficiently represented using an average stopping resistance, calculated by MVS, for the expected conditions and type (concrete block or Kennedy).

Next, the calculated average stopping resistance selected for a single stopping will be extrapolated to multiple stoppings modeled in the ventilation system. If every stopping was modeled in a ventilation system the schematic would be difficult, if not impossible, to use. In order to extrapolate the average calculated resistance, the approximate number

of stoppings to be modeled needs to be determined. The number of stoppings to be modeled will determine the parallel factor to be used. A parallel factor is used to expand the selected resistance for one stopping too many stoppings. For example, a parallel factor of ten represents ten stoppings. Using a parallel factor will simplify the model without reducing the accuracy of the ventilation model.

Conclusion

As new or expanding subsurface coal mines are increasing in size there is an increased need for accurate ventilation models. With the expanding coal mines there is an increased number of stoppings being used, which create a greater number of leakage paths. To accurately model a ventilation system of a subsurface coal mine the leakage paths created by stoppings in cross-cuts must be represented. Utilizing inaccurate resistances for stoppings can compromise the integrity of the model. Stopping resistance can be calculated using two methods; the United States Bureau of Mines (USBM) method, used to determine a resistance for a single stopping, and the Mine Ventilation Services (MVS) technique, in which an average resistance is calculated for multiple stoppings. Through data MVS collected from ventilation surveys of different subsurface coal mines, average resistances for stoppings were determined for stoppings in poor, average, good and excellent conditions. The calculated average stopping resistances were determined for concrete block and Kennedy stoppings. Using the average stopping resistance, measured and calculated using the MVS method, provides a ventilation modeling tool which can be used to construct more accurate and useful ventilation models.

References

Weiss E.S. et al. "Strength Characteristics and Air-Leakage Determinations for Alternative Mine Seal Designs" USBM R.I. 9477, 1993, 21 pp.

MVS Archive Records 1995-2007