Improving Duct Parameters to Design Auxiliary Ventilation in Mining Roadways Driven

Phuong Thao Dang1* Van Duyen Bui2
1Hanoi University of Mining and Geology, Hanoi, Vietnam
2Vocational College Coal - Minerals of Vietnam, Vietnam
*Corresponding author’s e-mail: 3260726148@qq.com

Abstract. The level of air leakage of air movement through the duct to the face in underground mine is an important factor in ensuring the efficiency of ventilation during mining roadways being driven in mine. Ventilation ducting system leakage can, in many cases, supply an insufficient quantity of air to the workplace. Based on the experimental data of the duct leakage measurement when mining roadways driven in Ha Lam Coal mine, a relationship of leakage coefficient, aerodynamic parameter and geometric parameter of the duct has been derived; also maximum vent length with certain auxiliary ventilation equipments has been determined.

1. Introduction
Ventilation in an underground mine is of critical importance considerations in coal underground mines during mining roadways being driven in mine. In Quang Ninh underground mines, the total length of new driven roadways each year amounts over ten thousands meters. In an underground mine, over ten faces at which regular work continues are made to mining operations.

At there, auxiliary ventilation systems used is the force system, in which the fresh air is led to the face through the fabric duct when mining roadways are driven. Flexible ducts have often been manufactured by Vinacomin – Cam Pha Materials Trading JSC, however there is no data of duct parameters as duct leakage, duct system resistance produced domestically. These parameters have to been referenced from abroad handbook to design the auxiliary ventilation. This leads to inaccurate design and the need to adjust auxiliary ventilation system during roadways being driven in mine. In addition, duct parameters shown in the form of tables or graphs make not convenient in the ventilation design.

The paper presents has been undertaken to derive analytical expressions for a relationship between leakage coefficient, maximum ventilation length and duct parameters.

2. Auxiliary ventilation in mining roadways driven
2.1. Typical parameters for auxiliary ventilation when mining roadways driven
The forcing system of duct and fan consists of a line of ducting system, to which a fan is connected to force air with certain kinetic energy into the face. This energy source will gradually decrease due to resistance of air movement along the ducting system. When coming out of the duct system, the air will carry a certain kinetic energy to ventilate the working face. This energy source is higher, the
aerodynamic parameters is greater. During air movement from the fan to the face, air kinetic energy gradually decreases and the air potential energy gradually increases.

In order to design the auxiliary ventilation system, it is necessary to determine the following parameters:

- Maximum vent length with certain auxiliary fan and duct,
- Ratio of the quantity of airflow beyond the fan to quantity of airflow reaching to face,
- Quantity of airflow exiting from the ducting system to the face
- Duct system resistance,
- Ductwork is positioned at the heading cross-sectional area,
- Airflow velocity (fresh airflow) at the face and exhaust airflow velocity,
- Methane average concentrations and microclimate conditions in the face.

Many factors mentioned above have been studied quite adequately. However, the first two factors have not been studied specifically and often have been determined relatively from tables, graphs when designing auxiliary ventilation system. The maximum length and leakage of ducting system are closely related. Large air leakage leads to reduce the ventilation length for working face.

2.2. Auxiliary ventilation in Quang Ninh underground mine

In Quang Ninh underground mines, fabric ducts and different types of fans have been used for the auxiliary ventilation system. Flexible duct are very popular because they are light weight (about 10 times lighter than metal duct), easy to handle and install and have low capital cost. However, flexible duct is lower durability than other types of ducts. Depending on the environment and material quality, duct may be used for 5-6 months, sometimes it can be reach 1 to 1.5 years.

In practice, in Quang Ninh mines, PVC coated fabric duct is suitable for high power fan in order to reduce level of the air leakage and increase durability of the ducting system, especially at site where a duct connects to the fan.

Duct is available in various lengths, generally in 10-50 m lengths but the ducts of 20 m length are common used in Quang Ninh mines. Typical duct diameters range between 0.6 m and 0.8 m but rarely can use as 1.0 m. The total length of new driven roadways, as well the total length of ducting system amounts over ten thousands meters annually.

Depending on actual requirements of the auxiliary ventilation, coal mine companies often use duct types of different diameters. In Ha Lam Coal mine Company, fabric duct coated double-sided PVC, which has diameters in range 0.7 to 1.0 m, are widely used (Table 1).

Table 1. Different diameter types of the double-sided PVC coated duct used in Ha Lam mine

| Diameter (m) | Cost $10^3$ VND/m | Total length of ducting system (m) | Length of the duct, m |
|--------------|-----------------|----------------------------------|----------------------|
| 0.5          | 101             | 800                              | 20                   |
| 0.6          | 125             | 1800                             | 20                   |
| 0.7          | 150             | 2600                             | 20                   |
| 0.8          | 177             | 2000                             | 20                   |
| 1.0          | 216             | 2000                             | 20                   |

3. Estimating leakage coefficient of duct used in in Quang Ninh mines

3.1. Factors affecting on duct leakage

Important factors affecting on the level of air leakage are duct material and duct fabrication. The article has been researched on ducts produced by Cam Pha Material Joint Stock Company. These ducts are currently being used in many mines in Vietnam.

Ducts of different sizes and diameters

Air leakage level depends on geometrical dimension of the duct as the length and the diameter.

Aerodynamic parameters
Air volume is one of the important factors to consider when estimating air leakage through ducting system into the face.

Regarding the pressure in the duct, studies on the level of airflow to the face [1, 2, 3 and 4] make the following remarks: the variability of the pressure values inside ducting system is not much that influences air leakage level about 1-2%.

**Duct system resistance**

Duct system resistance affects the degree of air leakage when the joints are of poor quality, but in the case of good installation practices, local duct resistance in ductwork has small.

At present, the results of the air leakage coefficient have been shown in the form of tables or graphs for certain types of the duct. In addition, many results do not account for airflow in ductwork. Therefore, it is necessary to derive the function indicating a relationship between leakage coefficient p and ducting length L (m), duct diameter D (m), airflow in ducting system Q (m³/s) supplied to the working face for different diameters of the duct: \( p = f (L, D, Q) \).

### 3.2. Air leakage prediction equation

The purpose of the paper is to find the function of many variables based on the experimental data: \( p = f (L, D, Q) \).

However, in many mines in Vietnam, there are not many values of the experimental data of the duct leakage with different diameters. In Ha Lam coal mine, typical duct diameters are 0.7 m and 1 m but rarely can use as 0.5-0.6 m. In the paper, evaluating the air leakage coefficient for the ductwork of 0.8 m diameter has been developed based on the experimental data (Table 2) at Ha Lam Coal mine [5].

Therefore,

\[ p = f (L, Q) \]

Supposing that air leakage coefficient in the ductwork can be described to be in the form of:

\[ p = 1 + c * L^a * Q^b \]  \hspace{1cm} (2)

Where: p: Leakage coefficient;
L: Duct length, m;
Q: Quantity of airflow in the ducting system, m³/s;
a, b, c: constants.

The way to linear the equation (2) is to use the natural logarithm equation (2).

\[ \ln(p - 1) = \ln(c) + b_1\ln(L) + b_2\ln(Q) \]  \hspace{1cm} (3)

### Table 2: Experimental data for the duct of 0.8m diameter measured at Ha Lam Coal mine

| Face                        | S, m² | Local fan | \( Q_o \) m³/s | \( Q_{face} \) m³/s | Values of \( p_i \) correspond to ductwork length \( L_i \) (m) when extending driven roadways |
|-----------------------------|-------|-----------|----------------|--------------------|--------------------------------------------------|
| Vent. Roadways of Longwall 1011-3-T-15 Area III, Seam 11 | 9.4   | FBDN-6.0/2x22 | 6.8            | 5.4                | \( L_{max} \) \( P_1 \) \( P_2 \) \( P_3 \) \( P_4 \) \( P_5 \) |
|                            |       |           |                |                    | 380       60          120            240            380           --          |
|                            |       |           |                |                    | 1.259     101         1.015          1.079          1.2592        --          |
| Vent. Haul Roadways level -270+ -250 Area III- Seam 10   | 9.4   | FBDN-6.0/2x22 | 6.8            | 5.2                | 482       100         180            286            360           452         |
|                            |       |           |                |                    | 1.316     1.03        1.0625         1.1333         1.214          1.308        |
| Ven. Roadways level -50 Area VI- Seam 10                | 14.3  | FBDN-6.7/2x30 | 8.6            | 6.6                | 590       140          220            320            410           560         |
|                            |       |           |                |                    | 1.303     1.062       1.117          1.1467         1.229          1.303        |
| Ven. Crosscut level -70+ -60 Area II- Seam 10           | 15.3  | FBDN-6.7/2x30 | 8.6            | 7.0                | 452       100          180            240            340           410         |
|                            |       |           |                |                    | 1.223     1.062       1.103          1.117          1.147          1.212        |

\( L_{max} \): Duct length total
Each set of data: \( \ln(p_i) \), \( \ln(L_i) \) and \( \ln(Q_i) \) under given data – duct diameter, with \( i=1, 2...n \).
With ducting length \( L_i \), the quantity of airflow in the ducting system \( Q_i \) is measured; the air leakage coefficient \( p_i \) is calculated as \( p_i = \frac{q_i}{Q_i} \) [6];

Where: \( Q_0 \) the quantity of airflow beyond the fan, \( m^3/s; \)
\( Q \) the quantity of airflow reaching the end of the ducting length - \( L_i \).

\( y_i \), \( x_{1i} \), and \( x_{2i} \) are denoted as: \( \ln(p_1 - 1), \ln L_i, \ln Q \), and \( \ln C \) respectively.

Equation (3) can be rewritten:

\[
y_i = b_0 + b_1 x_{1i} + b_2 x_{2i} \tag{4}
\]

Using linear regression analysis to fit these experimental data can derive the relationship between the air leakage coefficient, the quantity of the air in the ductwork and the ducting length.

In the least-squares model, the best-fitting line for the observed data is calculated by minimizing the sum of the squares of the vertical deviations from each data point to the line (if a point lies on the fitted line exactly, then its vertical deviation is 0) [7].

\[
E [(y_i - b_0 - \sum_{j=1}^{k} b_j x_{ij})^2] \rightarrow \min \tag{5}
\]

\( y_i \): independent variables;
\( x_{1i}, x_{2i} \): dependent variables.

The least squares estimates must satisfy:

\[
\frac{\partial (y_i - b_0 - \sum_{j=1}^{k} b_j x_{ij})^2}{\partial b_j} = 0 \tag{6}
\]

And

\[
\frac{\partial (y_i - b_0 - \sum_{j=1}^{k} b_j x_{ij})^2}{\partial b_0} = 0 \tag{7}
\]

For \( i = 1, 2... n; j = 1, 2 \)

To normal equations for two independent variables are:

\[
\sum_{i=1}^{n} y_i = n b_0 + b_1 \sum_{i=1}^{n} x_{1i} + b_2 \sum_{i=1}^{n} x_{2i} \tag{8}
\]

\[
\sum_{i=1}^{n} x_{1i} y_i = b_0 \sum_{i=1}^{n} x_{1i} + b_1 \sum_{i=1}^{n} x_{1i}^2 + b_2 \sum_{i=1}^{n} x_{1i} x_{2i} \tag{9}
\]

\[
\sum_{i=1}^{n} x_{2i} y_i = b_0 \sum_{i=1}^{n} x_{2i} + b_1 \sum_{i=1}^{n} x_{1i} x_{2i} + b_2 \sum_{i=1}^{n} x_{2i}^2 \tag{10}
\]

The solution to the system of the normal equations above (8, 9 and 10) are the least squares estimators of the regression coefficients.

Therefore, the air leakage coefficient for the duct of 0.8m diameter can be found based on data at Ha Lam Coal mine:

\[
p = 1 + 1.3013, 10^{-5} \cdot L^{1.448266} \cdot Q^{0.45038} \tag{11}
\]

Use the F-test can evaluate Pro (F) = 0.0000 with significance level is 0.5. This low a value would imply that the regression parameters are nonzero and the regression equation does have some validity in fitting the data.

3.3. Calculating maximum ventilation length for a certain airflow volume requirements to the face

Analysing a fan curve

In mine, a fan sizes is selected normally based on experience. One of the auxiliary fans used commonly in Quang Ninh coal mine is SDF-No.6.5-22x2. This fan is a 2-stage fan with each 22kW motor, airflow capacities range 5.7- 10.0 m3/s, and static pressures normally vary between 540 and 160 mmH2O.

The fan curve \( H = f(Q) \) in the form of an inverse curve (Figure 1). Quadratic polynomial fit to these data is as follows:

\[
H_i = -27.66*Q^2 + 332.53*Q - 450.5 \tag{12}
\]

Where: correlation coefficient \( r^2 = 0.9997 \)

**Determination of the maximum vent length**
Where \( H_o \): Static pressure of the ducting system can be calculated as:
\[
H_o = R_o \cdot p \cdot Q^2 \quad [8]
\]
Combining equation (12) and equation (13), gives:
\[
R_o \cdot p \cdot Q^2 = -27.66 \cdot Q^2 + 332.53 \cdot Q - 450.5
\]
(14)

\( R_o \): Duct system resistance, \( R_o = 6.48 \cdot 0.00048 \cdot L/D^5 \) (k\( \mu \));
\( p \): Leakage coefficient

Under the conditions of this study: using the fan SDF-No.6.5-22x2, the ductwork of 0.8 m diameter and amount of airflow required at the stope face \( Q= 4 \text{m}^3/\text{s} \),

Substituting values \( p = 1 + 1.3013 \cdot 10^{-5} \cdot L^{1.4826} \cdot Q^{0.45038} \) [5] into (Eq.14) then obtains maximum vent length \( L_{\text{max}} = 972 \text{m} \).

Similar to calculate above mentioned, maximum vent length for different airflow volume required at the stop face Table (3).

Table 3: The relationship between ventilation length and airflow need to bring to the face

| Q, \( \text{m}^3/\text{s} \) | 4.0 | 4.5 | 5.0 | 5.5 | 6.0 | 6.5 | 7.0 |
|-----------------|------|------|------|------|------|------|------|
| \( L_{\text{max}}, \text{m} \) | 972  | 718  | 551  | 485  | 430  | 384  | 322  |

Based on calculated results, the fit curve shows the relationship between ventilation length and airflow volume requirements to the face \( L_{\text{max}} = f (Q) \).
Fig 2: The relationship between ventilation length and airflow volume requirements to the face using the fan SDF-No6.5-22x2, the ductwork of 0.8 m diameter

4. Conclusion
In Quang Ninh mine, Viet Nam, in the past, fabric ducts were often imported from abroad, so that parameters of duct as duct leakage, duct system resistance were referenced from abroad handbook. However, at present, there is no data of the leakage coefficient of the duct produced domestically. Accurately estimating the leakage coefficient is thus crucially important to proper duct sizing and fan selection.

Results estimated has been based on the experimental data in Ha Lam coal underground mine. Using linear regression analysis to fit these experimental data can estimated the air leakage coefficient in the ducting systems.

Also, the research result has been used to optimize the auxiliary ventilation system. Optimization of the auxiliary ventilation system can save cost and energy.

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