A study on relationship of duct leakage and parameters of ducts in Quang Ninh mine

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Abstract

Air leakage of auxiliary ventilation ducting systems is the most common reason for the insufficient fresh air in the working face in underground mine. This value is important design parameter for mine auxiliary ventilation system that operates more effectively, with lower cost.

Therefore, determination of air leakage along auxiliary ventilation ducting systems has been examined. Also, factors which affect air leakage in the ducting system have been investigated. Experimental data are made on 0.7 m and 1 m diameter ducts over sections of ducts installing towards the working face in Quang Ninh mine.

Keywords: air leakage, auxiliary ventilation, duct, analytic function, working face.

Introduction

In Quang Ninh, coal underground mines have high methane content and total length of new driven roadways is large for expanding mining areas and growing coal output. Therefore, ventilation is one of the most important considerations in coal underground mines. Ventilation efficiency depends on fan performance parameters and duct aerodynamic characteristics. The most common auxiliary ventilation system is comprised the ductwork and the axial fan. Flexible duct used is lightweight, easy to handle and install. However, ventilation ducting system leakage can, in many cases, supply an insufficient quantity of air to provide a healthy, safe environment in the workplace.

In Viet Nam, in the past, due to flexible ducts were often imported from abroad, parameters of the duct as duct leakage, duct resistance were referenced from abroad handbook to design the auxiliary ventilation system. However, currently, flexible ducts have often been produced domestically, determination of a relationship of the duct leakage and the duct aerodynamic characteristic must been undertaken.

The result is also the basis for making plan to equip ducts and fans for the auxiliary ventilation system in Quang Ninh coal underground mine.

Theory of duct leakage

Factors affecting on air leakage through the duct

A literature review on air permeability of different duct materials shows that flexible duct usually has a greater air leakage than other types of the duct [1, 2 and 3]. This is due to the fact that duct fabrication was previously unsatisfactory. However, in recent years, flexible duct has been improved quality. It shown that in some mines, amount of duct leakage has small, but in the case of poor installation practices, air leakage is high.

Factors such as duct size and diameter, aerodynamic parameters in duct airflow influencing on duct air leakage have been examined.

Ducts of different sizes and diameters

Air leakage of the ducting system is affected by the length of duct. Obviously, when the duct length is longer, the ducting system requires more joints. For flexible ducting system, air leakage through these joints cannot be avoided. The degree of the air leakage in the ducting system depends on duct diameter; if the duct diameter - D is larger, the degree of the leakage is smaller due to the resistance of the duct that is inversely proportional to D^5 [1].

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 100 m.

Table 1. Different diameter types of the double-sided PVC coated duct used in Ha Lam mine (Dec. 2018)

Diameter mm	Cost 10^3 VND/m	Total length of ducting system m	Length of the duct m
500	101	800	20
600	125	1800	20
700	150	2600	20
800	177	2000	20
1000	216	2000	20

Aerodynamic parameters

Aerodynamic parameters which, is factors, determine level of air leakage through ducting system. Many researchers have shown that air leakage is proportional to airflow through the ducting system [2, 3, 4 and 5].

Pressure loss H influences degree of air leakage through ducting system. However, at value of $H \geq 200$ mmH_2O, the air leakage is significantly reduced [2]. In practice, the pressure is always greatest adjacent to the fan and so air leakage at the location near the fan leaks significantly more than that at location further away. It was shown that at the pressure of 150 daPa – the pressure inside ducting system during mining roadways being driven in mine, air pressure along length of the duct remains stable due to duct material that protects elastic deformation [5]. However, increasing the pressure to 2000-3000 daPa, permeability through ducting system increases the two – three folds. These pressure values are much higher than the pressure value inside the ducting system during working operations (the highest pressure value is 500-700 mmH_2O).

Auxiliary ventilation in mining roadways being driven in Quang Ninh underground mine

Auxiliary ventilation systems used is the force system, in which the fresh air is led to the face through the fabric duct. Fabric ducts and different types of fans are used for the auxiliary ventilation system. The hundreds of auxiliary fans are required for example, over 100 fans in Mao Khe, Vang Danh coal mines.

At present, roadways in Quang Ninh coal mines have a cross-section 10-15 m^2, maximum 30-32 m^2, over ten thousands meters of new driven roadways are driven annually. In order to expand mining areas, two inclined shafts with the length of over 1600 m and 1 km in Khe Cham and Mao Khe Coal mine respectively have been done. Due to coal mining activities extending to the depth, the lengths of the roadway for getting one thousand tons of coal become longer, for example, from 11-12 m increase up to 17-18 m in Mao Khe, Hon Gai and Ha Long coal mine; particularly up to 20-25 m in Giap Khau, Dong Vong mine in certain years.

In underground mining operation, it is necessary to provide sufficient airflow requirement to ensure a healthy, safe environment in the workplace. Improper selection of fans and ducts can degrade the effectiveness of the ventilation system and increase the cost of ventilating the mine.

Model for duct leakage

Duct leakage

When air flow is moved in ducting system, air leakage is always presented. Air leakage is a complicated aerodynamic phenomenon. If there is not air leakage through the duct, the pressure of the fan generated and the air flow throughout the ducting system can be described by a model quite accurately. Air leakage can be described in the following two physical models [6].

- Discrete – air leakage leaks through joints of ductwork
- Continuous – randomly distributed outlets along the ductwork walls.

For estimating level of the air leakage, the researcher [7] proposed the flow of the air leakage leaks in turbulent flow mode; but researcher [8] proposed flow of the air leakage in laminar flow mode. The work [9] shown that the mode of the air leakage is quite complicated and close to exponential function. Therefore, the results of the air leakage coefficient have been shown in the form of tables or graphs for certain types of duct.

Duct leakage in Quang Ninh mine

With fabric duct being used in Quang Ninh coal mines, it shows that air leakage depends on duct fabrication, installation and maintenance of the ductwork as well as the usage time in certain conditions in mine.

Level of air leakage is mainly influenced by the following factors: total length, diameter of the ducting and airflow in the ducting system:

- Currently, in Quang Ninth mines, airflow volume Q_{face} supplying to the face changes from 2 to 8 m^3/s for the duct of D = 0.6 ÷ 0.8 m; sometimes 1.0 m for large cross-section roadway.
- When the length of the duct is extended from 100 m to 700, 800 m, air leakage will increase quite markedly. Leakage sometimes exceeds 15-20% initial flow volume designed over 100 m ducting length.

Relationship between air leakage and parameters of duct

It is shown how to derive the function indicating a relationship between leakage coefficient p and ducting length L (m), airflow in ducting system Q (m^3/s) supplied to the working face for different diameters of the duct:

$$p = f(L, Q) \tag{1}$$

Accordingly, assuming that air leakage coefficient in the ductwork can be described to be in the form of:

$$p\ = 1 + c * L^a * Q^b \tag{2}$$

Where: p: Leakage coefficient;
L: Duct length, m;
Q: Quantity of airflow in the ducting system, m^3/s;
a, b, c: constants.

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

$$\ln(p-1) = lnc + alnL + blnQ \tag{3}$$

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 $p_i\ = \frac{Q_0}{Q_i}$;

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

The experimental data are made on 0.7 m and 1 m diameter ducts over sections of ducts installing towards the working face in actual field conditions in Ha Lam coal mine.

Each set of data: ln (p_i), ln (L_i) and ln (Q_i) under given data – duct diameter, with i=1, 2…n.

Linear regression analysis by using Stata software 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. Therefore, the air leakage coefficient for the ductwork of 0.7 m diameter can be estimated based on the experimental data (Table 2) at Ha Lam Coal mine by the regression method.

As a result obtained from Stata software, the air leakage coefficient for the duct of 0.7m diameter can be found based on data at Ha Lam Coal mine:

$$p\ = 1 + 2.0042048.10^{-4} * L^{1.051706} * Q^{0.677522}$$

L_{max}: Duct length total (4)

Table 2: Experimental data for the duct of 0.7m diameter measured at Ha Lam Coal mine

The Face	Q_o m^3/s	L_{max} m	Q_{face} m^3/s	p	Values of p_i, Q_i correspond to ductwork length L_i when extending driven roadways					
					L_1		L_2		L_3	
					Q_1	L_1/P_1	Q_2	L_2/P_2	Q_3	L_3/P_3
Haul Road level -185÷ -160 Area III- Seam 11	6.8	290	5,0	1.261	6.4	80 1.063	5.8	160 1.104	5.0	290 1.261
Ven. Roadways level -270÷ -250 Area III - Seam 10	5.2	190	4.8	1.1554	4.9	89 1.06	4.9	120 1.106	4.8	180 1.123
Ven. Roadways level -50 Area VI - Seam 10	5.2	245	4.5	1.1304	5	120 1.102	4.9	160 1.091	4.5	240 1.16
Ven. Roadways level -70÷ -60 Area II- Seam 10	5.2	120	4.7	1.0612	5.0	30 1.02	5	60 1.04	4.9	80 1.0612
Ven. Roadways of the Long wall 7-3.1	6.8	258	5.2	1.3077	6.2	60 1.033	5.8	120 1.104	5.2	250 1.248
Ven. Roadways Level -290 Area I - Seam 7	*6.8*	235	5.5	1.236	6.6	80 1.061	5.8	225 1.172		

L_{max}: Duct length total

Table 3: Experimental data for the duct of 1m diameter measured at Ha Lam Coal mine.

The Face	Q_o m^3/s	Q_{face} m^3/s	L_{max} p	Values of p_i, Q_i correspond to ductwork length L_i when extending driven roadways													
				Q_1	L_1/P_1	Q_2	L_2/P_2	Q_3	L_3/P_3	Q_4	L_4/P_4	Q_5	L_5/P_5	Q_6	L_6/P_5	Q_7	L_7/P_7
Vent. Haul Roadways -290 ÷ -210 Area III to IV, Seam 10	9.2	6.9	900 1.334	9.1	50 1.011	9	140 1.023	8.6	320 1.09	7.8	600 1.179	7.6	740 1.211	7.2	760 1.278		
Ven. Roadways 7.2.1 Seam 7	12.2	8.6	1280 1.419	11.1	180 1.099	10.8	370 1.129	10.3	540 1.184	9.8	740 1.244	9.6	860 1.271	9.2	960 1.336	8.8	1180 1.386
Haul Roadways, 2.1 Seam 7	12.2	8.6	1250 1.419	11.6	180 1.051	10.7	380 1.14	10.2	500 1.22	9.8	680 1.245	9.2	780 1.2708	9	920 1.355	8.6	1160 1.418

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.

Data set (Table 3) for the duct of 1m diameter at Ha Lam Coal mine have been analyzed as the same above. So that, it can be found:

$$p = 1 + 2.554.10^{-5} * L^{1.164} * Q^{0.686} \quad (5)$$

Prob > F = 0.0000 with significance level is 0.5. This implies that the regression equation does have some validity in fitting the data.

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 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.

The leakage coefficient of the ductwork can be determined based on the general evaluation of the influence of the factors, in which the duct length and diameter, airflow in the ductwork are very important.

A conceptual prediction model has been proposed based on the experimental data at Ha Lam Coal mine. Using linear regression analysis to fit these experimental data can estimated the air leakage coefficient in the ducting systems in Ha Lam coal underground mine.

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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