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Development of a Low Pressure Auxiliary Fan for Local Large-opening Limestone Mines

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Abstract At present, local limestone mines with large opening employ auxiliary fans for workplace ventilation which have been used in coal mines with much smaller airways. Considering the low static pressure loss in the large-opening mines, high pressure auxiliary fans face serious economical limitations mainly due to their excessive capacity. The optimal fan selected for the ventilation in large-opening working places should supply air quantity enough for maintaining safe environment and keep its operating cost as low as possible. This study focuses on the development of a low pressure auxiliary fan designed to have smaller range of the static head but to have more potential for higher ventilation and energy efficiency. The flow characteristics of high and low pressure auxiliary fans were theoretical as well as experimentally investigated to assess the ventilation efficiency in term of environmental and economical aspects. Moreover, the low pressure fan was tested in two limestone mine sites with small and large cross-sectional areas for evaluating its ventilation efficiency. Results from this study can be applied to improve the economy and efficiency of auxiliary fan for ensuring better air quality and work environment management.

Key words CFD analysis, Auxiliary fan, Fan selection, Large-opening mine, Work environment management

초 록 최근 대단면 갱도로 개발하고 있는 국내 석회석광산은 작업공간 환기를 위하여 과거 석탄광산에 광범위하게 사용되던 형태의 국부 선풍기를 주로 이용하고 있다. 대단면 갱도에서의 낮은 정압손실을 고려할 때 고풍압 선풍기는 과다 설비용량으로 인하여 비용측면에서 심각한 한계를 보이고 있다. 대단면 갱도에서의 최적 선풍기는 안전한 작업환경 유지를 위한 충분한 환기량을 공급할 수 있어야 할 뿐만 아니라 저운전비용도 보장하여야 한다. 본 연구는 대단면 갱도 내에서 높은 환기효율과 경제성을 가지는 저풍압 국부선풍기를 개발함이 목적이다. 이론적 연구와 아울러 2개소의 단면적이 다른 현장 실험 연구를 통하여 저풍압 선풍기의 환기효율을 분석하였다. 본 연구결과는 작업공간 공기질 및 작업환경 개선을 위한 국부선풍기의 경제성과 효율 제고에 적용 가능할 것으로 기대된다.

핵심어 CFD 분석, 국부 선풍기, 선풍기 선정, 대단면 갱도 광산, 작업환경관리

1. INTRODUCTION

In 2013, Korea met its demand for limestone resources of between 80×10^6 to 90×10^6 Mt/yr almost completely from domestic production by more than 100 mines. In 2013, Approximately 75% of limestone was used to produce cement, 12.1% of limestone was consumed in the manufacture of iron and steel products, and the rest was consumed by manufacturing

Received: Dec. 10, 2015

Revised: Dec. 24, 2015

Accepted: Dec. 24, 2015

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in the chemical industry and other unspecified uses (USGS, 2015). Most of the large open-pit limestone mines have started to go underground in recent years due to the depletion of easily-accessible high-grade ore body near the surface and also the strict environmental regulations. Since the demand for limestone expected to increase, so these mines will be developed with larger entries at the deeper level.

Developing and mining operations are mainly carried out by the diesel equipment such as drills, loaders, scalers, trucks, utility vehicles and rock bolters. In addition, other key operations such as drilling, blasting, air transport cause heavily polluted air. At a working face, a number of diesel equipment is operating simultaneously; in general, one loader, one utility vehicle, three trucks and one excavator can be seen. Consequently, this intense use of diesel equipment enhances risk of Diesel Particulate Matter (DPM) exposure and mine fire initiated by diesel engines.

In fact, most of the common ventilation knowledge and techniques, which are utilized in some nonmetal mines like coal underground mines, are not adaptable to large-opening limestone mines. Due to the fact that the large entries reduce the ventilation resistance and permit large air quantities to flow under extremely small mine static pressure, the existing ventilation system with high pressure auxiliary fan in underground limestone mines is no longer suitable. This paper ultimately aims at developing an auxiliary fan for large-opening mines with higher ventilation efficiency and low operating cost.

2. CURRENT PRACTICE OF THE WORKING PLACE VENTILATION BY HIGH PRESSURE AUXILIARY FAN IN LOCAL LIMESTONE MINES

In general, most of local underground limestone mine rooms have been developed as large openings. Typically, the entries of room-and-pillar mines are 6-9 m high and 10-15 m wide with rampway of 10-13 % grade. Horizontal drifts with vertical elevation difference of 8-20 m are developed toward the strike direction, sometimes extending several kilometers. The number of drifts in each level depends on the

width of seam; generally 2-5 drifts. Because large dimensions in limestone mines absolutely require large air quantities, it could not provide sufficient air to the lower level without sinking ventilation shafts. To deal with this issue, the auxiliary fans have been commonly used. However, the common type of fan was originally developed and designed for coal mines where their average dimensions are relatively smaller.

Unlike most underground coal mines and metal mines, moving adequate fresh air volumes in large-opening room-and-pillar mines with high pressure auxiliary fan presents several challenges due to the large spatial volume of the mine and the extremely low airflow resistance. Specially, it is challenging to keep airflow velocities high enough to effectively remove or dilute airborne contaminants. To address to the current diesel particulate concerns, large drift limestone mines will need large air volumes, which can be delivered at very small static pressure losses. However, in the local limestone mine with large cross section area, the use of high pressure auxiliary fan is not suitable because the fan typically does not operate at low static pressures with high efficiency.

3. DEVELOPMENT OF A LOW PRESSURE AUXILIARY FAN FOR LARGE OPENING LIMESTONE MINES

3.1 Necessity of low pressure fan in large-opening mines

Selection of a proper fan for mine plays an important role for ventilation efficiency in mines. In general, mine fans utilized in underground limestone mines are usually high pressure axial-vane fan meanwhile the centrifugal and propeller fans are occasionally used. These fan types are each designed for specific applications, and the selection of proper fan depends upon the ventilation application. Particularly, the selected fan needs to overcome the mine static pressure loss from resistance and discharge the required air quantity (Grau III et al., 2004). The static pressure loss can be expressed by Atkinson formula for mine ventilation as follows:

$$P_{\text{loss}} = \frac{K.L.P.V^2}{A} \quad (1)$$

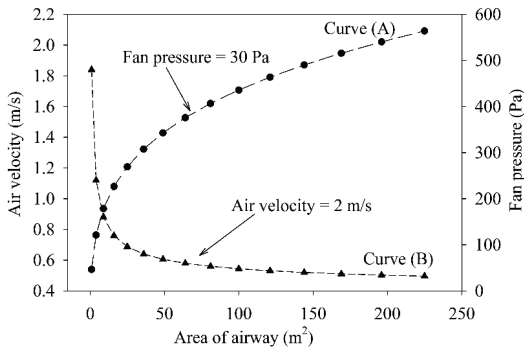


Fig. 1. Definition of distance between twin tunnels

- Where: P_{loss} - pressure loss (Pa)
- K - Frictional factor (kg/m^3)
- L - Length of airway (m)
- P - Perimeter of airway (m)
- A - Cross sectional area of airway (m^2)
- V - Air velocity (m/s)

The curve (A) in Fig. 1 shows the influence of dimension of airway on the air velocity generated by a constant fan pressure. It can be seen that if applying a constant fan pressure of 30 Pa, the air velocity created by this fan pressure increases when the dimension of airway increases. Meanwhile, curve (B) demonstrates the less fan pressure required to obtain the constant air velocity of 2 m/s. Therefore, Fig. 1 indicates that large amount of the air can be generated in large cross section area with only very little fan pressure.

The National Institute for Occupational Safety and Health (NIOSH) has investigated the unique ventilation requirements of large-opening mines to identify and to evaluate the effectiveness of various fan types to improve the ventilation and air quality in the underground workplace. Fig. 2 shows the airflow measurements with respect to distance from the two different fan types, ϕ 0.91 m vane-axial fan and ϕ 2.44 m propeller fan (Krog et al., 2006). The axial fan's high discharge velocity caused air recirculation within 90 m from the adjacent entries. High air velocity of axial fan moving down the main entry would catch the corner of the pillars and be directed perpendicularly down the cross-cuts (Krog and Grau, 2006). The high-speed of the expanding airflow caused the for-

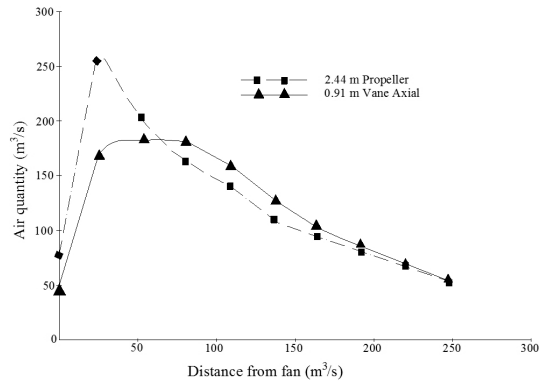


Fig. 2. Airflow characteristics for free-standing vane-axial and propeller fans (Krog and Grau, 2006)

mation of recirculation through the crosscuts. Conversely, in Fig. 2 the propeller fan moved a larger quantity of slower moving air and interacted differently with the surrounding air. In addition, the air leaving the propeller fan outlet was distributed rapidly over the entire cross-section of the drift (Krog and Grau, 2006).

By comparing different fan performances, many researches at NIOSH showed that propeller fans are more efficient at lower pressure and can produce larger air quantities at lower horsepower than axial-vane fans (Grau et al, 2002a, Grau et al, 2002b, Krog and Grau, 2006). In addition, due to the operational characteristics related to lower fan pressure and larger diameter, propeller fans provide better regional air coverage in large-opening mines than high pressure fan which have predominately been used (Chekan et al., 2006). Hence, based on the results presented in Fig. 1, 2 and some results of NIOSH, it can be concluded that low pressure fan is the most suitable for the ventilation needs in large-opening mines mainly due to the characteristics of producing large air quantities at lower power requirements.

3.2 Description of the low pressure fan

There are several principles to develop a low pressure fan as freestanding auxiliary fans in large-opening mines. Firstly, the low pressure fan is designed for low static pressure and large air quantities at higher efficiency. Secondly, the fan developed has to supply directly fresh air to the working places with air velocity allowed



(a) High pressure jet fan



(b) Low pressure jet fan

Fig. 3. High pressure jet fan

Table 1. Description of fan

Description	High pressure axial-vane fan (A)	New low pressure fan (B)	(B) / (A) (%)
Capacity (m ³ /min)	1,504	1,120	74.4
Pressure (Pa)	1275	235	18.4
Speed (rpm)	1,786	1,188	66.5
Total Efficiency (%)	39.7	60.5	+20.8
Power (kW)	37	15	40.5
Ampere (a)	62	28.9	46.6
Length (m)	3,450	2,230	64.6
Weight (kg)	1,090	792	72.6
Noise level (dB(A))	103 - 105	85	

under 4 m/s. Thirdly, based on the relationship between air velocity and relative dust concentration (McPherson, 2009), the expected air velocity supplying to working places of fan should be 2-2.3 m/s to minimize airborne dust concentration at working faces. Fourthly, the developed low pressure fan has to ensure to reduce hazard level including DPM and to create more safe working places. Finally, the fan developed has to minimize the operating cost. In brief, the low pressure fan must show environmental as well as economical advantages.

Based on the principles above, a new low pressure fan was developed. Fig. 3(a) shows an axial-vane high pressure fan which has been used commonly in large-opening limestone mines in Korea, while Fig. 3(b) illustrates a new low pressure fan being developed. The fan performance is presented in Tables 1 and 2.

It can be seen from Table 1 that the fan pressure of axial-vane fan (1275 Pa) was extremely higher than the new low pressure fan (235 Pa). The fan power of low pressure fan made up 40.5 % of the high pressure fan power. Similarly, the weight of low pressure fan constituted 72.6 % of high pressure fan weight. Being completely different, the total efficiency of low pressure fan is more than 20.8 % of high pressure fan. Their advantages and disadvantages are compared in Tables 2.

3.3 Computational Fluid Dynamics analysis

To assess the ventilation efficiency CFD analysis was carried out using ANSYS Fluent 15. Mine sites with 2, 3 and 4 entries were the targets for the CFD analysis. Fig. 4 shows one of the scenarios with three entries. The dimension of 310-410 m long entry was 10 m wide and 8 m high with 10 m × 10 m pillars.

Table 2. Comparison between high and low pressure fans

Comparing	Fan type	
	High pressure fan	Low pressure fan
Advantages	- Higher air discharge rate	- Less noise level (<85 dB(A)) - Higher fan efficiency - Lighter and shorter - Adjustable impeller blade angle
Disadvantages	- High noise level (103-105 dB (A)) - Low fan efficiency - Heavier and longer - Nonadjustable impeller blade angle	- Smaller air discharge rate

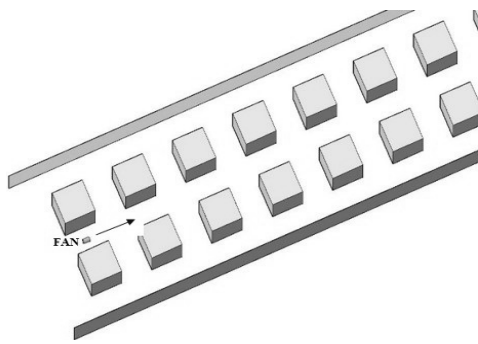


Fig. 4. Mine site for CFD analysis

Table 3. Fan characteristics in CFD analysis

Fan type		High pressure	Low pressure
Fan dimension	Discharge diameter (m)	1.2	1.2
	Length (m)	3.5	2.2
Power (kW)		37	15
Fan efficiency (h)		0.7	
Fan Pressure (Pa)		918	621
Fan discharge rate (m ³ /s)		28.2 m ³ /s	16.9 m ³ /s
Outlet velocity (m/s)		25	15
Duct installation		No	

The ventilation resistance (k) was assumed to be 0.014 kg/m³, which is a typical value measured in local limestone mines. The fan characteristics used for CFD analysis are shown in Table 3.

3.3.1 Air velocity distribution

To evaluate the ventilation efficiency, the air velocity along the main entry are compared. The results of

CFD analysis with high and low pressure fans are shown in Fig. 5. It can be seen that the airflow from two fans were significantly different. Fig. 5(a) (A-A') shows the velocity contours at 25m downstream of the high pressure fan. The airflow are concentrated at the center of the entry with the peak air velocity of 9.70 m/s. However, the fast-moving jet stream is much smaller with the low pressure. Fig. 5(b) (A-A') shows the cross-sectional velocity contour at same location, but the airflow was quickly dispersed across the entire drift with low-speed air with the highest air velocity of 7.89 m/s at the center.

A similar pattern is repeated at 105 m further down the entry. As shown in Fig. 5(a) (B-B'), the air stream recorded at 105 m downstream of the high pressure fan still keep a high velocity at the center, 6.82 m/s. However, in the case of low pressure fan, the highest velocity is measured at the center of 4.38 m/s. This implies the peak velocity decayed rapidly with low pressure fan. More details of characteristic of air velocity are described in the following section.

Fig. 6 shows the velocity profiles on the cross-section at 125 m downstream. Obviously, the velocity profile of the low pressure fan was much closer to the uniform over the most part of the cross-section. Moreover, the airstream leaving the low pressure fan expanded rapidly to cover the entire cross-section of the entry. This relatively uniform distribution of the air velocity indicates much better characteristics for contaminant dilution over the cross-section.

3.3.2 Air velocity recirculation

In local limestone mines developed mostly by the

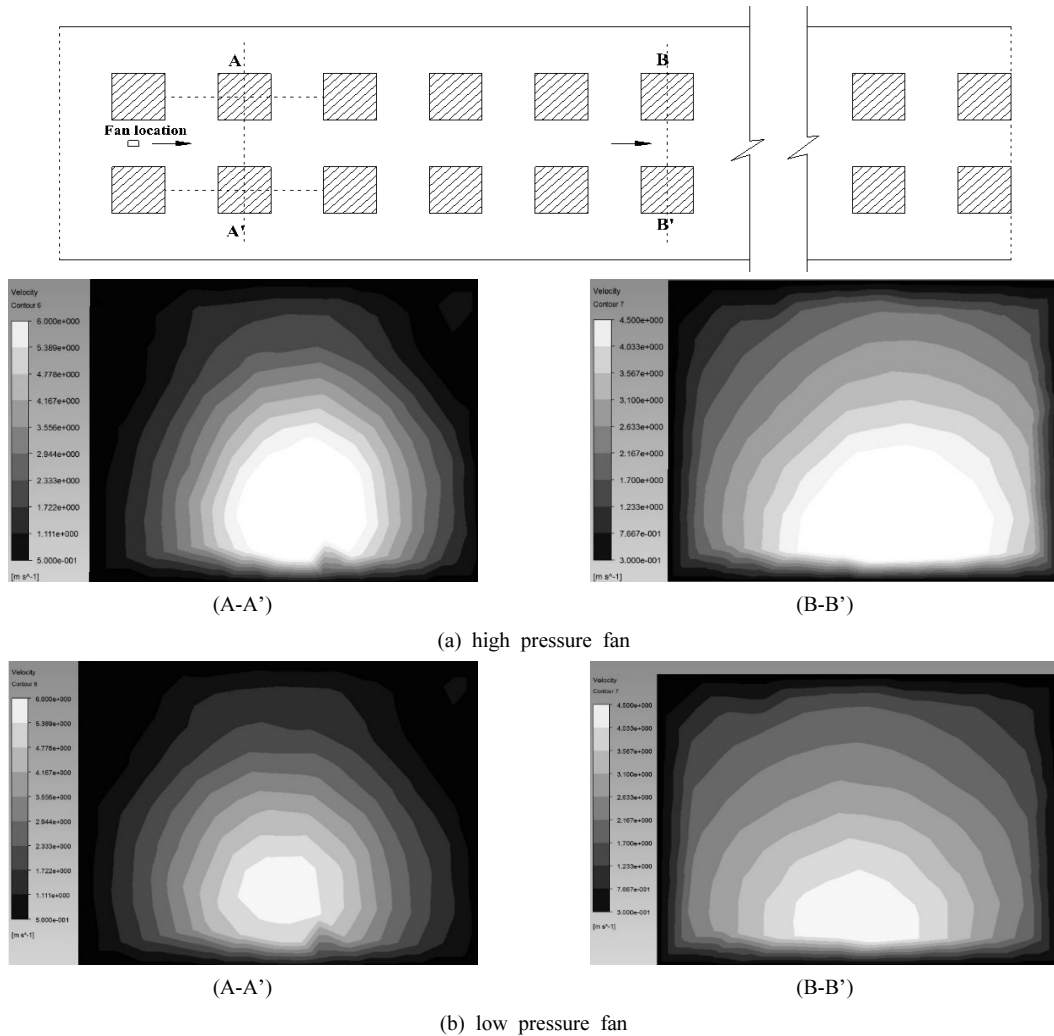
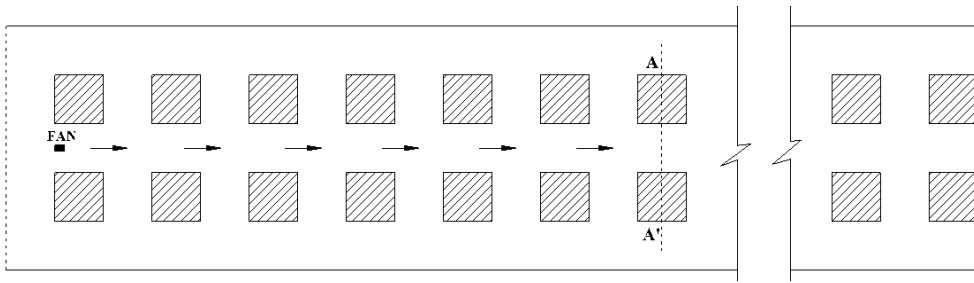


Fig. 5. Velocity distributions over the cross-sections at 1 and 5 cross-cuts downstream

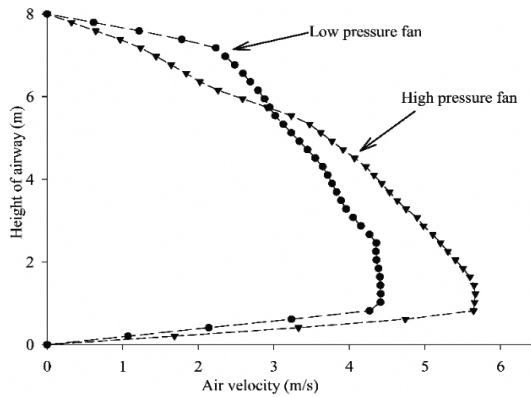
room-and-pillar mining method with large openings, the airflow pattern created by auxiliary fan is highly complicated, and consequently it leads to low ventilation efficiency. Increasing airflow rate of the fan results from raising kinetic pressure in the downstream but simultaneously lower static pressure. Due to the low static pressure, airflows through the cross-cuts are generated coming from adjacent entries to the fan entry. Thus, the airflow rate gradually increases along the downstream to a certain distance. This phenomenon, called venturi effect, exits in all the working without stopping line in underground limestone mine (Lee and

Nguyen, 2014).

The venturi effects were clearly demonstrated with high as well as low pressure fan in Fig. 7. The numbers in the figure are the flow velocity illustrating the air moved through the first and second cross-sections by venturi effects. The high pressure fan showing higher kinetic pressure resulted in higher venturi effects compared to low pressure fan. Particularly, the considerable amount of the airflow was recirculated through the first and second cross-cuts downstream. In the case of the high pressure fan, 16 % of the airflow at 25 m downstream and 7.2 % at 105 m downstream was

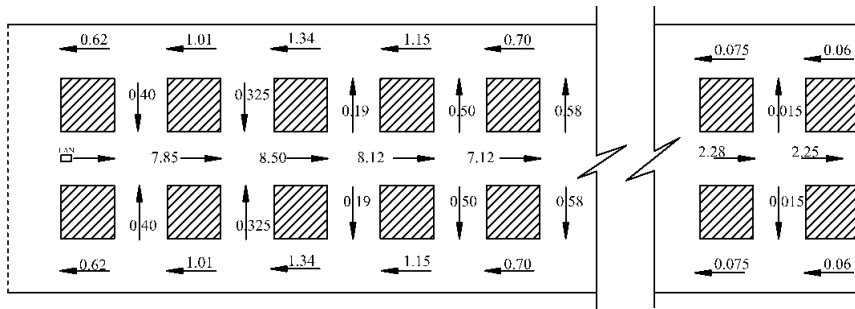


(a) Velocity measurement location (A-A')

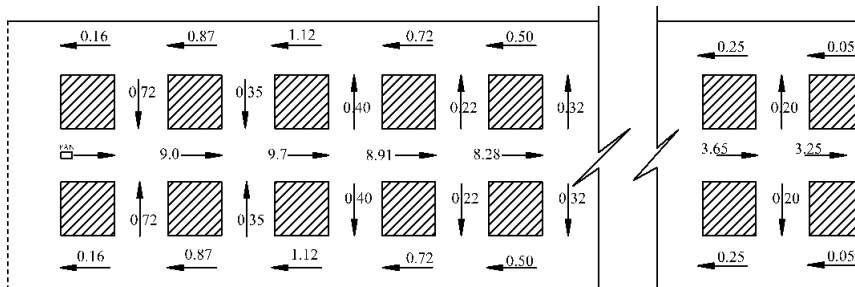


(b) Velocity profile over the cross-section (A-A')

Fig. 6. Velocity profile over cross-section areas at 125 meters distance from fan



(a) low pressure fan



(b) high pressure fan

Fig. 7. Velocity distribution of fans (unit in m/s)

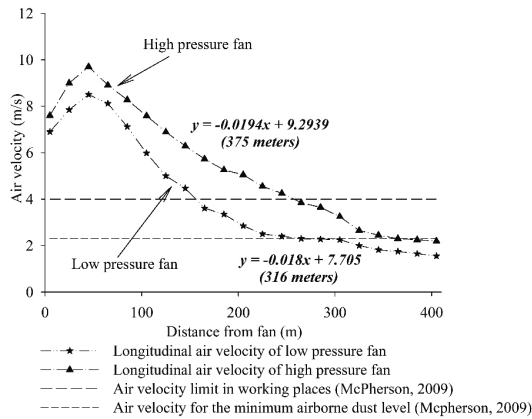


Fig. 8. Air velocity decay characteristics of fans

coming through the first and second cross-cuts. In contrast, this figures created by low pressure were 10 and 7.6 %, respectively. Hence, this means that air recirculation of contamination into the intake airway was smaller with low pressure fan.

3.3.3 Air velocity decay characteristics

The first step to design an effective ventilation system in large-opening limestone mines is to determine the total air quantity and flow pattern that is needed for effective dilution and removal of DPM and other contaminants. As previously noted, the fan has to supply directly fresh air to working places, and the ideal air velocity supplied to working spaces is about 2-2.3 m/s (McPherson, 2009). Due to these limitations, the total dust concentration can be minimized, and also it ensures to keep airflow high enough for effective removal and dilution of airborne contaminants as well as DPM.

To evaluate the air supply rate to working places, the velocity distribution of fan is calculated based on the CFD results. Fig. 7 shows the velocity distribution of the high and low pressure fans in case of three entries. It can be seen that the axial air velocities of the high pressure the fan entry were higher than the low pressure fan; at the last crosscut section 2.25 m/s with low pressure fan and 3.25 m/s with high pressure fan.

The graph in Fig. 8 demonstrates the velocity decay

characteristics. The decaying rates of the longitudinal velocity along the fan entry are similar with 0.018 and 0.019 m/s per meter for low and high pressure fans. However, the low pressure fan having relatively higher static pressure shows a stable velocity range between 200-320 m downstream, while in the same region the high pressure fan loses its kinetic energy at a much higher rate. This difference implies the low pressure fan can be employed to supply a stable airflow rate to the working spaces approximately 200-320 m downstream. Another aspect observed in Fig.8 is the distance where the velocity decrease to 2 m/s, which was suggested as an upper limit of the velocity at the working place by McPherson (2009). The different in the distance was only 59 m, less than three cross-cuts with low pressure fan. As a result, the identified velocity decay provided the options to determine the suitable location to install fan to ensure the ventilation efficiency.

3.3.4 Economic consideration of fan

To compare the economical aspect of fans, the operating costs of fan are compared. Under the consumption of annual operating hour of 8 hours/day, 365 days/year and the power cost of \$ 0.08 per kWh. As a result, the total annual cost can be calculated as follow:

$$\text{Cost}_{FAN} (\$/\text{year}) = \left(\frac{P_{Fan} \cdot Q}{1000 \eta} \right) * e * \frac{8\text{hrs}}{\text{day}} * 365\text{days}/\text{yr} \quad (2)$$

In which: F_{pressure} : Fan pressure (Pa)

Q : Airflow (m^3/s)

η : Efficiency of fan

e : Unit cost of power \$ 0.08 per kWh

As shown in Table 4, results in higher horsepower requirements of high pressure fan leads to higher operating cost. Particularly, the operating costs were 8,639 and 3,502 \$/year for high and low pressure fan, respectively. As a result, operating the high pressure fan costs was 2.47 times higher than low pressure fan. This helps to increase ventilation efficiency in term of economical aspect in large-opening underground mines.

Table 4. The cost of fan operation per year

Economic consideration	Low pressure fan	High pressure fan
Fan Pressure (Pa)	621	918
Airflow (m ³ /s)	16.9	28.2
Efficiency of fan (η)	0.7	
Cost of power (\$/kWh)	0.08	
Cost of operation (\$/year)	3,502	8,639
Comparing cost of operating of fan	2.47	

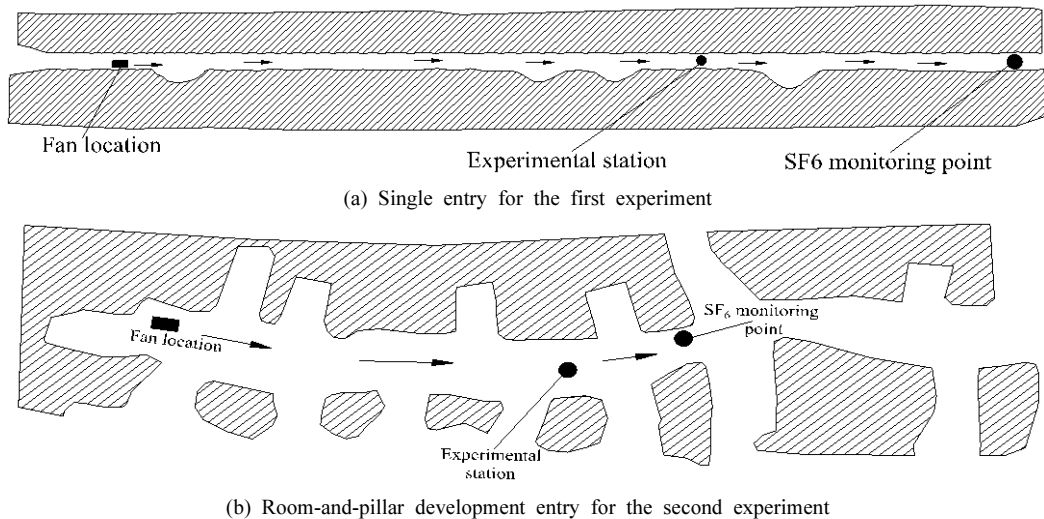


Fig. 9. The location performed two experiments

3.4 Experiment of the low pressure fan performance

On site tests were carried out to evaluate the performance of the low pressure fan developed in this study. The low pressure fan henceforth, called “the test fan”. The test site was a large-opening limestone mine at Samchock. As shown in Fig. 9, the first test location was a single entry with 6.15 m wide and 5.45 m high, initially developed as a ventilation slope. The second one was a room-and-pillar development section with 15.5 m wide and 7.1 m high (Fig. 9b). The main objective of the test was to measure the performance of low pressure fan, fan pressure and induced velocity. During the two experiments, the natural ventilation pressure was measured ahead of the fan startup, and the air velocity was monitored at several locations downstream. Since the cross-sectional area was not constant in the airflow path, SF6 tracer

gas was used to measure the air velocity. At the same time, the ventilation resistance coefficient, (k) in Atkinson equation, was derived to calculate the fan induced pressure in the entry.

The airway for the first experiment was 375 m long with the area of cross section of 33.5 m². The fan was installed at one end of the airway and the air flew down a slope of 4.5 %. In the second test, the fan was placed in a dead end entry with the cross-sectional area of 110.1 m². While the natural ventilation pressure was clearly observed in the first test, the isolated location of the entry in the second experiment resulted in no natural ventilation effect.

Frictional pressure drops through airways can be determined accurately using gauge-and-tube technique. The gauge and tube method allows the direct measurement of frictional pressure differentials using a

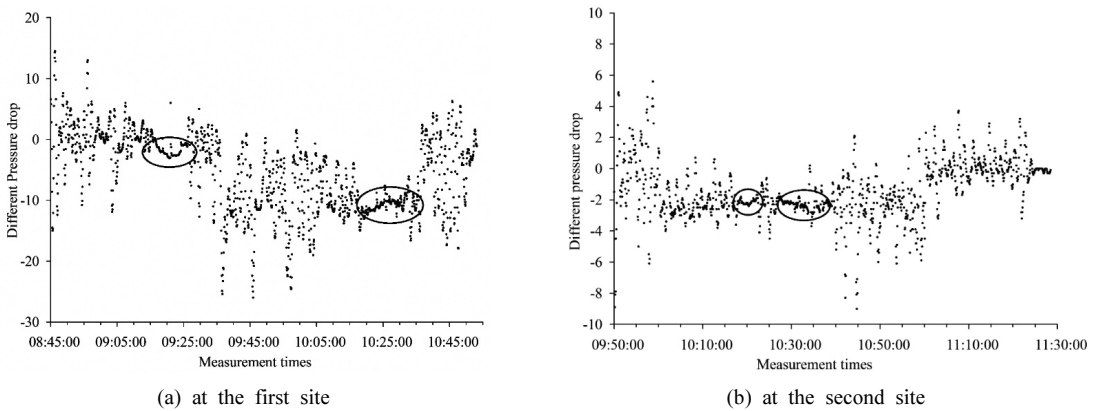


Fig. 10. Variation of differential pressure

Table 5. The estimation resistance coefficient (k)

Experiment	Time	Fan operation time	ΔP (Pa)	V (m/s)	Resistance coefficient (k)
First test	9/21/2015	2: 40 PM ~3:00 PM	-0.195	0.884	0.0012
		3: 26 PM ~ 3:50 PM	-7.426	1.533	0.0150
	9/22/2015	9: 20 AM~ 9:28 AM	-1.684	0.915	0.0095
		9: 50 AM ~ 9: 54 AM	-8.658	1.612	0.0158
		10:20 AM ~10:29 AM	-10.763	1.531	0.0218
Average (k)					0.0126
Second test	11/10/2015	1:05 PM ~ 1:55 PM	0.031	0.134	0.0442
		2:45 PM ~ 3:00 PM	-2.089	0.980	0.0554
	11/11/2015	10:18 AM ~ 10:21 AM	-2.163	1.027	0.0522
		10:26 AM~10:33 AM	-2.265	1.041	0.0532
	Average (k)				

digital manometer connected to a length of tubing, the ends of which are connected to the total pressure ports of pitot static tubes. Fig. 10 demonstrates the results of pressure drop collected by gauge-and-tube method. It can be seen that the value of recorded pressure was fluctuated dramatically. Two main reasons can be formed for the variation of differential pressure. The fluctuating natural ventilation pressure and the movement of workers and equipment near the sites. From Fig. 10, two segments for each test are chosen for estimating (k), since these segments show relatively stable pressure differential:

9:20 AM and 10:19 AM in the first test and 9:31 AM and 10:26 AM in the second one. The estimation

results for (k) based on Atkinson equation are shown in Table 5. The resistance coefficients (k) of the second test site are extremely higher than the first site mainly due to the cross-cuts connected to the adjacent entries. The observation of higher resistance coefficient in the second test performed in a room-and-pillar mining section is due to the existence of cross-cuts between the fan and the monitoring station.

As discussed above, the dimension of airway impacts on velocity created by constant fan capacity (Fig. 1). Therefore, to evaluate the velocity created by the test fan, the SF_6 tracer gas method was used to determine air velocity. This method is useful in evaluating the effectiveness of auxiliary fans, measuring low flow

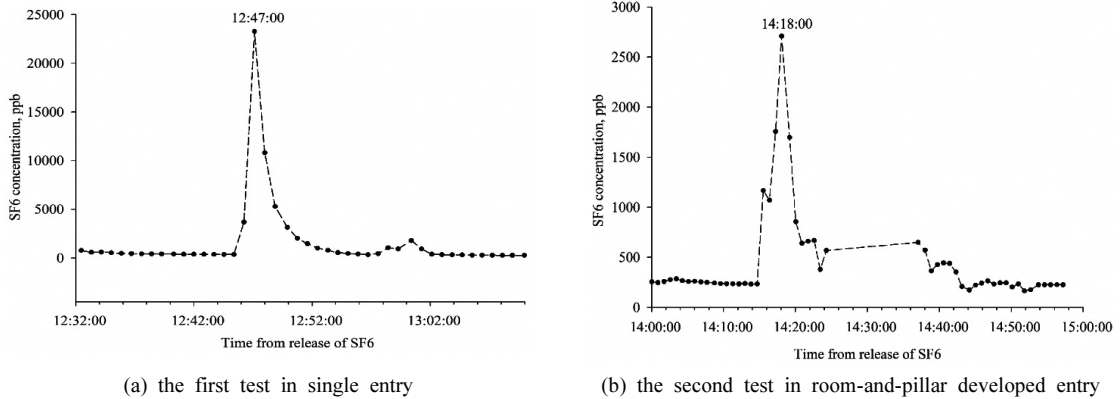


Fig. 11. SF₆ concentration measured at the monitoring station

Table 6. Results of two experiment of SF₆ tracer gas method

Experiment	First experiment	Second experiment
Distance between fan and monitoring station (m)	325	125
Drift height (m)	5.45	7.1
Drift width (m)	6.15	15.5
Resistance coefficient (<i>k</i>)	0.016 - 0.036	0.074 - 0.092
Arrival time of SF ₆	8 minutes	2 minutes 35 second
Average velocity (m/s)	0.68 (A)	0.81 (B)
Comparing velocity (B/A)	1.2	
Average air quantity (m ³ /s)	22.69 (A)	88.75 (B)
Comparing air quantity (B/A)	3.9	

velocities, probing the air circulating near a working face region where ventilation appeared to be poor, and estimating volumetric flow rates in airways of large cross-sectional area and having low flow velocities (Thimons et al., 1974). The results of the SF₆ dispersion experiments are shown in Fig. 11.

Fig. 11 demonstrates SF₆ concentration after releasing into the atmosphere. In the first experiment SF₆ was dispersed at 12:40 PM, 7 minutes later SF₆ was detected and then reached the peak concentration at 12:48 PM. The distance from point of releasing SF₆ to sample location was 325 m, and the peak concentration arrival of SF₆ gas to the monitoring station mainly due to the advection took 8 minutes. It indicates the average velocity of the air was about 0.68 m/s. Similarly, in the second experiment at larger cross-section area with

higher resistance coefficient, the average velocity was 0.81 m/s as summarized in Table 6. The average velocity by the test fan in large cross-section areas was 1.2 time higher than velocity in the smaller cross-sectional entry. Furthermore, the air quantity in large cross-sectional areas was higher 3.9 times. Consequently, even though in the condition of high resistance factor the low pressure test fan can generate more air quantity in large cross section area. This is actually an distinctive advantage of the low pressure fan compared to the conventional product.

4. SUMMARY AND CONCLUSIONS

Auxiliary fan plays a crucial role in underground mine ventilation. The high pressure axial-vane fan being

predominantly used in large-opening mines in Korea is not suitable because this fan was designed mainly for coal underground mines. This paper aims at developing a low pressure auxiliary fan for providing significant potential to increase ventilation efficiency and to reduce capital as well as operating costs. The results of CFD analysis and on-site study are summarized as follows:

1. The low pressure fan is designed and developed to be suitable for the characteristics of large-opening limestone mines with low airflow resistance factor and higher air volume requirements. The velocity profile over cross-sectional areas of the low pressure fan is more uniform than the high pressure fan, so the low pressure fan is better for diluting and mixing airborne contaminants.
2. The low pressure fan can minimize the air recirculation into the intake airway by reducing the influence of venturi effect caused by smaller kinetic energy.
3. The velocity decay characteristics of fan contributes to find the suitable location to install fan ensuring ventilation efficiency. The low and high pressure fans show a similar decay rate and also the distance range to supply sufficient air velocity to the working spaces.
4. In terms of economical aspect, low pressure fan with lower power requirement leads to less operation cost. In the case studied in this paper, the operating cost of low pressure fan was 2.47 times smaller than those of conventional products.
5. The experiments carried out at underground limestone mine sites show that even though in the condition of high resistance factor the average velocity created by the low pressure fan in large cross-section areas was 1.2 times higher than that generated in small cross-section area. Especially, the air quantity in large cross-sectional areas was 3.9 times higher. Thus, the large amount of the air can be pushed away with the low pressure fan in large cross-section areas.
6. In large-opening limestone mines with large cross-section areas in Korea, the high pressure fans used commonly have too excessive capacity energy inefficiency, and less economics. Hence, low pressure fan is strongly recommended for local limestone mines with potential for higher ventilation efficiency and less capital as well as operating costs.

ACKNOWLEDGEMENT

This research was supported by a grant from the Energy Technology Development Program (grant No. 2013T100100021) funded by the Ministry of Trade Industrial and Energy of the Korean government.

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