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Gao Jianliang Shi Qinpu
Hu Weimin Yang Yunliang

THE STUDY OF THE PATTERN OF METHANE DISTRIBUTION IN DESCENSIONALLY VENTILATED FACE

INTRODUCTION

In order to provide the working face with more air, some new types of ventilation system for the working faces, such as. W-type. Double-Z-type etc., have been used. Basically they are merely the combination of U-type ascensional and descensional ventilation systems. But the use of descensional ventilation system has been strictly restricted for a long time because of the prejudice against it. In the Safety Regulation for Coal Mines of China, it is restricted to be used in the coal face where the inclination is less than 12 degrees. However, because of it advantages in providing better climatic conditions and preventing methane from buildup and in dust suppression, more and more faces have been ventilated descensionally and some studies about it have also been made. For example, the descensionally ventilated faces in West Germany accounted for 45% of the total working faces in May, 1980, and the coal produced in descensionally ventilated faces in ZhongLiangShan colliery in China in 1983 accounted for 78,4% of the mine's total output. Alla studies about descensional ventilation show little difference in its effect on dust suppresion and climatic control in the face. But experts hold different opinions on the pattern of methane distribution and emission in descensionally ventilated face. In this paper we shall discuss the pattern of methane distribution in descensionally ventilated faces. The pattern of methane emission in such faces will be discussed in another paper.

THE MIXING MECHANISM OF METHANE AND AIR

1. In static air

When there is no air flow, i.e. V = 0 (V represents the average velocity of the air flow), the molecular diffusion is the only mixing agent.

The mixing process is very slow and emitted methane will build up very easily. The mass transfer process obeys Fick's law:

$$m = - p_m D \frac{dC}{d\vec{n}} \tag{1}$$

where:

m - diffusion flux rate through a unit area perpendicular to $\vec{n}$,

c - methane concentration,

p_m - methane density,

D - coefficient of molecular diffusion.

According to Fick's law it can be seen that the methane is transfered only from high concentration point to the low concentration point, and the counter process will never happen. So we can say that once mixing of methane with air has been completed, molecular diffusion will kepp it in such a state and the gas will never seperated into layers. When the face is ventilated descensionally, even in the case of ventilation stopage, the methane which has been already mixed with air will never float up and build up at the roof of the face again.

2. Laminar flow

When there is an air flow, i.e. V = O, the mixing process will be completed by two different mechanisms, one is molecular diffusion and the other is mechanical diffusion in which the methane is carried by air flow and mixes with it. The combination of molecular and mechanical diffusion is named convective diffusion. If the air flow is laminar, because the crosswise pulse velocity of the air current is equal to zero the capacity of convective diffusion is also weak and the methane will build up easily.

3. Turbulent flow

When the air flow is turbulent, because of the effect, of crosswise pulse velocity the methane in different layers mixes with each other and the mixing capacity increases greatly. The effect of molecular diffusion can be neglected. The mixing process is mainly completed by the work done buoyance and turbulent shearing stress. The ratio of the work done by buoyance to that done by the turbulent shearing stress can be used to represent the turbulent mixing capacity, it also called Richardson Numer, denoted by R_i:

$$R_i = -\frac{g\frac{d\rho}{dz}\cos\Theta}{\left(\frac{dv}{dz}\right)^2} \quad (2)$$

where:

R_i - Richardson Number,

p - the density of the mixed fluid,

g - acceleration of gravity,

z - distence of the emitting face (see fig. 1),

Θ - analge between Z axis and vertical.

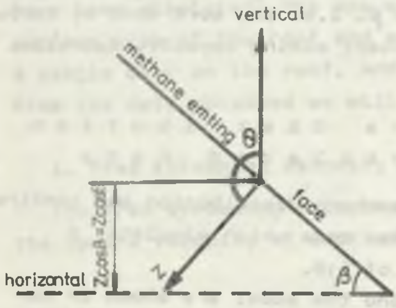


Fig. 1

Rys. 1

If $R_i < 0$ ($\beta > 90^o$), the work done by methane buoyancy is positive which is helpful to the mixing process. If $R_i > 0$ ($\beta < 90^o$) the work done by methane buoyance is negative which is against the mixing process, the larger the R_i is, the more turbulent shearing work is needed to overcome the buoyance, the weaker the turbulent mixing capacity will be and the easier for the methane build-up. $(dv/dz)^2$ is proportional to $(V-V_m)$ V - average velocity of flow, V_m average velocity of methane layer). When β increases V_m increases too. According to the values of R_i in different cases the following points can be drawn:

1. Because the direction of the air flow is against the direction of the methane buoyance in descensional ventilation, the relative velocity between air flow and methane layer is larger and R_i is less than that in ascensional ventilation. The turbulent mixing capacity is stronger with descensional ventilation than with ascensional ventilation.

2. In descensionally ventilated face, the larger the air velocity, the larger the relative velocity between air and methane layer, the less R_i and the stronger the turbulent mixing capacity. In ascensionally ventilated face, if $V > V_m$ with the increase of V, R_i decreases and the turbulent mixing capacity increases. If $V < V_m$ with the increase of V, R_i increases and the turbulent mixing capacity decreases.

3. When the methane is emited from the floor ($\beta > 90^o$) $R_i < 0$, the turbulent mixing capacity is strongest. When the methane is emitted from the coal face wll ($\beta = 90^o$), the turbulent mixing capacity is stronger.

When the methane is emitted from the roof ($\beta < 90^o$), the turbulent mixing capacity is the weakest.

4. When the methane is emitted from the roof, with the increase of β, $\cos\beta$ decrease. Because $(V-V_m)$ increases in descensional ventilation or when $V < V_m$ in ascensional ventilation R_i in both cases decreases. The turbulent mixing capacity in descensionally ventilated face and when $V < V_m$ in ascensionally ventilated face increases with the increase of β.

5. When the methane is emitted from the coal wall of the face $\cos\theta = 0$, in the direction perpendicular to the wall the work done by the buoyance is zero, and the turbulent mixing capacity depends on only the turbulent shearing stress. In descensionally ventilated face and in ascensionally ventilated face when $V < V_m$ the turbulent mixing capacity increases with the increase of β. In ascensionally ventilated face when $V > V_m$ the turbulent mixing capacity decreases with the increase of β.

6. When the methane is emitted from the floor, the work done by buoyance is positive and decreases with the increase of the inclination β. Because in ascensionally ventilated face when $V > V_m$, $|V - V_m|$ decreases also with the increase of the inclination β. i.e. the work done by turbulent shearing stress decreases, the turbulent mixing capacity decreases with the increase of the slope β.

The Pattern of Methane Distribution in Descensionally Ventilated Face

In order to study the pattern of the methane distribution and confirm the points above drawn, a similar model was made which simulates a trapezoid roadway with a geometric scale of 1:8.

The main dimensions of the prototype and the model are shown in table 1.

Table 1

The main dimensions of the prototype and the model

Name	Upper width mm	Lower widht mm	Height mm	Perimeter mm	Diameter of the props mm	Prop span mm	Hydraulic diameter mm	Cross-section area m^2	Not cross-section area m^2	Length m
Prototype	2160	2860	2180	9436	180	1000	2310	5.47	4.30	48
Model	270	357.5	272.5	1179.5	22.5	125	290	0.0855	0.0672	6

As far as the authers are aware, such studies have also been made abroad by experiment. But the slopes of their model were within 6^o when methane and air were used as the media. And in the experiment for which the slopes could be adjusted to higher values, brine and water were used as the media instead of methane and air. Because there are differences between the behaviors of the liquid mixing process and gas mixing process, we think that the nature of the methane with air has not been fully reveled, especially if the slope is high (more than 12^o, for instance). In our model high concentration methane and air are used, as the media and the slope of the model can be adjusted arbitrarily from 0^o to 45^o, and the air velocity and methane emission rate can also be adjusted as required. The methane concentration of every measuring point is measured by the method of gas chromatography with a data processor.

From dimensional analysis the main similarity rule was derived as being q/VD^2 where q is the methane emission rate, V represents the average velocity of the flow, and D denotes the hydraulic diameter.

Preliminary test shew that the flow in the testing part of the model was steady, and the methane emission was well distributed along the model and the air leakage is little. And it is regarded as being suitable for the study of the pattern of the methane distribution.

During the experiment two different situations of methane emission have been simulated. One was with the methane emitting from the whole surface area of the roof and another was with the methane emitting from a single slot on the roof. And more than 4000 data have been obtained. From the data obtained we will discuss the following aspects:

1. Free streaming velocity of methane roof layers V_f

The free streaming velocity of methane roof layers V_f is defined as the upward velocity of emitted methane along the roof when the air velocity is equal to zero. The methane emitted from the roof has a tendency to move upward along the roof if the roadway is not horizontal. It is this tendency that makes the methane behavior different with descensional and ascensional ventilation. During our experiment the V_f was measured at various inclinations and methane emission rates. The results are summarized in fig. 2. It is apparent that the methane free steaming velocities are greatly increased by small changes in slope β at first. As the inclination increases further this effect becomes less marked and as the inclination increases to a certain value (about

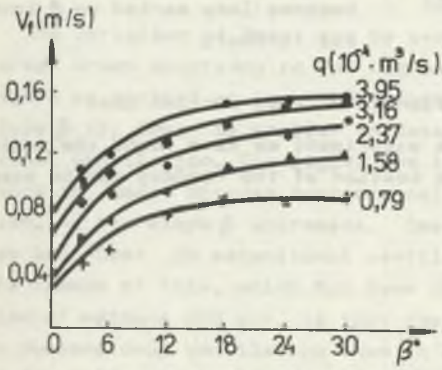


Fig. 2. The effect of inclination on the free steaming velocity at various methane emission rates

Rys. 2. Wpływ nachylenia na prędkość przepływu swobodnego przy różnych częstościach emisji metanu

30°) V_f remains constant. The velocity of methane free streaming V_f also increases as the methane emission rate q increases.

2. The velocity necessary to prevent backing of methane roof layers against the air flow in descensional ventilation V_b

Becuase of the tendency of emitted methane to move upward along the roof, the methane roof layers will move uphill for some distance in the opposite direction to the descensional ventilation flow if the air flow velocity is not big enough. This phenomenum is called the backing of the methane foof layers. In order to prevent this from occuring, the air velocity must be bigger than a threshold value witch is named as the velocity necessary to prevent backing of the methane roof layers against the air flow in descensional ventilation, represented by V_b. The result on this shown in fig. 3.

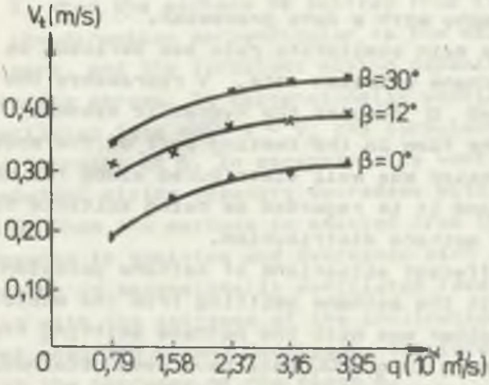


Fig. 3. The experimentally measured velocity necessary to prevent backing of methane roof layers against the air flow in descensional ventialtion

Rys. 3. Doświadczalnie zmierzona prędkość (przewietrzania) niezbędna aby zapobiec naporowi rozprzestrzeniającego się metanu z warstw przystropowych mimo przepływu powietrza w wentylacji prądem zstępującym

It can be seen that the value of V_b is not constant, but increase with the increase of the slope β and the methane emission rate and this effect becomes less marked as β increases further.

3. The maximum methane concentration in a cross section Cmax

From the data obtained during the experiment we have found the masimum methane concentration is a cross section of the readway can be expressed by the following equation:

$$Cmax = K_1\left(\frac{100q}{VD^2}\right)^{K_2}\left(\frac{x}{D}\right)^{K_3} \tag{3}$$

where:

D - hydraulic diameter,

x - distance from the measuring point to the methane emission source,

K_1, K_2, K_3 - constants which are relative to the direction of the flow and the slope β.

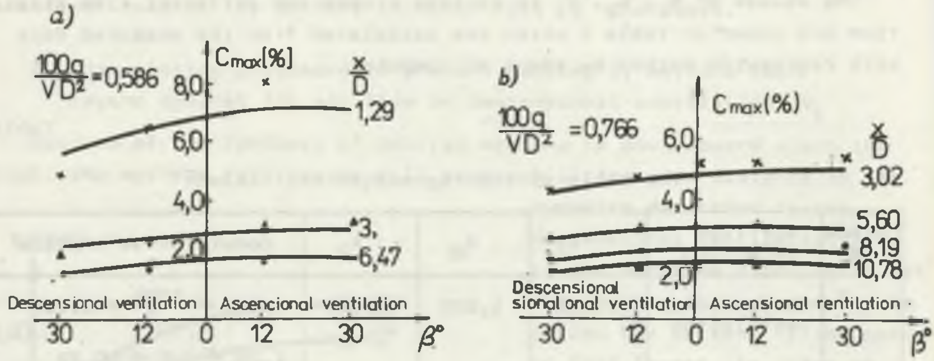
The values of K_1, K_2, K_3 in various slopes and different flow direction are shown in table 2 which are calculated from the measured data with regression method by means of computer.

Table 2

The table of the regression coefficient

Slope β	Air flow derection	K_1	K_2	K_3	Domain of definition
30^0	descensional ventilation	11.961	1.072	-0.747	$0.085 < \frac{100q}{VD^2} < 0.927$ $1.29 < X/D < 10.78$
12^0	descensional ventilation	14.390	1.142	-0.778	$0.085 < \frac{100q}{VD^2} < 0.927$ $1.29 < X/D < 10.78$
0^0	-	15.672	1.179	-0.793	$0.085 < \frac{100q}{VD^2} < 0.941$ $1.29 < X/D < 10.78$
12^0	ascensional ventilation	16.586	1.218	-0.793	$0.085 < \frac{100q}{VD^2} < 0.955$ $1.29 < X/D < 10.78$
30^0	ascensional ventilation	16.527	1.222	-0.778	$0.085 < \frac{100q}{VD^2} < 0.955$ $1.29 < X/D < 10.78$

The variation of Cmax can be seen from fig. 4a, 4b, 4c, in which the curves drawn accoridng to the regression equation (3). From the table and figure we noticed an important point, that is, no matter how big the slope β is. Cmax is smaller in descensional ventilation than in ascensional ventilation. The bigger the inclination is, the bigger the difference in Cmax between descensional ventilation and ascensional ventilation. As the slope β increases. Cmax in descensional ventilation decreases and Cmax in ascensional ventilation increases, and vice versa. The reason of this, which has been discused in the part of mixing mechanism of methane and air, is that the turbulent mixing capacity is stronger in descensional ventilation than in ascensional ventilation, and that R_i in downhill ventilation decreases and R_i in uphill ventilation increases as the inclination β increases.



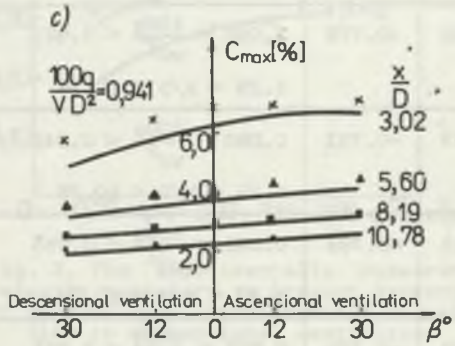


Fig. 4. The effect of inclination on the maximum methane concentration in a cross section

Rys. 4. Wpływ nachylenia na maksymalne stężenie metanu w przekroju

4. The length of methane roof layers

In order to calculate the lenght of methane roof layers we must define what is meant by methane roof layers. People had different definitions in the past. In this paper a methane roof layer is defined as the area where the methane concentration is higher than a critical value which may be the maximum concentration allowed in Safety Regulation for Coal Mines. From the regressive equation (3) we can calculate the length of methane roof layers X_o in different conditions, as shown in fig. 5 (the critical value of methane concentration is 2%).

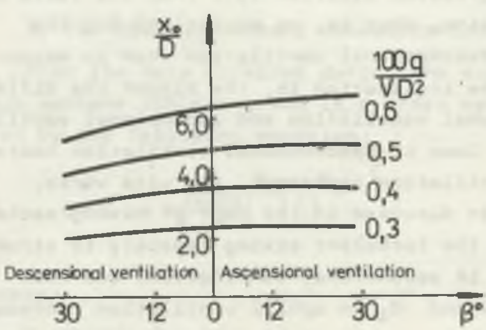


Fig. 5. The dependence on slope B of the lenght of methane roof layers

Rys. 5. Zależność długości obszaru zalegania metanu w warstwach przystropowych od nachylenia B

No matter how large the slope β is, in the same conditions the methane roof layers are shorter with descencional ventilation than with ascensional ventilation. As the slope β increases the length of methane roof layers increases in ascensional ventilation and decreases in descensional ventilation.

5. The velocity required to dilute the methane roof layers

The existence of the methane roof layers is harmful to the mine safety. However, it is very difficult, even impossible, to eliminate the layers, because there is always high concentration methane near the point where methane is emitted. And also it is not necessary to eliminate it. Nevertheless, it is important to control the layers in a safe range. In order to do so, the velocity required is defined as the velocity required to dilute the methane roof layers, which can be calculated from equation (3). The results calculated are shown in fig. 6, from which we can see that no matter how large the slope β is, if other conditions being equal the velocity required to dilute the methane roof layers is less with descensional ventilation than with ascensional ventilation, and as the inclination β increases it increases with ascensional ventilation, and decreases with descensional ventilation.

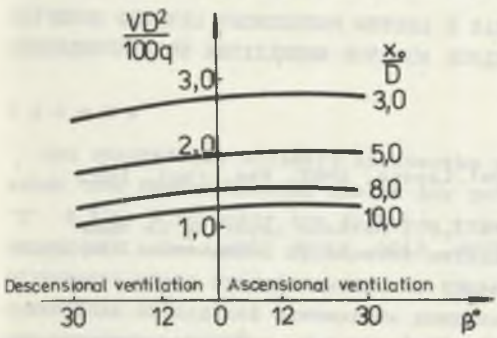


Fig. 6. The dependence on slope of the velocity required to dilute the methane roof layers

Fig. 6. Zależność prędkości (przepływu powietrza) potrzebnej do rozrzedzenia metanu w warstwie przystropowej

Conclusions

1. The turbulent mixing capacity can be represented by the Richardson number R_i which is the ratio of the work done by the buoyance to the work done by the turbulent shearing stress. The larger R_i, the stronger the turbulent mixing capacity.

2. With descensional ventilation the Richardson number is less, and the turbulent mixing capacity is stronger than with ascensional ventilation, so in descensionally ventilated face the emitted methane can be quickly diluted and hard to build up.

3. With descensional ventilation the maximum methane concentration Cmax is less, and the length of the methane roof layers is shorter, and the velocity required to dilute the methane roof layers is less than with ascensional ventilation.

4. As the slope β increases. Cmax the length of methane roof layers and the velocity required to dilute the methane roof layers decrease with descensional ventilation and increase with ascensional ventilation.

5. Once the mixing has been completed, the methane will not float up and stratificate, even though there is no air flow.

In short, the descensional ventilation has many advantages over the ascensional ventilation in preventing the methane from buildup. The bigger the β, the more obvious the advantages, so there is no reason for the descensional ventilation to be restricted to the coal face where the inclination is less than 12°.

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Recenzent: Prof. dr hab. inż. Mirosław Chudek

Wpłynęło do Redakcji w czerwcu 1988 r.

STUDIUM WZORU ROZMIESZCZENIA METANU NA PRZODKU WENTYLOWANYM PRĄDEM ZSTĘPUJĄCYM

S t r e s z c z e n i e

W celu zapewnienia większej ilości powietrza w przodku roboczym zastosowano nowe typy systemów wentylacyjnych dla przodków roboczych takich, jak typ "W", typ podwójne "Z" itp. W zasadzie są one jedynie połączeniem systemów wentylacji wstępującej i zstępującej. Ale zastosowanie systemu wentylacji zstępującej było ściśle ograniczone przez długi czas z uwagi na uprzedzenie do niego. W przepisach bezpieczeństwa dla kopalń chińskich jego zastosowanie ograniczone jest do przodków węglowych, w których nachylenie jest mniejsze niż 12°. Jednakże z uwagi na korzyści w zapewnieniu lepszych warunków klimatycznych i uniemożliwieniu nagromadzenia się metanu oraz w tłumieniu zapylenia coraz więcej przodków wentylowanych jest zstępująco i przeprowadzone zostały badania w tym zakresie. Na przykład przodki wentylowane zstępująco w Niemczech Zachodnich obejmowały 45% wszystkich przodków roboczych w maju 1980 roku, a węgiel produkowany w przodkach wentylowanych zstępująco w kopalni ZhongLiangShan w Chinach w 1983 r. wynosił 78,4% całej produkcji kopalni.

Wszystkie badania wentylacji zstępującej wykazują nieduże różnice co do wpływu na tłumienie zapylenia, regulację klimatyczną w przodku, lecz eksperci mają różne opinie co do wzoru rozmieszczenia i emisji metanu w przodku wentylowanym zstępująco.

W artykule omówimy rozmieszczenie metanu w przodkach wentylowanych zstępująco. Wzór emisji metanu w tego rodzaju przodkach omówiony będzie w innym referacie.

ИЗУЧЕНИЕ ФОРМУЛЫ РАЗМЕЩЕНИЯ МЕТАНА В ЗАБОЕ ВЕНТИЛИРОВАННОМ НИСХОДЯЩИМ ПОТОКОМ ВОЗДУХА

Р е з ю м е

Для обеспечения большего количества воздуха в рабочем забое применялись новые типы вентиляционных систем для рабочих забоев типа "W", типа двойное "Z" и т.д. В принципе они являются только соединением систем восходящей и нисходящей вентиляции. Применение нисходящей вентиляции было долгое время ограничено из-за предубеждений. По правилам безопасности в китайских шахтах применение нисходящей вентиляции допускается в угольных забоях, уклон которых не превышает 12^{o}.

Однако, принимая во внимание, что нисходящее вентилирование улучшает климатические условия в забое, исключает накопление метана, а также уменьшает степень запылённости, всё больше забоев вентилируется таким образом и в настоящее время проводятся исследования в этой области.

Например, в ФРГ в мае 1980 года количество забоев с нисходящей вентиляцией составляло 45%, а добыча угля в Китае из забоев с нисходящим вентилированием составляла 78,4% добычи всех шахт.

Все исследования в области нисходящей вентиляции показывают, что влияние её на уменьшение запылённости и регулировку климата в забое невелико. Однако, эксперты имеют различные взгляды относительно размещения и эмиссии метана в забое с нисходящей вентиляцией.

В статье обсуждается размещение метана в забоях с нисходящей вентиляцией. Формула эмиссии метана в таких забоях будет рассметриваться позднее в отдельной работе.