MINE VENTILATION SYSTEM VARIABLE RESISTANCE REGULATE AIR QUANTITY ECONOMY AND ITS IMPACTS ON ARTISANAL MINE IN IVORY COAST

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ABSTRACT: *The artisanal gold mining is one of the major illegal activities in Ivory Coast. Thousands of indigents and foreigners including men, women and children are involved in this dangerous activity. Contracting contagious diseases such as HIV/AIDS and multiple lung diseases are commonplace on the artisanal mining sites due to the air pollution. For this reason, the differential analysis, research mine ventilation system by changing the working windage adjustment for air flow of the economy, identifies factors, obtained discriminant variable resistance air volume control economic quantitative criteria for underground actual situation of joint variable resistance method and economic variable resistance than the concept of the development of effective mine ventilation system to improve air quantity adjusting rheostat economical way. The findings of this study can help lead to the safety of mining practices in order to improve health and safety of the miners who are involved in artisanal mining activities in Ivory Coast and other mining sites over the world.*

KEY WORDS: Ivory Coast; mine ventilation system; air volume control; economy; joint variable resistance; economic variable resistance ratio.

INTRODUCTION

According to the definition, artisanal and small-scale mining refer widely to miners using inadequate technical materials to run mines. Due to advancement in technology nowadays, some small miners don't use artisanal methods and they have huge operations (Veiga et al., 2014, 2015). In order to express small, medium, large, and informal mining activities which are mostly run by illegal miners who carried out using low technology or with minimal machinery, it is common to use the term artisanal mining (Veiga, 1997). Over 100 million people around the world rely on this sector for income, mainly in developing counties. Ivory Coast, a country in western part of Africa with an annual gold production which rose from 10 tons in 2014 to 23.5 tons in 2015. The artisanal mining mainly refers to mining operated by individuals; groups or communities (foreigners and indigenes) illegally due to fact illegal miners mostly don't adopt the legal status. The active involvement of many people in artisanal mining activities in Ivory Coast is mainly due to the high abject poverty rate and the low price of agriculture products. In order to

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solve the poverty issue and better their lives, the people engaged in artisanal mining in all the part of the country. Even when the artisanal mining sector has harmful side effects (environmental, social and financial challenges) that undermine country's development, there is potential contribution to development of the state through the provision of employment, increasing local purchasing power, stimulating local economic growth and slowing urban migration.

  At present, for mine ventilation, air volume control studies mainly focused on the stability of the ventilation system [1,3-4], the mine ventilation system air volume control economy little research, no quantitative judgment mine ventilation system air volume control economy good or bad condition, making adjustments during the ventilation system layout and the lack of scientific basis, affecting the entire economy of the mine ventilation system is not conducive to their economic evaluation. In this paper, mine ventilation system air volume control rheostat economy-depth study to determine the impact of factors that determine its quality and to identify quantitative conditions, so as to formulate reasonable measures to improve mine ventilation system air volume control rheostat economy, as efficient production of coal mine and gold mine safety to create good conditions. Therefore Adopting an effective mine ventilation system is of critical benefit to Ivory Coast. Utilizing natural or mechanical air pressure, the mine ventilation system is established to provide fresh air as well as expel foul air to the working faces. And with mining activies in Ivory Coast getting deeper, underground mining is inevitable in the coming 10 years. There are many differences between open pit mining and underground mining. When the mining depth increases, the temperature becomes higher than the surface ground and will increase with deeper exploitations. Aditionally, mining activities always generate hazardous gases and dusts- diesel emissions, blasting fumes, radiation, dusts, battery emissions, and many other contaminants-which are harmful to the workers and will cuase some occupational diseases, such as silicosis, or even worse. The following is the main components of surface ground air (Table.1).

Table1. main components of surface ground air

conponent	Mass concentration / %	Bulk concentration / %
oxygen (O_2)	23.17	20.90
nitrogen (N_2)	75.55	78.13
carbon dioxide (CO_2)	0.05	0.03
rare gases	1.23	0.94

Once the air comes into mining shafts, both its compoents and properties will change, the concentration of oxygen decreases while the concentration of carbon dioxide increases; various toxic gases and dusts mixing in and the changing of the air temperature, moisture and pressure (please crosscheck). Besides O_2, N_2, CO_2 and water vapour, the main components of the

underground mining air are CH_4, CO, H_2S, SO_2, NO_2, NH_3, H_2 and dusts, with CO, H_2S, SO_2 with NO_2 being the most harmful components. Thus, underground mining would not be possible without a ventilation system.

In underground mining, air is necessary not only for breathing but also to disperse chemical and physical contaminants (gases, dusts, heat, and humidity). Ventilation is the control of air movement, its amount, and direction. It is sometimes described as the lifeblood of a mine, the intake airways being arteries that carry oxygen to the working areas and the returns veins that conduct pollutants away to be expelled to the outside atmosphere. Without an effective ventilation system, no underground facility that requires personnel to enter it can opreate safety. Literature [4] shows that an effective mine ventilation system possesses such assets as follows: diluting and expelling 80%-90% of the hazardous gas, reducing 70%-80% of the fine particles and ousting 60%-70% of the heat of the working faces. These merits offer protections for the mining activities and also some suggestions as post medical checks,training, strategy of controlling dust, dust masks wearing, monitoring of gas in order to decrease the working incidents. Indeed, it can also improve the miners' working productivity at a lower cost.

Ventilation mining in China

China's research for ventilation system started with the establishment of the PRC. Since the 1950s, researches in mine ventilation theory and technology have achieved some major breakthroughs.

(1) extensive research and measurement on the roadway ventilation resistance
 (2) the establishment of a variety of work surface turbulence equations and mass transfer analysis of pollutant concentration calculation method provides a theoretical basis for the method of calculation of the amount of wind.
(3) application of computer calculation and analysis of complex ventilation network, provides an effective method of analysising mine ventilation system.
(4) developed Jet Ventilation and techniques and the applications to use wind flow pressure to regulation and directional airflow control technology
(5) deepening the research of unsteady flow law in the case of mine fire, established a number of typical wind flow control program.

A MINE VENTILATION SYSTEM AIR VOLUME CONTROL RHEOSTAT FACTORS AFFECTING ECONOMY

Qualitative Analysis

 In coal mines, ventilation systems for air volume often due to the mining face of change and transfer of gas emission and other natural conditions change and change the fan performance changes itself. In order to ensure the mine air and fan demand for economical operation, the need for timely supply of air volume control. Variable resistance which the economic benefits of air-flow method (please crosscheck) are constrained mainly by two factors: First, to meet the

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demand for air volume after the economic gains, mainly determined by the scale of production. The second is to change the drag caused by the additional energy consumption and cost of the project. The energy consumption is mainly used for ventilation ductwork to overcome resistance and maintain air flow stability. The law of resistance shows that only ~~with~~ the air flow and pressure drag on. In summary, the impact of the mine ventilation system air volume control rheostat law economic factors includes wind, drag, engineering and production scale.

Branch changes on the economic impact of wind resistance

In the mine ventilation system management process, air volume change at the mining area producing a continuous change. When the wind through the natural points cannot meet the need, it often used to change the drag method to regulate air flow to ensure that mine's demand for wind. Most of our coal mining using wings or wings, each wing has a separate return air tunnel, the implementation of partition and airy, and respectively, and the simultaneous production of multiple mining areas, each with a down hole location constitutes a complex wind parallel networks (difficult making a meaning out of the highlighted. Please rephrase). To facilitate the analysis, the mine ventilation network simplification of Figure 1 consists of three parts:

Mine the total inlet branch 3, equivalent drag r3; mine total return air branch 4, equivalent drag r4; mine segment with the wind segment branch 1, 2, the equivalent wind resistance r1, r2. The need to increase the air flow branch for the branch including a large air volume r1, including the other branches of the equivalent branch r2.
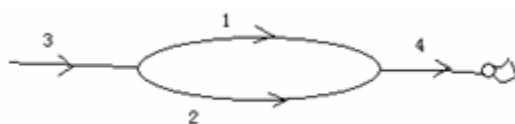
Fig 1 Simplified ventilation network graph

Where r1, r2 respectively Mine Main Fan constitute two independent circuits.

The increasing resistance adjustment

To increase resistance to increased air volume regulator, that is, greater wind resistance of the branch, a large amount of air is required to increase the air volume branching approach. Because mine total drag.

$R = r_0 + \dfrac{1}{\left(\dfrac{1}{\sqrt{r_1}} + \dfrac{1}{\sqrt{r_2}}\right)^2}$, Where $r_0 = r_3 + r_4$; When the drag r1 Changes; r1 differential on both

sides, Available $dR = K_1 dr_1$ **(1-1);** Where $K_1 = \dfrac{1}{r_1\sqrt{r_1}\left(\dfrac{1}{\sqrt{r_1}} + \dfrac{1}{\sqrt{r_2}}\right)^3}$; Seen, when the drag

increases, the total drag increases.
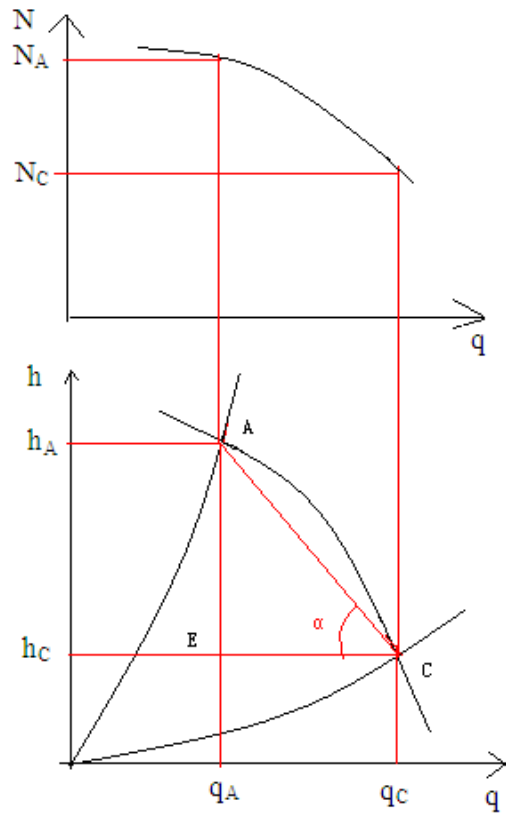
Fig 2 Mine Ventilation Resistance, main fan performance curve

Shown in Figure 2; Let $\overline{CE}$ and $\overline{CA}$ connection angle α , the $\triangle AEC$ in the infinitesimal,

$\tan \alpha = \dfrac{\overline{EA}}{\overline{CE}}$; $\overline{AE} = dh_f$, $\overline{CE} = -dq_f$, So $dh_f = -\tan \alpha\, dq_f$, **(1-2);** Where, q_f , h_f , respectively

for the main mine fan air flow and air pressure.

Law by the wind pressure $h_f = Rq_f{}^2$; Differentiations $dh_f = 2Rq_f dq_f + q_f{}^2 dR$ **(1-3)**

Parallel pressure ventilation network according to law $h_1 = h_2$

Obtain $r_1(q_0 - q_2)^2 = r_2 q_2{}^2$; its differentiations $dq_2 = K_2 dq_0 + K_3 dr_1$ **(1-4)**

$$K_2 = \dfrac{1}{\sqrt{\dfrac{r_2}{r_1}} + 1} \; , \quad K_3 = \dfrac{q_0\sqrt{\dfrac{r_2}{r_1}}}{2r_1\left(\sqrt{\dfrac{r_2}{r_1}} + 1\right)^2}$$

Where q_0 is the inlet and return air branch Airflow, Size equal to q_f , h_1 , h_2 respectively of the

branch 1,2 pressure , q_1 , q_2 respectively, the air flow rate for the branch 1,2.

Obtained by the above equations can be derived

$$dq_0 = -X_1 K_1 dr_1 \, , \qquad (1-5)$$

$$dq_2 = (K_3 - X_1 K_1 K_2)dr_1 \, , \quad (1-6)$$

$$dh_f = \tan \alpha\, X_1 K_1 dr_1, \qquad\qquad (1-7)$$

Where, $X_1 = \dfrac{q_0{}^2}{2Rq_0 + \tan \alpha}$

When r_1 increases, by the (1-5) shows that the total amount of wind q_0 mine be reduced,

By the (1-6) combined the actual situation shows,

$K_3 - X_1 K_1 K_2 > 0$, So branch 2 air volume increases q_2 ,

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By the (1-7) shows that it is the work of the main fan pressure h_f increases.

Meanwhile, the (1-1) shows that, when increases, increases, so the main fan operating point changes.

Shown in Figure 2, the operating point changes from the point C to point A, resulting from the total air volume q_C mine decreased to q_A, the ventilation resistance increases from the point h_C to h_A, increasing the fan power is set by N_C N_A.

Increasing resistance in the regulation for the centrifugal fan can increase the wind tunnel gate resistance (to reduce its opening) [2]. This method is relatively simple and implementation cost of the project is small, and suitable for the production of smaller mines. However, from the above analysis, this approach will bring additional energy consumption, affecting the total air volume ventilation system stability. So adjust the time not too long

The reduction in resistance adjustment

Reduction in resistance adjustment that reduces total intake, return air branch drag, increasing the total amount of wind to increase the air volume required a larger air volume branch in two ways.

When the drag r_0 changes, the

$$R = r_0 + \frac{1}{\left(\dfrac{1}{\sqrt{r_1}} + \dfrac{1}{\sqrt{r_2}} \right)^2}$$

r_0 Differential on both sides, we get $dR = dr_0$ **(1-8)**

Seen, when the drag A1 is reduced, the total drag decreases.

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And then the $r_1(q_0 - q_2)^2 = r_2 q_2{}^2$ Differentiations $dq_2 = \dfrac{dq_0}{1+\sqrt{\dfrac{r_2}{r_1}}}$;   (1-9)

From $(1-2)$ $(1-3)(1-8)(1-9)$ were derived restaurants $dq_0 = -X_1 dr_0$ **(1-10)**

$$dq_2 = \frac{-X_1 dr_0}{1+\sqrt{\dfrac{r_2}{r_1}}}$$

(1-11)

$$dN = \tan \alpha\, X_1 dr_0 \qquad \textbf{(1-12)}$$

When r_0 is increased by (1-10) it shows that the total amount of wind q_0 mine increased by (1-11) and shows that two branches of the increased air flow q_2 also by (1-12) shows that the main fan working pressure decreases.

   Meanwhile, the (1-8) shows that when r_0 decreases, R decreases, making the main fan operating point to change. Shown in Figure 2, the operating point changes from point A to point C, resulting in the total air volume from the mine increased to q_A q_C, the ventilation resistance is reduced to the h_A h_C, fan power is reduced to the N_A N_C.

 The reduction in resistance regulation in general, is in the mine (or system) of the main inlet and return air duct taken to increase in parallel roadway, reduce air duct, wide brush roadway, replacement of the friction coefficient smaller shoring, and other measures to reduce local resistance [2]. From the above analysis, this approach allows the main fan running costs of the economy, but the cost of the project is large, suitable only for large-scale production of the mine.

MINE VENTILATION SYSTEM FOR AIR VOLUME ADJUSTMENT RHEOSTAT ECONOMIC ANALYSI

Mine ventilation system air volume control rheostat definition of economics

When the ventilation network, a drag strip r_i change in wind direction, assuming drag increment is dr_i, the resulting change in the total amount of drag is dR, then its total economic benefits the mine ventilation system M impact ψ_i, Can be expressed as $dr_i \propto \psi_i \left(i = 1, 2, 3, ..., n \right)$, ψ_i is the mine ventilation system for air volume adjustment rheostat revenue degree, the size of the reaction of the drag is changed economic growth, namely economy. Set up

Wherein, dM D is the change in the network has the drag dr_i, when the mine ventilation system changes in the value of total economic benefits. ψ_i is larger, indicating that the variable resistance regulate air flow economy better.

Economic introduction of variable resistance than λ_e

By the previous analysis, adjustment for changing the working speed air flow method, increasing resistance adjustment and reduction in resistance regulation advantages and disadvantages. To resolve this contradiction in the actual production, two methods can be applied: Reduce intake, return air branch drag, increased need to wind fewer branches drag, which combined increased need to wind a large branch of the air flow in order to meet production requirements [5]. The method of this regulation is defined as the amount of wind resistance combined variable air volume control method, increasing resistance and resistance reduction ratio known as the Joint variable resistance ratio.

Joint variable resistance method model shown in Figure 1-1, r_3 and r_4 are required a reduction in the total resistance of the mine into the return air branch $\left(r_0 = r_3 + r_4 \right)$, r_2 thus is the need to increase the amount of wind branch, r_1 including the need to increase resistance to other branches,

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including branches equivalent branch. Wherein r_1, r_2 and r_0, respectively, and the main mine fan constitute two independent loops.

$$\psi_i = \frac{dM}{|dR|} \qquad \textbf{(2-1)}$$

Mine Main Fan constitutes two independent loops, and meets $\Delta r_0 = -\lambda \Delta r_1$. Wherein Δr_0, Δr_1 of the branch into the return air drag and wind resistance change amount Branch 1.

When λ met $\psi_i = \frac{dM}{|dR|} \to \max$, economics highest point of λ is defined as the economic variable resistance ratio, denoted by λ_e.

Insufficient air flow ventilation system, can easily lead to accumulation of gas, causing suffocation and explosion, ventilation and safety effects and the indirect effects of mine efficiency. The mine ventilation network should be to ensure the mine ventilation system airflow stability [1], under the premise to maximize economy.

Mine Ventilation System Joint Economic Analysis rheostats

Joint variable resistance model for economic analysis, design total intake, return air drag r_0 and r_1, respectively, a branch change Δr_0, Δr_1 and $\Delta r_0 = -\lambda \Delta r_1$, the total drag variation ΔR, the increase in total revenue for the ΔM. Settlement revenue per unit time is as shown in Table 2-1.

Table 2-1 rheostat adjusted income statement

Branch	1	2	3.4
Air volume to meet revenue ten thousand Yuan A 万元\ m^3	0	$A\Delta q_2$	0
Increase power consumption B 万元 $\backslash kw$	$B\Delta N_1$	0	$B\Delta N_0$
Power consumption to maintain stable air flow C 万元\ m^3 （ $\Delta q_0 \geq 0$ 时 $C=0$	0	0	$C\Delta q_0$
Engineering cost D 万元	0	0	Dr_0
ΔM	$A\Delta q_2 + B\Delta N + C\Delta q_0 + Dr_0$		

Where, ΔN_1 and ΔN_0 are the branches 1 and 3 (or 4) drag to change the main cause of the mine ventilation system fan power variation, $\Delta N = \Delta N_0 + \Delta N_1$

From the previous analysis, the mine ventilation system to change the working method windage adjustable air volume gains and r_0, r_1 branch related to changes in wind resistance, assuming that only the operating point is changed, the characteristic curve did not change. To this end, the mold shown in united rheostat.

Type variable resistance caused due to economic analysis of the changes.

Let branches 1 and into the back, the wind drag each branch change Δr_1, Δr_0; Parallel networks mine total differential of total drag $dR = dr_0 + K_1 dr_1$ **(2-2)**

According to the law $h_1 = h_2$ parallel pressure ventilation network was $r_1 (q_0 - q_2)^2 = r_2 q_2^2$,

Therefore $dq_2 = K_2 dq_0 + K_3 dr_1$, **(2-3)**

All kinds can be derived from the above $dN = h_f dq_f + q_f dh_f$

By the (1-4) know; Can be obtained from Table 2-1; dM=Adq$_2$+BdN +Cdq$_0$+Dr$_0$ **(2-4)**

Set up $dr_0 = -\lambda dr_1$,

$$\lim \frac{dM}{|dR|} = \begin{cases} \dfrac{(AK_2X_1 - CX_1 - D)\lambda + A(K_3 - K_1K_2X_1) - B(1-K_1)K_4 - CX_1K_1}{\lambda - K_1}, & 0 \le \lambda < K_1 \\[4mm] \dfrac{(AK_2X_1 - CX_1 - D)\lambda + A(K_3 - K_1K_2X_1) - B(1-K_1)K_4 - CX_1K_1}{K_1 - \lambda}, & K_1 < \lambda \end{cases} \quad (2\text{-}5)$$

Among $K_4 = \dfrac{\tan\alpha}{2Rq_0 + \tan\alpha}$

The above analysis shows that when $\lim \dfrac{dM}{|dR|} \to \max$ is full, from the economic point of view, the system shows the most reasonable proportion of variable resistance adjustment. From (2-5), when the characteristic curve is not changed, $\tan\alpha$ constant, economy ψ_i and λ, only the scale of production, and therefore according to the different production scale, drawing the $\psi_i - \lambda$ curve.

The analysis shows that when the mine production is smaller, allows $\dfrac{A}{D} < \dfrac{K_1}{K_3}$
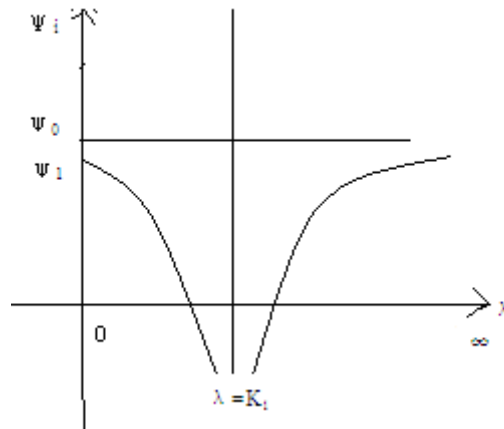

Figure 3 Small-scale mine air volume control rheostat economy curve

Smaller yield, $\psi_j - \lambda$ curve as shown in Figure 3.When $\lambda = 0$ is, that only the method of increasing resistance adjustment, has a relatively high economic,

$$\psi_i = \frac{A(K_3 - K_1 K_2 X_1) - B(1 - K_1)K_4 - CX_1 K_1}{K_1}$$

There is no visible problem engineering expenses, mainly due to the additional energy consumption and output and total air volume changes, so adjust the time not too long, otherwise too much additional energy consumption, impacts the economy. When $\lambda \to \infty$, that resistance reduction method using only regulate $\psi_i = AK_2 X_1 - D$, there is no additional visible decline in wind energy issues, due to production of smaller, so the cost of the project is a major constraint on economic factors. Although the reduction in resistance of the main fan running costs the economy, but construction costs are too high and the economy with respect to increasing resistance method improves the magnitude is not large, so the production of smaller mines, reduction in resistance adjustment method is not practical.

When $0 < \lambda < \infty$, that combined variable resistance adjustment, λ increases, ψ_i decreases and then increases, but is always less than the economic adjustment reduction in resistance is low, when combined variable resistance ratio $\lambda = K_1$, the mine changes in the value of total drag $\Delta R \to 0$, drag curve indicated by the mine, no additional energy consumption, air flow stability [1], the existing scale of production, the reduction in resistance larger proportion of project costs, up from Figure 1-4 shows that at this time the most economical poor. Visible production scale is small, the increasing resistance of the best economic regulation. At such production conditions, the reduction in resistance regulation or co-resistance reduction method is not advantageous.

When the large-scale production meets the $\frac{A}{D} > \frac{K_1}{K_3}$, the production of large, $\psi_i - \lambda$ curve is shown in Figure 4. When the $\lambda = 0$ or $\lambda \to \infty$, that is, only increasing resistance adjustment or

just adjust the resistance reduction, economy are relatively low. When $0 < \lambda < \infty$, i.e. a joint variable resistance, ψ_i with λ first increases and then decreases when the $\lambda = K_1$, $\psi_i \to \max$, economy best, so $\lambda_e = K_1$, this time drag mine changes in the value of total $\Delta R \to 0$, from the mine drag curve can also be seen, no additional energy consumption, and stable air flow, relative to the scale of production, the proportion of project costs are relatively small, so efficiency is relatively high, consistent with the economic analysis.

So in this production conditions, the joint variable resistance method most superiority, λ closer λ_e, mine ventilation system air volume control economy is higher.
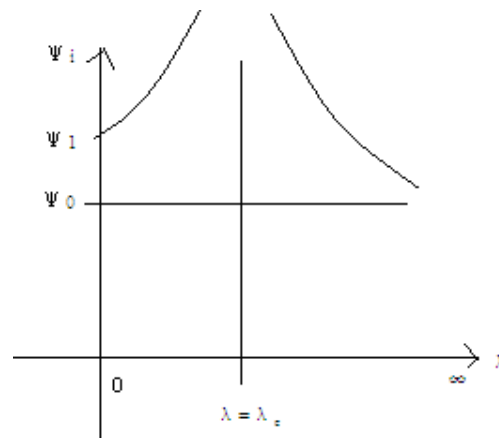
Figure 4 large air volume control rheostat mine economy curve

Seen above analysis and reduction in resistance with increasing resistance to regulate air flow characteristics match. $\lambda = \lambda_e$ time of significance is that the change in the value of the mine total drag $\Delta R \to 0$, mine drag curve does not change, no additional energy consumption, ventilation system air flow stable and rational engineering, economy best.

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MAIN CONCLUSION

Rheostat for adjusting the mine ventilation system air flow when the mine ventilation system should be considered wind stability [1], the scale of production, energy consumption, and engineering, to choose the best method for regulating the mine ventilation system to ensure safe and economical operation.

Joint variable resistance method is suitable for large-scale production of the mine, then you can adjust the resistance reduction and comprehensive adjustment method has the advantage increasing resistance, variable resistance proportional ratio $\lambda = \lambda_e$ variable resistance air volume control has the highest economy.

Increasing resistance mine ventilation system air volume control should be avoided in the mine well into the main, install conditioning return air duct, or affect the air flow stability [1], indirectly affect economy. Reduction in resistance adjustment, should be avoided in the construction of the tunnel with the wind resistance reduction, because the cost of the project, a large, complex operation, and can be reduced slightly, with little success, the economy is poor.

Optimization of mine ventilation system design, as far as possible pre-designed mine ventilation system network architecture, resistance distribution and air flow with the actual situation and put into operation in line to reduce the daily mine ventilation system regulation times it had to keep the main fan working conditions point for stability, reduce the additional energy consumption and maintenance cost of the project.

Conclusion

The objective of any ventilation system is twofold. First, the primary ventilation must allow air through the main airways to the immediate working area out by the working faces, thus making fresh air available for face ventilation, and then return the contaminated air through return (exhaust) airways to the surface. Second, the face ventilation system must be designed to

effectively utilize the available air in the immediate working area to sweep the working face, to capture and remove dust, and to dilute and carry away gas, if any, emitted during mining activities. The Ivory Coast mines need an effective ventilation system to create suitable micro-environment of the working face. Constructing such system gives solution to the heat problems and has profound significance on the safety in the mine thus making the mine activities a good exploitation.

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