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Energy saving possibilities for ventilation fan in underground coal mines

This paper presents energy saving and improve performances of the ventilation fan in the underground coal mines. There shows the enhancement of life of the ventilation fan, diminution of mine operational cost because most of the coal mines are energy demanding [1]. There presented a ventilation fan run in such a manner to provide sufficient air quantity for miners. Also, at the same time is reduced the energy consumption by running the ventilation fan at rated speed only for working hours. Subsequently, a case study presented along with their relevant parameters affecting on performance of ventilation fan such as, airflow, differential air pressure, speed, power consumption, ventilation on demand (VOD) etc..

Keywords: *Energy saving; low cost; ventilation on demand (VOD); affinity laws.*

I. Introduction

Mine ventilation system combination of surface and underground installations and the system varies from site to site depending on the ore body structure, geological conditions, climatic conditions and mining methods [2]. In view of the fact that, utilization of natural ventilation is an inefficient method in deep underground mines, usage of appropriate ventilation equipment is an undeniable issue.

Ventilation fans are especially utilized for providing air flow in splits and faces, inefficient fans in mines increase capital and operational costs. In addition, unsuitable fans provide lower or higher range of air flow. Higher range of air flow increases operating costs and lower range of air flow decreases safety. Most of the ventilation fans are designed to deliver a higher volume of air than is actually required. Due to this operational cost and maintenance cost increased. Moreover in present condition we are running the ventilation fan continuously in a day (24 hours). In the case of non working hours we can switch off the fan, but problem is after switched off, during starting period/hours fan will have heavy load. In this case we have to use same motor/fan in optimum way as per air demand in mine.

To overcome this complexity we need to reduce the ventilation fan speed at certain periods/hours with different speeds at required air demand. This entire procedure can be done by monitoring and controlling the parameters [3], since parameters such as air quantity, pressure and speed plays very important role in mine to achieve acceptable efficiency and savings in power consumption of ventilation fan [4]. This paper shows a solution to reach an efficient ventilation system and energy cost saving in mine ventilation by controlling parameters based on the fan speed. The results of our proposed method show its superiority by comparing with the real time underground coal mine data.

II. Air quantity and pressure requirement

Some kind of pressure is necessary to cause airflow in mine. The purpose of ventilation fan is to supply mechanically produced pressure at some point in mine. The pressure required to circulate a certain quantity through an airway can easily be calculated if the resistance of the airway is known either from measurement. It must be noted here that for accuracy, both friction and shock resistances should be estimated. Knowing the pressure requirements for each air way, the total pressure required for the whole mine can be calculated [5]. This involves the control of quantities flowing through the other splits by installing regulators, is a simple means of ventilation control in other words ventilation-on-demand (VOD) [6]. Ventilation-on-demand reduces the waste by matching the ventilation to what is actually required in various places in mine.

Another method for reducing flow in an airway with less wastage is to reduce the main fan pressure causing flow. This method however is rarely practiced since it involves special adjustments in the fan. Estimation of the leakage at various parts, total air quantity requirements and volumetric efficiency for each system. Leakage of air should be minimized and recirculation avoided. Leakage reduces the volumetric efficiency of ventilation and consequently increases the cost of ventilation [7].

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III. Mine ventilation case study

For demonstration purpose a case study is presented and real time data is taken from VK-7 mine which is located at Kothagudem, Telangana, India.

A. Overlapping Hours

According to Indian standards coal can be extracted from mines in three shifts, those are mentioned in Table I. In real world these shifts can be categorized into three, they are general shift, maintenance shift and production shift. In general shift and maintenance shift, miners can arrange materials and machinery for coal extraction, for this arrangement it takes minimum 1 to 2 hours and to reach exact production coal areas miners takes 30 to 45 minutes, these hours are called as overlapping hours. More over at midnights and holidays there is no need to run the fan at rated speed. As per regulations, in mines work can be done by continuous 8 working hours per shift but practically after every working shift we have an overlapping hour. In this particular hours workers may work or not, for this hour also ventilation fan running with same speed as per working hours. According to VOD, we reduce the fan speed for these particular hours and we can create minimum pressure. By increasing and decreasing the fan speed for every overlapping hour and we calculate the overall average efficiency of fan in a day and we try to improve the fan efficiency and it results in reducing the power consumption that indicates the energy can be saved.

Table I Shifts and working hours Schedule

Shifts	Working hours
1st	07:00 am to 03:00 pm
2nd	03:00 pm to 23:00 pm
3rd	23:00 pm to 07:00 am

Table II Specifications of motor

Motor	Induction
Capacity	220kW/300HP
Rated voltage	3.3 kV
Rated speed	970 RPM
Rated current	54 Amps

IV. Energy saving and operation of ventilation fan

Energy saving and operation of ventilation fan is mainly depends on speed of motor, coal production working hours, and number of miners. This is due to fact that they control the speed of the motor and speed can be varied according to VOD. In order to do so we take a closer look to the so called affinity laws [8] which are used to express relationships between the variables such as speed, airflow, pressure and power involved in the operation and performance of mine ventilation fans. Most HVAC (heating ventilation air conditioning) equipment is designed to perform during peak loads [9]. These loads occur rarely during the operating year. To control flow during off-max load conditions, flow control devices such as dampers, valves, inlet guide vanes and bypass systems are used. These devices are effective, but not energy efficient. Referred to as the affinity laws, allows the equipment to meet the partial load requirement in mine and save energy, from affinity laws we can write

- Airflow is directly proportional to speed i.e., $\frac{Q_2}{Q_1} = \frac{RPM_2}{RPM_1}$
- Pressure is directly proportional to square of the speed i.e., $\frac{H_2}{H_1} = \left(\frac{RPM_2}{RPM_1}\right)^2$
- Power is directly proportional to cube of the speed i.e., $\frac{P_1}{P_2} = \left(\frac{RPM_2}{RPM_1}\right)^3$

So to support a load, we select a motor to meet a specific starting requirement and running output power, torque, and speed. However, through the affinity laws, we identify that there is significant potential energy savings associated with reducing a motor speed and, by association, horsepower [10]. So if we can define the required change in motor speed to meet the change in flow for a load, the change in required power is proportional to the cube of the change in speed from one system point to another. The change in required torque is proportional to the square of the change in speed from one system point to another. These relationships can be expressed through the following equations

- $\mathrm{hp}_1 = \mathrm{hp}_2 \left(\frac{RPM_2}{RPM_1}\right)^3$
- $\mathrm{Torque}_2 = \mathrm{Torque}_1 \left(\frac{RPM_2}{RPM_1}\right)^2$

V. Proposed methodology

From affinity laws we can calculate the power consumption and cost in terms of rupees for four different cases according to overlapping hours of the mine. Consider a 300 hp motor that drives a ventilation fan. The fan operates at full speed (970 rpm) and motor specifications are mentioned in Table II. Since this particular ventilation fan accommodates a varying load, the fan does not need to be run at full speed throughout the day and therefore according to VOD load schedule is changed, which can estimate the power, speed required by a motor is proportional to the cube of the speed. The operational cost [11] is calculated with the following formula

Cost = Power (kW) × Running Time (hours) × Cost/kWh

Case 1: When constantly running ventilation fan at full speed and tariff for industries Rs.6/kWh

Cost at full speed in a day $C = 300 \times 0.746 \times 24 \times 6$

$C = Rs. 32,227/-$

a) Power and cost at overlapping hours with 20% speed

Let us consider three numbers of overlapping hours in a day

$$\text{Power } (P_1) = 300 \times \left(\frac{20}{100}\right)^3 = 2.4 \text{ hp}$$

Cost $(C_1) = 2.4 \times 0.746 \times 3 \times 6 = Rs.32/-$

b) Power and cost at working hours with full (100%) speed

Let us consider 21 numbers of working hours in a day Power $(P_2) = 300$ hp

Cost $(C_2) = 300 \times 0.746 \times 21 \times 6$

$= Rs. 28,198/-$

c) Total cost saving for 24 hours in a day

$C_T = C - (C_1 + C_2)$

$= 32,227 - 28,230$

$= Rs. 3,996/-$

=12.3% of cost

d) Total annual cost saving

$C_{A1} = 350 \times 3996 = Rs.13,98,870/-$

Case 2: When constantly running ventilation fan at full speed and tariff for industries Rs.6/kWh

Cost at full speed in a day $C = 300 \times 0.746 \times 24 \times 6$

$C = Rs. 32,227/-$

a) Power and cost at overlapping hours with 50% speed.

Let us consider 3 numbers of overlapping hours in a day,

$$\text{Power } (P_3) = 300 \times \left(\frac{50}{100}\right)^3$$

$= 37.5$ hp

Cost $(C_3) = 37.5 \times 0.746 \times 3 \times 6$

$= Rs.503.55/-$

b) Power and cost at working hours with full (100%) speed

Let us consider 21 numbers of working hours in a day Power $(P_4) = 300$ hp

Cost $(C_4) = Rs. 28,198/-$

c) Total cost saving for 24 hours in a day

$C_T = C - (C_3 + C_4)$

$= 32,227 - 28,701.55$

$= Rs. 3525.45/-$

= 10.9% of cost

d) Total annual cost saving

$C_{A2} = 350 \times 3525 = Rs.12, 33,750/-$

Case 3: When constantly running ventilation fan at full speed and tariff for industries Rs.6/kWh

Cost at full speed in a day $C = 300 \times 0.746 \times 24 \times 6$

$C = Rs. 32,227/-$

a) Power and cost at overlapping hours with 60% speed

Let us consider 3 numbers of overlapping hours in a day

$$\text{Power } (P_5) = 300 \times \left(\frac{60}{100}\right)^3$$

$= 64.8$ hp

Cost $(C_5) = 64.8 \times 0.746 \times 3 \times 6$

$= Rs.870/-$

b) Power and cost at working hours with full (100%) speed

Let us consider 21 numbers of working hours in a day

Power $(P_6) = 300$ hp

Cost $(C_6) = Rs. 28,198/-$

c) Total cost saving for 24 hours in a day

$C_T = C - (C_5 + C_6)$

$= 32,227 - 29,068$

$= Rs. 3,159/-$

= 9.8% of cost

d) Total annual cost saving

$C_{A3} = 350 \times 3159 = Rs. 11, 05,650/-$

Case 4: When constantly running ventilation fan at full speed and tariff for industries Rs.6/kWh

Cost at full speed in a day $C = 300 \times 0.746 \times 24 \times 6$

$C = Rs. 32,227/-$

a) Power and cost at overlapping hours with 80% speed

Let us consider 3 numbers of overlapping hours in a day

$$\text{Power } (P_7) = 300 \times \left(\frac{80}{100}\right)^3$$

$= 153.6$ hp

Cost $(C_7) = 153.6 \times 0.746 \times 3 \times 6$

$= Rs. 2062/-$

b) Power and cost at working hours with full (100%) speed

Let us consider 21 numbers of working hours in a day Power $(P_8) = 300$ hp

Cost $(C_8) = Rs.28,198/-$

c) Total cost saving for 24 hours in a day

$C_T = C - (C_7 + C_8)$

$= 32,227 - 30,260$

= Rs.1,967/-

= 6.1% of cost

d) Total annual cost saving

C_{A4} = 350 × 1967 = Rs. 6, 88,450/-

In this study we found that, the speed of induction motor is varied as per requirements of mine production timings and energy cost saving are calculated. According to above calculations it is clear that a small reduction in speed can save a large amount of energy.

VI. Results and discussion

Parameters such as flow rate, pressure, speed and hps are determined based on mine working hours and VOD and details of which are given in Tables III and IV.

TABLE III COSTS AT REDUCED SPEEDS FOR 3 NUMBER OVERLAPPING HOURS IN A DAY

Speed	Horse power (kW)	Cost/day	Cost/annum
20%	2.4	Rs.32/-	Rs.11,220/-
50%	37.5	Rs.503/-	Rs.1,76,050/-
60%	64.8	Rs.870/-	Rs.3,04,500/-
80%	153	Rs.2062/-	Rs.7,21,700/-

TABLE IV AIRFLOWS AND PRESSURE AT REDUCED SPEED FOR OVERLAPPING HOURS

Speed	Airflow (m^3/min)	Pressure (mmhg)
20%	1520	13.6
50%	3800	34
60%	4560	40.8
80%	6080	54.4

If a fan runs continuously with full capacity for 24 hours then the energy cost can be Rs.32,227/-. Similarly, in the case of overlapping hours with 50% speed, the energy cost can be Rs.28,701/- . Therefore, the cost of energy saving over 24 hours is Rs.3,526/- (i.e., Rs.12, 33,995/- is saved per year if a similar cycle progress throughout the year). Table III shows cost per day and plotted in Fig.1, Table V shows energy cost savings per day and year as well at overlapping hours. These are plotted in Fig.4. It should be noted that the annual cost savings are calculated for 350 days only.

This amusing methodology gives one possible solution to save the energy cost that might be achieved in this example. Various factors/parameters can affect on performance of ventilation fan and energy saving such as the resistance, fan curves, operating points and requirements of flow rates.

TABLE V COST SAVINGS PER DAY AND ANNUM AT DIFFERENT SPEEDS

Speed/3 hours	Speed/21 hours	HP/3 hours (kW)	HP/21 hours (kW)	Savings/ day	Savings/ annum
20%	100%	2.4	300	Rs.3996/-	Rs.13,98,870/-
50%	100%	37.5	300	Rs.3526/-	Rs.12,33,995/-
60%	100%	64.8	300	Rs.3159/-	Rs.11,05,650/-
80%	100%	153	300	Rs.1967/-	Rs.6,88,100/-

Fig.1 shows the variation of cost at different speeds in a day and we have observed that when operational cost increases we need to run the fan with optimum speed.

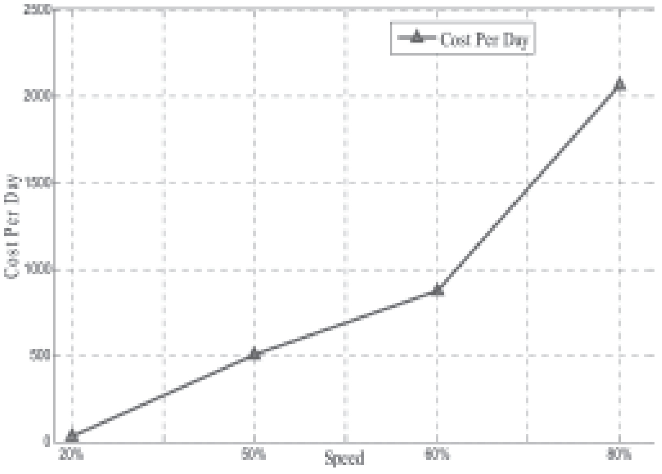

Fig.1 The variation of cost at different speeds per day

Fig.2 shows the variation of pressure at different speeds in a day and we have observed that pressure is increased gradually with increasing fan speed.

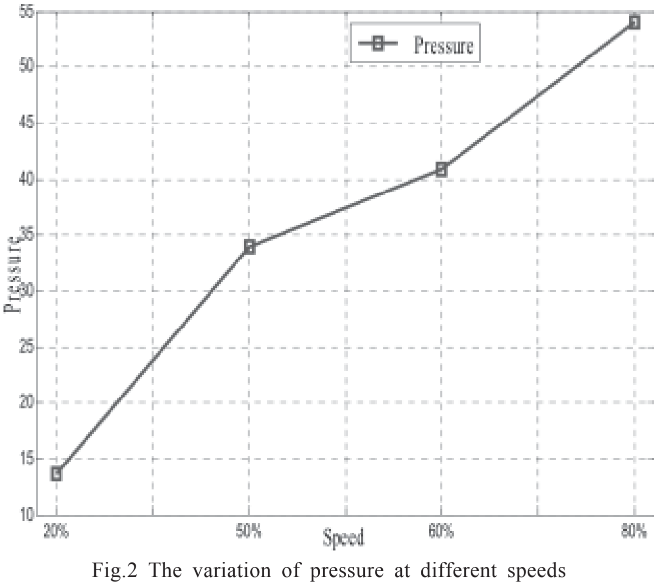

Fig.2 The variation of pressure at different speeds

Fig.3 shows the variation of airflow at different speeds in a day and we have observed that airflow is increased gradually with increasing of fan speed. When higher volume of air is available in a mine it may be possible to run the fan with minimum speed to reduce the power consumption.

Fig.4 shows the cost savings per annum at different speeds and we have observed that savings are decreased gradually with increasing fan speed.

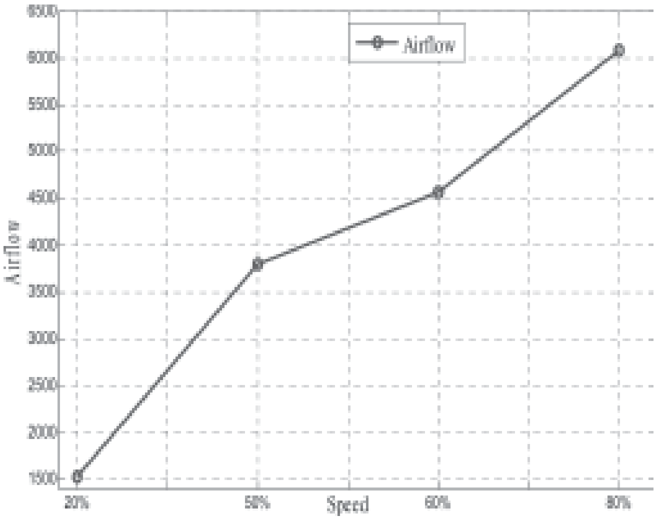

Fig.3 The variation of airflow at different speeds

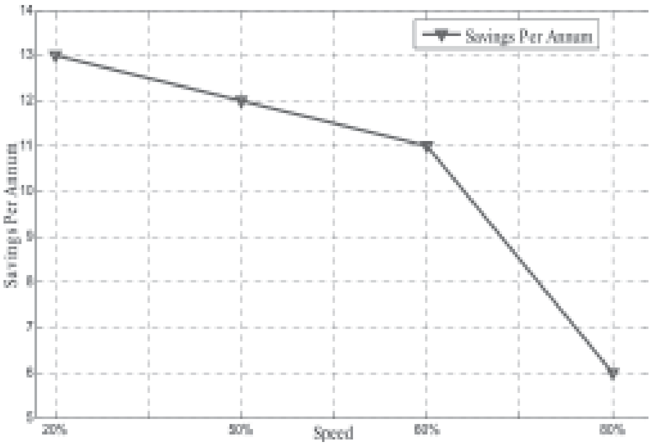

Fig.4 The cost saving per annum at different speeds

VII Conclusion

This study has demonstrated that within the slight focus of main ventilation fans, in spite of that general lack of data there exists an opportunity of significant savings in both the electricity saving and air quantity which can be utilized efficiently. A 10% increase in fan efficiency with 10% decrease in electricity consumption results in energy saving per day and year. This primary finding is an additional motivation to re-visit all the ventilation fans for global underground mining operations. Therefore our aim is to identify the specific installations where the performance is not energy efficient. Once this is done a special caring ventilation fan maintainers will approach the relevant personnel and suitable implementations are done for this simple practice.

An everlasting solution to this problem is the use of variable frequency drive (VFD) with the fan/motor; this allows the fan to operate at reduced speed and power. VFD is used to control fan speed that meets the minimum ventilation requirements without wasting energy. The speed can be adjusted to maintain a high efficiency fan while still meeting the ventilating requirements of the mine throughout the mine life.

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