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Ramakrishna Morla

University of Wollongong, [rm746@uowmail.edu.au](mailto:rm746@uowmail.edu.au)

Shivakumar Karekal

University of Wollongong, [skarekal@uow.edu.au](mailto:skarekal@uow.edu.au)

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## Selection of fan(s) to dilute DPM for multi-seam board and pillar coal mines using Hardy Cross and CPM methods

### Abstract

Multi-seam coal mining comprises of a large number of working sections. A well-organized ventilation system is necessary to supply adequate air quantities to all working sections and to dilute diesel particulate matter (DPM) within the statutory limits. In this paper, an attempt has been made to optimize fan(s) operating points in a multi-seam mine using a combination of Hardy-Cross and critical path methods. Selection of parallel fan sizes was further explored using computational fluid dynamics (CFD). Simulation results show that operating two surface parallel fans results in low total air power and low fans pressure

### Keywords

methods, coal, hardy, pillar, cross, board, cpm, multi-seam, dpm, dilute, mines, fan(s), selection

### Disciplines

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**SELECTION OF FAN(S) TO DILUTE DPM FOR MULTI-SEAM BOARD AND PILLAR COAL MINES USING HARDY CROSS AND CPM METHODS**Ramakrishna Morla<sup>\*1</sup>  
ShivakumarKarekal<sup>2</sup><sup>\*1,2</sup>School of Civil, Mining and Environmental Engineering, Faculty of Engineering and Information Science, University of Wollongong, NSW, Australia, 2522**ABSTRACT**

Multi-seam coal mining comprises of a large number of working sections. A well-organized ventilation system is necessary to supply adequate air quantities to all working sections and to dilute diesel particulate matter (DPM) within the statutory limits. In this paper, an attempt has been made to optimize fan(s) operating points in a multi-seam mine using a combination of Hardy-Cross and critical path methods. Selection of parallel fan sizes was further explored using computational fluid dynamics (CFD). Simulation results show that operating two surface parallel fans results in low total air power and low fans pressure

**Keywords:**

Ventilation network; DPM; Fan; booster fan; CFD; Hardy-cross

**INTRODUCTION**

The conventional board and pillar mine ventilation system is operated by a single main mechanical ventilator; however, multiple fans or upgrading the fan size is required to safely achieve future enhanced production targets[2]. The main issue with the multiple fans is that of choosing an optimum combination of fan(s) for a single return airway and it is further complicated if the booster fan is included within the ventilation system [6 - 8].

In coal mines, the main fan(s) operates continuously and therefore, the selection of fan(s) should consume minimum total air power of a fan in order to supply adequate air quantity. The air power requirement of a fan is the product of the fan total pressure (p) and air quantity (q). If there are n fans in the system, the total air power requirement of the mine is the sum of air power of the n number of fans [1,9].

Various research studies have been conducted to select the best combination of fan(s) with minimum total air power consumption. Some of these studies are based on the Hardy-Cross method [4,5,13], linear equation and linear equivalence [15,16], critical path method [3] and simplex method [14]. Presently, coal mines are using various 3D ventilation software's like ventsim, Ventnet, etc., but these packages require details of fan(s) as an input data, not accurate and slower process.

This paper describes a selection of fan(s) for multi-seam typical ventilation network mines using the combination of Hardy-Cross and critical path methods. The proposed method is fast, accurate and will provide fan operating points.

To conduct ventilation network simulation studies, considered GDK 11 incline mine of Singareni Collieries Company Limited (SCCL), India [11,12].

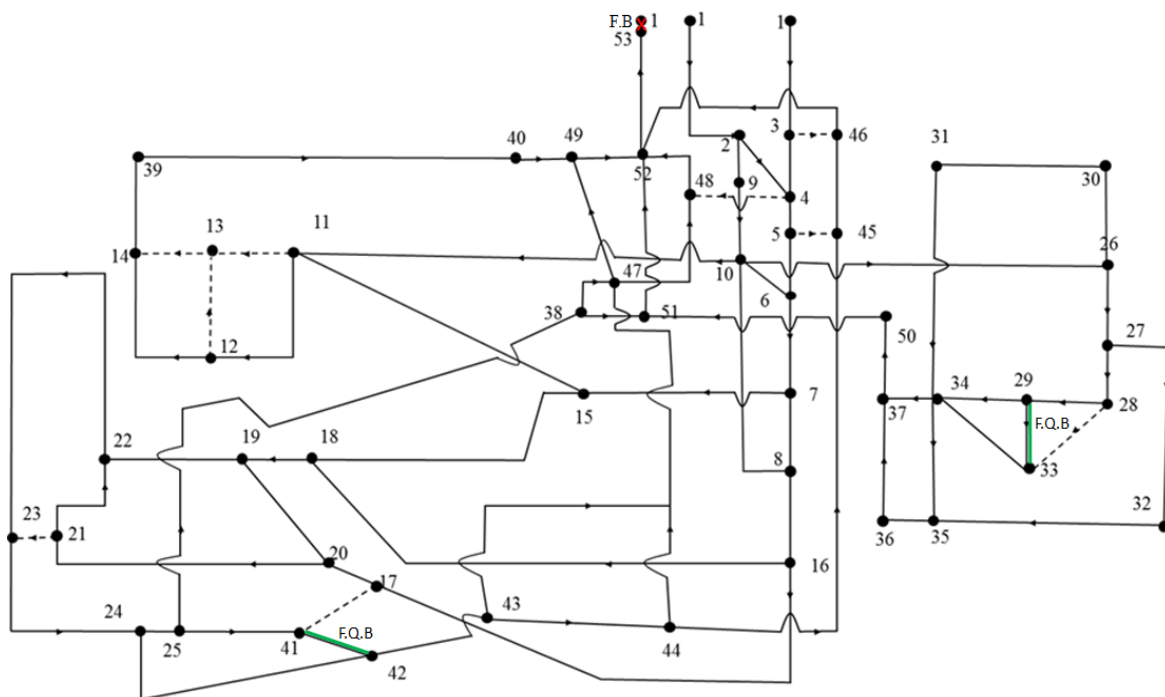
The mine is located in RG-1 area of Ramagundam region of SCCL, between north latitudes 180 41' 30'' and 180 41' 10'' and east longitudes 790 32' 58'' and 790 34' 54'' [19]. The full dip of the coal seams is between 1 in 8 to 1 in 10 in the direction of N 600 E. A total of four extractable seams are under exploitation in this mine and gassiness of the seams classified as degree-1. Thickness of seam-1 is 3.97 to 6m and this seam is initially exploited with conventional board and pillar mining later longwall and continuous miner systems were introduced in this seam. Seam-2 is exploited with board and pillar method of mining using electrical load haul dumpers (LHD) and its thickness is 1.36 to 3.96m. Reserves in a seam-3 is mining with blasting gallery method and its thickness is 4.57 to 11.37. Reserves in seam-4 is developing and extracting with board and pillar method with hydraulic sand stowing mining method using electric LHDs and its thickness is 1.8 to 4.27m.

## MATERIALS AND METHODS

## The Study Areas

The ventilation system of the mine is operated by a single surface axial flow fan of 300hp capacity at 650 Pa pressure with 205 m<sup>3</sup>/s quantity. Where fan pressure is the total pressure. The overall resistance of the mine is 0.15 Ns<sup>2</sup>/m<sup>8</sup> which is very low due to more parallel airways in both intake and returns.

Figure 1 show the simplified ventilation network diagram of a coal mine [12]. It contains 53 nodes, 78 branches, two main intakes and one main return shaft. The network also contains few air leakage branches, shown by the dotted lines, two fixed quantity branches are shown as F.Q.B and a fan branch shown in as F.B. Air quantity in this network always flow from the lower node number to the higher node number.



**Figure 1.** Simplified ventilation network diagram of a coal mine

To conduct initial ventilation network simulation studies, field survey including both pressure and quantity surveys have been carryout in the mine. Air velocity was measured using a vane anemometer and differential pressure measurements were carried out by using Magnehelic differential pressure gage and flexible transparent PVC tube. After completion of field survey, basic ventilation network was established, and resistance of each network work branches were calculated using measured pressure and quantity ( $R=p/q^2$ ).

**Table 1** show the details of 78 branches of the ventilation network diagram [12]. It includes starting node (S.N), ending node (E.N) and resistance (R) in Ns<sup>2</sup>/m<sup>8</sup>. From the table, it can be observed that a few leakage branches have high resistance values.

**Table 1: details of network branches (starting and ending nodes) with resistance**

S.N	E.N	R	S.N	E.N	R	S.N	E.N	R	S.N	E.N	R
1	2	0.00788	11	15	0.11317	25	41	0.00718	40	49	0.18423
1	3	0.00439	12	13	9.36000	26	27	0.00554	41	42	0.05174
2	4	0.01174	12	14	0.04800	26	30	0.91209	42	43	0.00406
2	9	0.10229	13	14	0.60718	27	28	0.00422	43	44	0.00406
3	4	0.00109	14	39	0.13159	27	32	0.50000	44	45	0.03973
3	46	68.0000	15	18	0.01268	28	29	0.00486	44	47	0.03322
4	5	0.00053	16	17	0.11268	28	33	10.8000	45	46	0.02738
4	48	69.9200	16	18	0.04012	29	33	0.06235	46	52	0.10229
5	6	0.00199	17	20	0.06443	29	34	19.2400	47	48	0.18631
5	45	13.5098	17	41	3.48750	30	31	0.11612	47	49	0.12141
6	7	0.00176	18	19	0.00055	31	34	1.19923	48	52	0.18793
6	9	0.00566	19	20	0.00116	32	35	0.10000	49	52	0.01503
7	8	0.00234	19	22	0.03816	33	34	0.04865	50	51	0.00159
7	15	0.00629	20	21	0.00258	34	35	0.16875	51	52	0.00089
8	16	0.00547	21	22	0.00330	34	37	0.01166	52	53	0.00223
8	10	0.01370	21	23	0.45569	35	36	0.02500	53	1	0.00100
9	10	0.00114	22	23	0.01048	36	37	0.07500			
10	11	0.00951	23	24	0.00506	37	50	0.01590			
10	26	0.00477	24	25	0.00160	38	51	0.22956			
11	12	0.03656	24	42	0.19139	38	47	0.02905			
11	13	64.1975	25	38	0.01021	39	40	0.08685			

Where  
S.N is the Starting Node  
E.N is the Ending Node  
R is the Resistance  $Ns^2/m^8$

To simulate the ventilation network, Hardy-Cross method was used. The aim of the Hardy-Cross method analysis is to find the air quantity in the ventilation circuit and to estimate the flow intensity error in the ventilation circuit [20] and which is further modified by Wang [21].

$$Q = Q_a + \Delta \quad (1)$$

$$\Delta = - \frac{\sum \pm R_i Q_i^2}{2 \sum R_i Q_i} \quad (2)$$

$$\Delta = - \frac{\sum_{i=1}^{i=n} b_{ki} (R_i |Q_i| Q_i - P_{ni} - P_{Fi})}{2 \sum_{i=1}^{i=n} b_{ki}^2 R_i |Q_i|} \quad (3)$$

Where

$\Delta$  is the flow intensity error in loop ( $m^3/s$ ),  $Q_a$  is assumed quantity,  $b_{ki}$  is the fundamental matrix element of the loop,  $P_{ni}$  is the increasing pressure by reason of natural ventilation in the branch,  $P_{Fi}$  is the increasing pressure by reason of installed fan in the branch  $R$  is the branch resistance and  $Q$  is the quantity.

The output from Hardy-Cross simulator is verified and observed that the results are below  $\pm 5\%$  of actual measurement, which validate the accuracy of the data. After validation of the data, various alternatives were simulated for designing and optimisation of the ventilation system.

The mine is planning to introduce diesel-powered load haul dumpers(LHD) or diesel-powered utility vehicles and man riding vehicles in the blasting gallery(BG)panel and other working seams. Because of its greater flexibility than standard electrical equipment, high efficiency, easy maintenance, consistency and durability to transport men and material, many nations have been using for most of their underground coal mining for transport and production activities [22]. The main concern with the diesel equipment is exhaust fumes which contain a mixture of diesel particulate matter(DPM) and pollutant gases [23].

### **Characteristics and health effects of DPM**

DPM is the by-product of incomplete combustion of fuel in the diesel engine, sub-micron in size and contain solid core of elemental carbon, the core surface adsorbs many other toxic substances that are transported with particulate and can penetrate deep into the lungs. More than 1800 different organic compounds have been identified as adsorb into the elemental carbon core, such as organic chemicals, condensed liquid hydrocarbons, and inorganic compounds [24].

Various research studies have been proved a potential link between occupational exposure to diesel exhaust and lung cancer [22, 26, 27]. Recently, in United States, National Cancer Institute (NCI) has conducted a research study in a cohort of 12315 workers in eight mines, which include 198 lung cancers deaths and 562 incidents density-sampled control objects. They concluded that significant increased trend in lung cancer risk with increasing cumulative respirable elemental carbon(REC) and average REC intensity. These study results show that diesel exhaust exposure may cause lung cancer in humans and may represent potential public health burden [17].

As per coal mines regulations, the recommended 8-hour time weighted average exposure standard of elemental carbon (EC) fraction when expelled from a diesel engine is  $0.1 \text{ mg/m}^3$ . Which is approximately equal to  $0.16 \text{ mg/m}^3$  total carbon(TC) or  $0.2 \text{ mg/m}^3$  diesel particulate(DP). The minimum ventilation quantity required to overcome diesel emissions and heat stress where a diesel engine operates shall be such that ventilation current of not less than  $0.06 \text{ m}^3/\text{s/Kw}$  of maximum capacity of the engine or  $3.5 \text{ m}^3/\text{s}$  whichever is greater. If more than one diesel engine is being operated in the same ventilation current the diesel engine rated Kw shall be added [18].

To dilute DPM with in the statutory limit and to eliminate chances of spontaneous combustion fire in BG panels [10], the air quantity in branch 41-42 need to increase from  $25 \text{ m}^3/\text{s}$  to a minimum of  $30 \text{ m}^3/\text{s}$  and branch 29-33 from  $38 \text{ m}^3/\text{s}$  to at least  $45 \text{ m}^3/\text{s}$ . Increasing higher operating pressure of the fan to get more air quantity results in a greater chance of air leakage in goafs and the chance of sponcom and fire [10]. Therefore, new fan(s) operating pressure must be kept to a minimum.

To fulfil specified requirements with minimum total air power, the mine is planning to introduce new fan(s). To find the optimum fan(s) types and/or arrangements, ventilation network simulation studies have been conducted using Hardy-Cross and CPM methods in following three cases:

- selection of optimum single surface fan
- selection of optimum surface fan and underground booster fan
- selection of optimum surface parallel fans.

### **DETAILS OF VENTILATION NETWORK SIMULATION STUDIES**

In general, the selection of a main fan for a given condition is decided by simulating the network with fan operating points from characteristic curves and using regulators in other road ways to supply adequate air quantity to the fixed branches. These procedures may not minimize the total air power or may not fulfil fixed quantity branches requirements [6]. The following simulation studies may solve these issues with minimum fan operating pressure and power consumption.

#### **Selection of optimum single surface fan**

In this case, a combination of Hardy-Cross and critical path method has been used to select the ideal size of the main surface fan. Initially, the network is simulated with the Hardy-Cross simulator. It provides the required booster fan (-ve) or regulator (+ve) pressure in the fixed quantity branches. The resistance ( $R_{Res}$ ) of the fixed quantity branches is updated by adding new resistance ( $r_{ei}$ ) with old resistance [6]. Then with the critical

path forward pass procedure is used to know the minimum possible pressure required to ventilate the mine then updates the new main fan pressure CPM pressure output. This process will continue until no booster fan pressure is required in the fixed quantity branch.

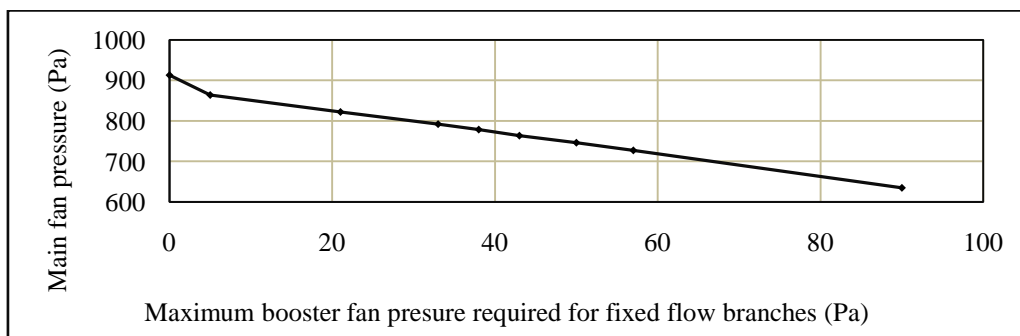
After 17 iterations, the simulator has achieved specified results,

Table 2 shows the results of simulation studies with a single surface fan. If the main fan run at 913Pa pressure and 242m<sup>3</sup>/s quantity, no booster fan pressure is required in fixed quantity branches.

**Table 2: Results of simulation studies with single surface fan**

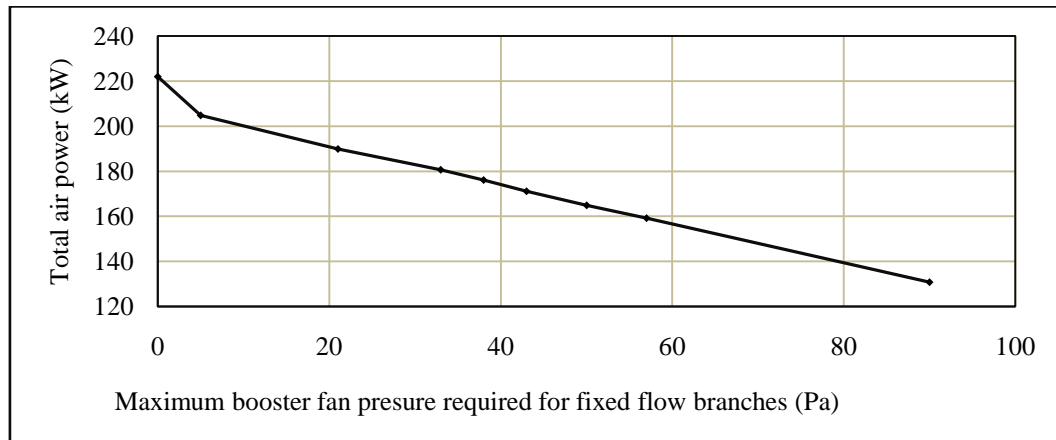
Fan type	Branch	Pressure (Pa)	Air quantity (m <sup>3</sup> /s)	Total air power (kW)
Main Fan-1	Surface (53-1)	913	242	221
Details of fixed quantity branches				
Branch	Fixed quantity (m <sup>3</sup> /s)		Regulator (+) / booster pressure (-) (Pa)	
29-33	45		+13.8	
41-42	30		0.0	

Figure 2 shows ventilation network simulation results in relation to the main fan pressure and maximum booster fan pressure required in fixed quantity branches. It is clearly seen that the main fan pressure increases with decreasing booster fan pressure. In the first iteration when the main fan is at 638 Pa pressure, a maximum of 90 Pa booster fan pressure is required in fixed quantity branches and finally, if the main fan pressure is 913 Pa, no booster fan pressure is required in the fixed quantity branches.



**Figure 2. Variation of main surface fan pressure with increase in booster fan pressure to maintain fixed quantity of air in each branch.**

Figure 3 shows a variation of total air power with respect to maximum booster fan pressure required in fixed quantity branches. Total air power is gradually increased with reduced fixed branch booster pressure. It can be seen that at 221kW total air power, no booster fan pressure is required for fixed quantity branches.



**Figure 3. Variation of total airpower with booster fan pressure to maintain fixed air quantity**

#### Selection of optimum combination of surface fan and booster fan

In this case, the mine was planning to install a booster fan in branch 47-49. Simulation studies were conducted by a combination of a main fan at surface and a booster fan in branch 47-49 so that the total air power could be minimized without using a booster fan pressure in fixed flow branches. The network simulator and CPM procedures were run at different booster fan pressures. For each iteration, booster fan pressure increased with a step of 10 Pa [6].

The results of simulation studies in Table 3 show that when the main fan and booster fan pressure are 882 Pa and 60 Pa, no booster pressure is required in fixed quantity branches. Quantity delivered by a main fan is  $240 \text{ m}^3/\text{s}$  and booster fan in branch 47-49 is  $37 \text{ m}^3/\text{s}$ . The main fan pressure is reduced from 913 Pa to 882 Pa. Reducing the chance of air leakage between the panels and/or seams results in less chance of spontaneous combustion.

**Table 3: Results of simulation studies with main fan and booster fan**

Fan type	Branch	Pressure (Pa)	Air quantity ( $\text{m}^3/\text{s}$ )	Air power (kW)	Total air power (kW)
Main Fan-1	Surface (53-1)	882	240	211.68	213.9
Booster fan	47-49	60	37	2.22	
Details of fixed quantity branches					
Branch	Fixed quantity ( $\text{m}^3/\text{s}$ )		Regulator (+) / booster pressure (-) (Pa)		
29-33	45		+14.7		
41-42	30		0.0		

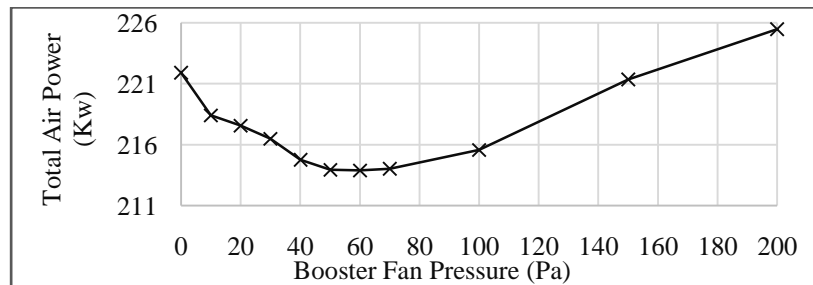
Table 4 and Figure 4 show results of simulations with the main fan on the surface and the booster fan in branch 47-49. Initially, without the booster fan, total air power was 221.89 kW. After the booster fan is added to the network, total air power is reduced by increasing the booster fan pressure. At 60 Pa of booster fan pressure, the total air power reduced to 213.90 kW. Later, it increases with booster fan pressure.

**Table 4: Results of simulation studies for total air power at different booster fan pressures**

Booster fan pressure in branch 47-49 (Pa)	Total air power (kW)
0	221.89
10	218.42
20	217.58
30	216.50
40	214.76
50	213.96
60	213.90
70	214.03
100	215.58



150	221.34
200	225.47



**Figure 4. Total air power and booster fan pressure relationship**

#### Selection of optimum two parallel surface fans

Ventilation network simulation studies have been conducted with two parallel surface fans. Parallel fans generally need to operate at the same capacity as blade angle fans and both are electrically inter-locked in such a way that shutting off one fan will automatically shut off the other[12].

Table 5 shows the ventilation network simulation results with two parallel fans using the Hardy-Cross and CPM simulator. The results show that if both fans are operated at 814 Pa pressure and air quantity of 121m<sup>3</sup>/s, no booster pressure would be required in fixed quantity branches. The results also show that if the main fans run in parallel, total air power would be 196.98kW, which is very 7% lower than that of case 2.

**Table 5: Results of simulation studies with two parallel surface fans are as follows**

Fan type	Branch	Pressure (Pa)	Air quantity (m <sup>3</sup> /s)	Air power (kW)	Total air power (kW)
Main Fan-1	53-1	814	121	98.49	196.98
Main Fan-2	53-1	814	121	98.49	
Details of fixed quantity branches					
Branch	Fixed quantity (m <sup>3</sup> /s)		Regulator (+) / booster pressure (-) (Pa)		
29-33	45		+14.5		
41-42	30		0.0		

#### CFD MODELLING OF AIR FLOW

To conduct modelling investigations, the commercially available CFD package ANSYS Fluent (version 18) was used. CFD simulations were carried in the following four steps.

##### Construction of computational domain

A 190 m depth air shaft with 6 m diameter was designed for this simulations. Two fan houses of 10 m long and 6 m in diameter was included on top of the air shaft. For the CFD simulations, the outlet fan pressure was used as a boundary condition.

##### Construction of computational mesh

To achieve accurate results, finer mesh was used with half-million computational cells. Minimum size of cell used to construct the mesh was 7.2 x 10<sup>-3</sup> m. Minimum edge length of cell was 0.025 m and size function was proximity and curvature. Program controlled inflation with seven layers were used in the mesh.

##### Governing equations

To model air flow in the shaft, considered flow in the shaft and fan house as a turbulent flow, Reynolds-Averaged Navier-Stokes equation was used. In Reynold's averaging, the solution variables in the exact Navier-Stokes equations are consisting of time averaged and fluctuated components for velocity components [25].

$$u_i = \bar{u}_i + u_i' \quad (4)$$

Where  $\bar{u}_i$  and  $u_i'$  are mean and fluctuating velocity components ( $i=1,2,3$ ).

Reynolds-averaged Navier-Stokes (RANS) equation was obtained by substituting time and average velocity in momentum equation:

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_i} (\rho u_i) = 0 \quad (5)$$

$$\frac{\partial}{\partial x} (\rho u_i) + \frac{\partial}{\partial x_j} (\rho u_i u_j) = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j} \left[ \mu \left( \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} - \frac{2}{3} \delta_{ij} \frac{\partial u_l}{\partial x_l} \right) \right] + \frac{\partial}{\partial x_j} (-\rho \overline{u_i u_j}) \quad (3)$$

Where  $-\rho \overline{u_i u_j}$  is Reynolds stress can be solved with Boussinesq hypothesis and Reynolds stress models (RSM). In Boussinesq Hypothesis, the Reynolds stress are related to the mean velocity gradient [25].

$$-\rho \overline{u_i u_j} = \mu_t \left( \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) - \frac{2}{3} (\rho k + \mu_t \frac{\partial u_k}{\partial x_k}) \delta_{ij} \quad (6)$$

To determine turbulent viscosity  $\mu_t$ ,  $k - \varepsilon$  model was used.

$$\mu_t = \rho C_\mu \frac{k^2}{\varepsilon} \quad (7)$$

Where  $C_\mu$  is a constant,  $k$  is the turbulence kinetic energy and  $\varepsilon$  is the turbulent dissipation rate and turbulent heat transport is modelled using the concept of the Reynolds analogy to turbulent momentum transfer. The modelled energy equations are as follows:

$$\frac{\partial}{\partial t} (\rho E) + \frac{\partial}{\partial x_i} [u_i (\rho E + p)] = \frac{\partial}{\partial x_j} \left[ \left( k + \frac{c_p \mu_t}{\sigma_k} \right) \frac{\partial T}{\partial x_j} + u_i (\tau_{ij})_{eff} \right] + S_h \quad (8)$$

Where  $k$  is the thermal conductivity,  $E$  is the total energy and  $(\tau_{ij})_{eff}$  is the deviatoric stress tensor, defined as

$$(\tau_{ij})_{eff} = \mu_{eff} \left( \frac{\partial u_j}{\partial x_i} + \frac{\partial u_i}{\partial x_j} \right) - \frac{2}{3} \mu_{eff} \frac{\partial u_k}{\partial x_k} \delta_{ij} \quad (9)$$

The standard  $k - \varepsilon$  model is based on the model transport equations for the turbulence kinetic energy ( $k$ ) and its dispersion rate ( $\varepsilon$ ). The model transport equation for  $k$  is derived from the exact equation, while the model transport equation for  $\varepsilon$  was obtained using physical reasoning and bears little resemblance to its mathematically exact counterpart.

In the derivation of the  $k - \varepsilon$  model, the assumption is that the flow is fully turbulent, and the effect of molecular viscosity is negligible. As the mine air considered as fully turbulent flow,  $k - \varepsilon$  model is valid for mine air.

The turbulent kinetic energy,  $k$ , and its rate of dissipation,  $\varepsilon$ , are obtained from the following governing equations [25]

$$\frac{\partial}{\partial t} (\rho k) + \frac{\partial}{\partial x_i} (\rho k u_i) = \frac{\partial}{\partial x_j} \left[ \left( \mu + \frac{\mu_t}{\sigma_k} \right) \frac{\partial k}{\partial x_j} \right] + G_k + G_b - \rho \varepsilon - Y_M + S_k \quad (10)$$

$$\frac{\partial}{\partial t} (\rho \varepsilon) + \frac{\partial}{\partial x_i} (\rho \varepsilon u_i) = \frac{\partial}{\partial x_j} \left[ \left( \mu + \frac{\mu_t}{\sigma_\varepsilon} \right) \frac{\partial \varepsilon}{\partial x_j} \right] + C_{1\varepsilon} \frac{\varepsilon}{K} (G_k + C_{3\varepsilon} G_b) - C_{2\varepsilon} \rho \frac{\varepsilon^2}{K} + S_\varepsilon \quad (11)$$

Where  $G_b$  is the generation of turbulence kinetic energy due to buoyancy,  $G_k$  is the production of turbulence kinetic energy due to the mean velocity gradient,  $Y_M$  is the contribution of the fluctuating dilation in compressible turbulence to the overall dissipation rate,  $C_{1\varepsilon}$ ,  $C_{2\varepsilon}$  and  $C_{3\varepsilon}$  are constants.  $S_k$  and  $S_\varepsilon$  are user defined source terms.

## RESULTS AND DISCUSSIONS

CFD simulation studies show that if the mine is ventilated by single surface fan, air flow quantity ( $q = \text{area} * \text{velocity}$ ) of 242 m<sup>3</sup>/s is achieved at 920Pa of main fan pressure. Negative pressure indicates the mine is operated by the exhaust ventilation system (

Simulation studies also conducted by a combination of 200 hp and 300 hp capacity of parallel fans. From the Figure 6 it can be observed that use of a low capacity fan (200 hp) results in very low velocity and pressure in reverse direction, while use of a high-capacity fan (300 hp) results in high air velocity and pressure. Due to high pressure differences within the fans chamber, there would be a high risk of both fans run in stall zone and

damage). Air velocity in the shaft is 8.6m/s and high turbulent flow with different air velocities can occur in the fan house.

CFD simulation studies also show that when both fans run at the same capacity of 300hp and blade angle, uniform distribution of air velocity and low pressure drop occurred in the fan house and at the air shaft, **Ошибка! Источник ссылки не найден.** From the figure, it can be observed that air flow quantity of  $242\text{m}^3/\text{s}$  is achieved at 815Pa of each main fan pressure.

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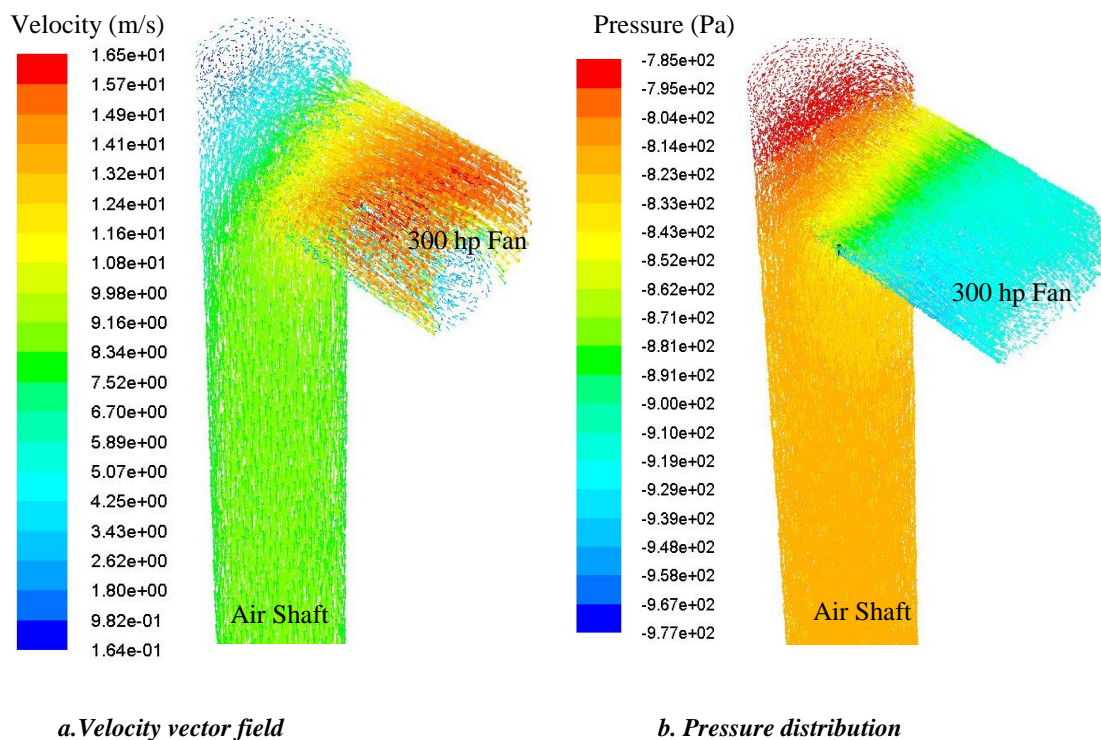
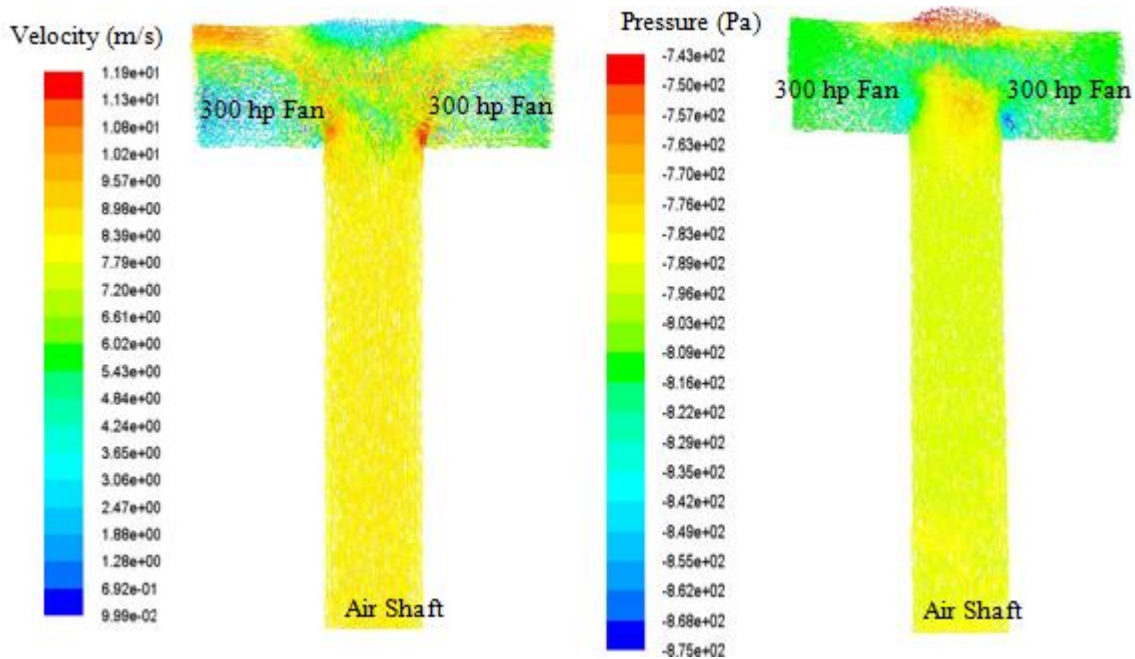


Figure 5. Velocity and pressure distribution in shaft with one fan of 300hp, view from fan housetop

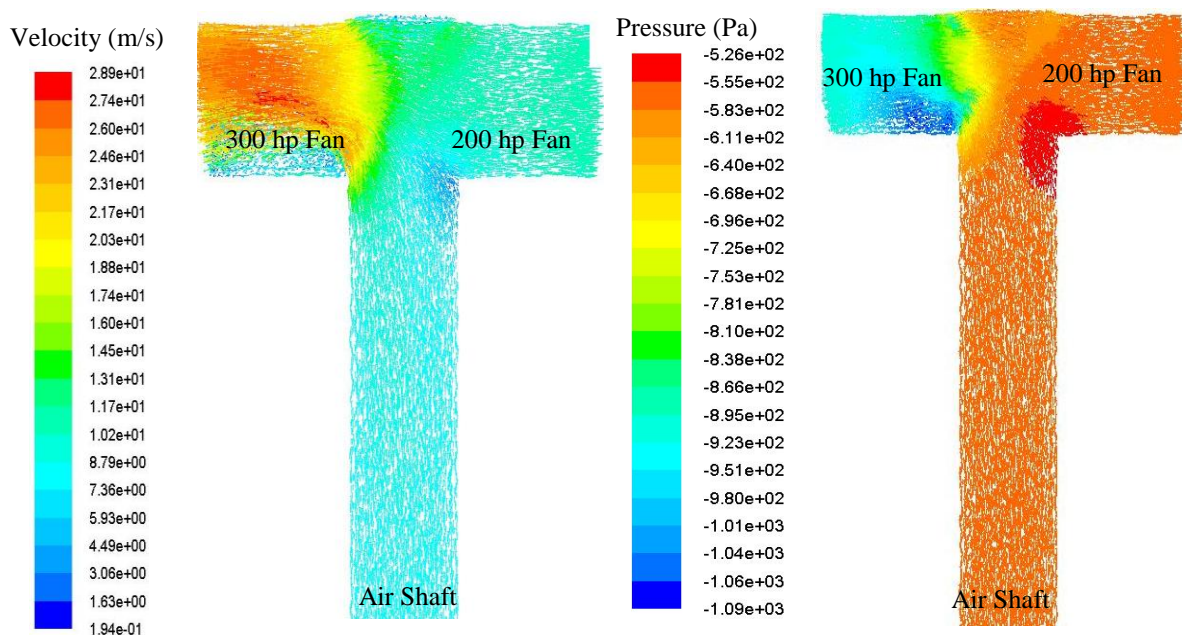


a. Velocity vector field

b. Pressure distribution

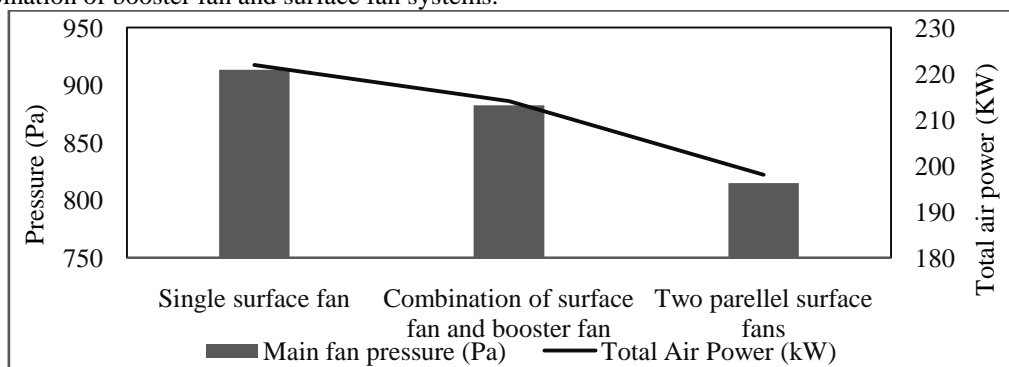
Figure 6. CFD model with two 300 hp fan velocity and pressure distribution, view from fan house top

Simulation studies also conducted by a combination of 200 hp and 300 hp capacity of parallel fans. From the Figure 6 it can be observed that use of a low capacity fan(200 hp) results in very low velocity and pressure in reverse direction, while use of a high-capacity fan (300 hp) results in high air velocity and pressure. Due to high pressure differences within the fans chamber, there would be a high risk of both fans run in stall zone and damage



*a. Velocity vector field**b. Pressure distribution***Figure 6.** CFD simulation results with a combination of 200 hp and 300 hp fans velocity and pressure distribution, view from fan house top

Figure 7 show results of simulation studies conducted using the combination of Hardy Cross and CPM methods for single surface fan, combination of booster fan and surface fan and two parallel surface fans systems. The total air power of a parallel surface fans system is 10% lower than the single surface fan and 7% lower than that of combination of booster fan and surface fan systems.

**Figure 7.** Main fan pressure and total air power variations with three simulation case studies**CONCLUSIONS**

The combination of Hardy-Cross and CPM procedures is useful in solving multi-seam critical ventilation network mines to dilute DPM within in the statutory limit. Simulation results show that the upgrading of the single surface fan to supply greater air quantity results in high fan pressure of 913 Pa. This may lead to higher chances of sponcom as well as higher consumption of total air power, 221 kW. The combination of main and booster fans causes low air pressure at main fan of 882 Pa and low air power of 213 kW. In this case, the booster fan must operate at correct operating point, function of the booster fan above or below the operating point causes excessive power consumption. Results also show that operating two surface parallel fans results in low total air power of 197 kW and low fans pressure of 814 Pa. In this case, the two fans need to operate at the same capacity and blade angle.

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