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SELECTION OF OPTIMUM COMBINATION OF FANS FOR BORD AND PILLAR COAL MINES - A CASE STUDY

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ABSTRACT: A good design of ventilation system for a mine should supply adequate air flow for all workings. One of the objectives of the ventilation planning is to select optimum operating points for the fan and its combinations to achieve the required air flow rate. It will improve the safety conditions and minimise the total air power consumption. The objective of this study is to increase ventilation quantity with low operating pressure and effective utilisation of the main mechanical ventilator. Ventilation simulator and CFD modelling studies were conducted with different combinations of fans. Operating parallel fans with the same capacity and blade angle at the return air shaft is the best possible solution for achieving this objective. A detailed case study of the pressure survey of the ventilation network and the simulation results is presented.

INTRODUCTION

In India, Singareni Collieries Company Limited (SCCL) is one of the biggest coal producing company with 36 underground and 14 opencast mines in operation. To increase the production capacity in the currently operating underground mines demands full utilisation of main mechanical ventilator(s). At high fan pressures there is a chance of air leakage through fire seals, ventilation stopping's and barriers, which will lead to fires. Due to differential pressures in multi seam workings there can be air breathing into different seams, which lead to spontaneous combustion and fires.

The total production capacity including underground and opencast mining methods of SCCL is approximately 52 Mtpa. Of this, 12 Mtpa of coal is produced from underground mining operations using methods like bord and pillar, longwall, continuous miner and blasting gallery. Underground coal mining in SCCL is currently operating at a maximum depth of 500 m and most of the operations are carried at 200 to 400 m depth.

In SCCL most of the main fans are axial flow fans rated between 150 to 225 kW. Out of 36 underground mines highest pressure delivered by the main fan is 860 Pa and highest quantity delivered is 200 m^3/s. The average resistance of the mines is 0.0365 Ns^2/m^8, air flow quantity is 133 m^3/s and pressure develop by main fans is 540 Pa. The company is spending US$2.84 million per annum for main fans power consumption. The average power cost of the main fan for SCCL operated mines is US$136 per annum per pascal.

The SCCL has proposed to increase a production capacity from various existing underground mines by effectively utilising the available fan facilities and building additional infrastructure wherever needed. A detailed case study of the GDK 11 incline was carried out to assess the necessary action taken.

GDK 11 INCLINE

GDK 11 incline is situated in RG-I area of SCCL which is located at a distance of 18 km from Ramagundam Railway Station. The mine has four workable Seams (I, II, III and IV) and the gradient of the seams is 1 in 8 and the gassiness of the seams classified as degree-I. All the seams were extensively developed by bord and pillar methods. Reserves in Seam-I are extracted by Continuous Miner Technology at a maximum depth of 350 m. Reserves in Seam-II are being developed and extracted by semi-mechanization with Load Haul Dumpers (LHD). Reserves in Seam-III are extracted by the Blasting Gallery (BG) method. Reserves in Seam-IV are extracted by hydraulic stowing with LHDs.

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Details of existing ventilation system

GDK 11 incline has four intakes ie. main incline dip (MID), manway dip (MWD), 3rd entry and an 80 m depth intake shaft. All these four intakes were connected to seam I. This mine has a 190m depth return shaft, which is connected to seam I, II and III. The diameters of the return and intake shafts are 6 m. The mine has one Voltas made 225 kW fan with a maximum blade angle of 32.5^{o}. The total air flow quantity delivered by the main fan at 650 Pa pressure is 205 m^3/s. Table 1 shows the details of the existing ventilation system.

Table 1 - Details of existing ventilation system

Sl.No	Parameter	Details
1	Seam-I quantity (m^3/s)	106.10
2	Seam-II quantity (m^3/s)	26.11
3	Seam-III quantity (m^3/s)	44.85
4	Seam-IV quantity (m^3/s)	27.94
6	Total air quantity (m^3/s)	205.00
7	Pressure drop(Pa)	650
8	Total Air power (kW)	133.35
9	Power consumption per year @ 60% Efficiency	1 945 450
10	Power cost per year @ US$0.0678/kWh	131 901

The overall resistance of the mine is 0.15 Ns^2/m^8 and the area of equivalent orifice of the mine is 9.7 m^2. Pressure drop at the return air shaft is 94 Pa (14%) and at the intake entries is 82 Pa (12.6%). All intakes and returns have parallel paths.

Objective

GDK 11 incline has planned to improve its production targets from 0.8 Mtpa to 1 Mtpa. For achieving this production target the main mechanical ventilator(s) should satisfy the following conditions:

- The overall required quantity for the mine should be 235 m^3/s but with the existing 225 kW single fan it is only possible to get up to 205 m^3/s;
- A new ventilation system should be used with only one return shaft;
- The fan(s) should operate at the lowest operating pressure (<900 Pa).

To meet the above specified objectives for the GDK 11 incline, the following schemes for upgrading can be considered for the existing ventilation and to meet the projected capacity:

- Effective utilisation of existing entries and provision of additional new entries;
- Re-organization of existing ventilation systems;
- Optimum utilisation of existing capacity of main fans;
- Installation of high capacity main fan;
- Usage of booster fans;
- Introduction of an optimum combination of parallel fans.

For the use of high capacity fans, it requires high initial investment and construction of new fan house. These fans operate at high pressure which leads to fire. Inclusion of new entries is a time taking process and may take three to four years of time. With booster fans it is possible to get additional quantity but its usage in bord and pillar method of SCCL mines is not practised due to pillar fires. Fixing of parallel fans is more convenient and better suitable for delivering high quantity of air at low operating pressure.

Simplified ventilation net work diagram

The simplified ventilation network diagram (Manohar and Morla, 2011) of GDK-11 incline has 53 nodes, 79 branches and 11 tunnels. Figures 1 to 4 shows the nodes, branch locations, intakes and return paths of the simplified ventilation network diagrams of the mine.

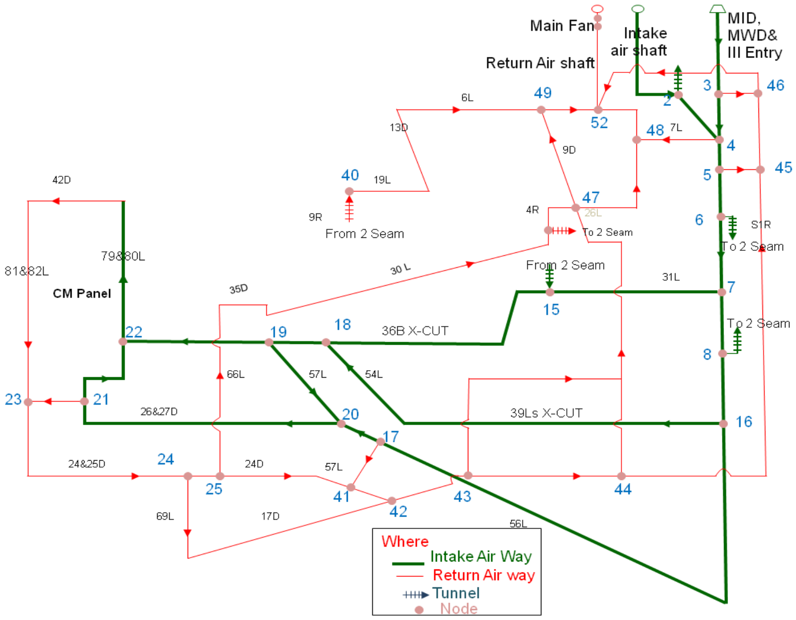
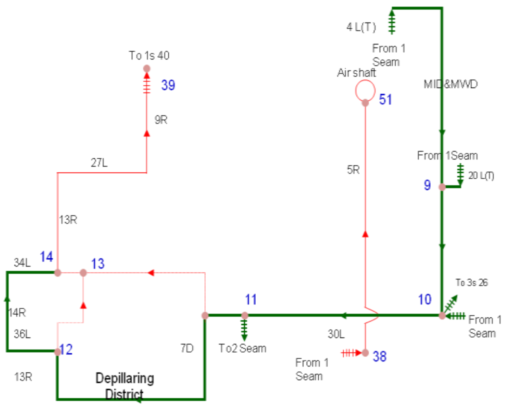


Figure 1 - Simplified ventilation network diagram of seam I



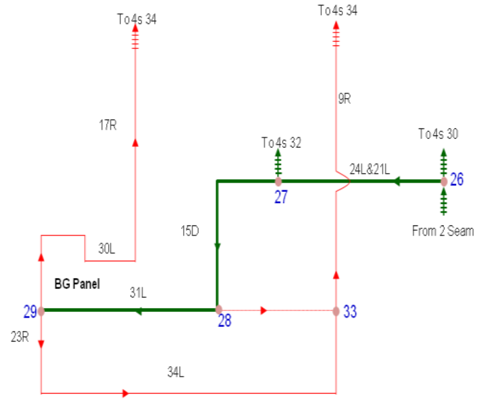


Figure 2 - Simplified ventilation net work Diagram of seam-II **Figure 3 - Simplified ventilation network diagram of seams-III**

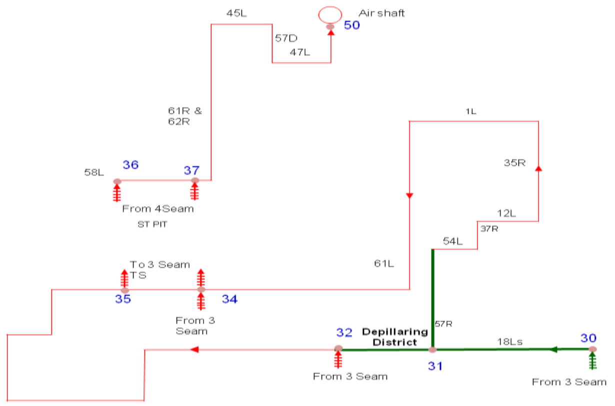


Figure 4 - Simplified ventilation net work diagram of seam-III Top Section and seam-IV

Branches details

Field study was conducted to measure air quantity and pressure drops between the nodes. Using the equation R= (P/Q^2) the resistances of all branches were calculated. Table 2 shows the starting node and ending node of the branches and their resistance values.

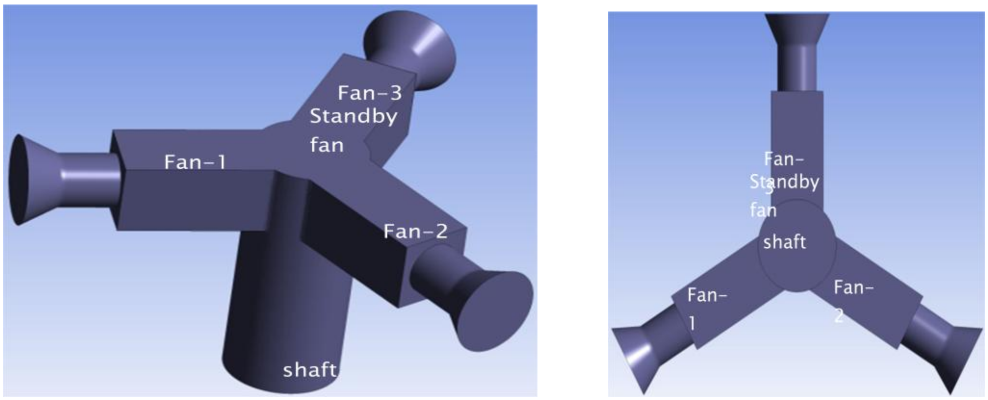
Table 2 - Branches with resistances values

S.	E.N	R	S.N	E.N	R	S.N	E.N	R	S.N	E.N	R
1	2	0.0078	11	15	0.11317	25	41	0.00718	40	49	0.1842
1	3	0.0043	12	13	9.36	26	27	0.00554	41	42	0.0517
2	4	0.0117	12	14	0.048	26	30	0.91209	42	43	0.0040
2	9	0.1022	13	14	0.60718	27	28	0.00422	43	44	0.0040
3	4	0.0010	14	39	0.13159	27	32	0.5	44	45	0.0397
3	46	68	15	18	0.01268	28	29	0.00486	44	47	0.0332
4	5	0.0005	16	17	0.11268	28	33	10.8	45	46	0.0273
4	48	69.92	16	18	0.04012	29	33	0.06235	46	52	0.1022
5	6	0.0019	17	20	0.06443	29	34	19.24	47	48	0.1863
5	45	13.509	17	41	3.4875	30	31	0.11612	47	49	0.1214
6	7	0.0017	18	19	0.00055	31	34	1.19923	48	52	0.1879
6	9	0.0056	19	20	0.00116	32	35	0.1	49	52	0.0150
7	8	0.0023	19	22	0.03816	33	34	0.04865	50	51	0.0015
7	15	0.0062	20	21	0.00258	34	35	0.16875	51	52	0.0008
8	16	0.0054	21	22	0.0033	34	37	0.01166	52	53	0.0022
8	10	0.0137	21	23	0.45569	35	36	0.025	53	1	0.001
9	10	0.0011	22	23	0.01048	36	37	0.075			
10	11	0.0095	23	24	0.00506	37	50	0.0159			
10	26	0.0047	24	25	0.0016	38	51	0.22956			
11	12	0.0365	24	42	0.19139	38	47	0.02905			
11	13	64.197	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

Parallel fans

In a parallel fan arrangement, three main fans installed at top of the upcast shaft are set to operate at uniform capacity and blade angle. Any two fans will be in continuous operation and the other fan is kept as standby. All of these parallel fans are electrically inter-locked in such a way that shutting off one of the fan will automatically shut the other fan. Figure 5 shows the arrangement of parallel fans.



(a) Isometric view **(b) Plan view**

Figure 5 - Arrangement of the parallel fans and the upcast shaft

Details of simulations

For achieving the specified objective, simulation studies were conducted with ventilation simulator (Sastry and James, 1985) for different cases. The details of ventilation simulations with different cases are outlined in Table 3.

Table 3 - Details of simulations

Case	No. of. Intakes & Details	No. of. Returns & Details	No. of fans & Capacity	Fan Blade Angle	Fan constants
Existing	4 (MID,MWD, 3rd entry and 80 m shaft)	1 (190m shaft)	1 (225 kW)	32.5°	A=-0.02398 B=1701
Case 1	4 (MID,MWD, 3rd entry and 80 m shaft)	1 (190m shaft)	1 (375 kW)	15°	A=0 B=1000
Case 2	3 (MID,MWD and 3rd entry)	2 (80 &190m shafts)	2 (225 kW)	17.5° each	A=-0.04412 B=1484.62
Case 3	4 (MID,MWD, 3rd entry and 80 m shaft)	1 (190m shaft)	2 parallel fans (225 kW each)	17.5° each	A=-0.04412 B=1484.62
Case 4	4 (MID,MWD, 3rd entry and 80 m shaft)	1 (190m shaft)	2 parallel fans (225 kW each)	15° & 17.5°	A=-0.04953 B=1319.20 (For 15°)
Case 5	4 (MID,MWD, 3rd entry and 80 m shaft)	1 (190m shaft)	2 parallel fans (225 kW each)	17.5° & 20°	A=-0.03372 B=1489.94 (For 20°)
Case 6	4 (MID,MWD, 3rd entry and 80 m shaft)	1 (190m shaft)	2 parallel fans (150&225 kW)	17.5° each	A=-0.0362 B=760 (150kW fan)

Fan constants (A and B values) calculated from fan characteristic curve with the least square approximation method. All cases had four intake air ways and one return air way but case 2 has three intakes and two returns. Case1 had a 375 kW fan, case 6 had a combination of 150 kW and 225 kW fans and all other cases have 225kW fan(s). First three cases have single fan and all other cases have parallel fans. All intakes are connected to one seam and air travels through tunnels to other seams. The return air shaft is connected to seam I, II and III. Figure 6 and 7 shows the details of intake and return air ways for all cases.

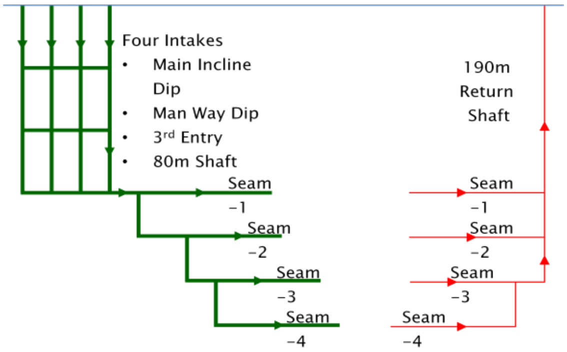


Figure 6 - Intake and return airways of existing, Case-1, 4, 3, 5 and 6

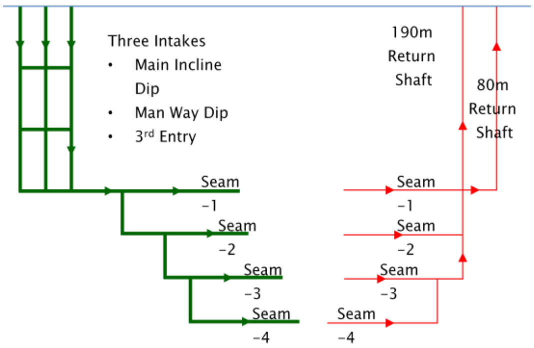


Figure 7 - Intake and return airways of Case-2

SIMULATION RESULTS AND DISCUSSIONS

In case 1, the ventilation system operates with a 375 kW fan at 15° blade angle with four intakes and one return air way. The 375 k W fan is able to supply 246 m^3/s of air flow quantity which is sufficient for all the seams but the pressure developed by this fan is 1 000 Pa, which is very high, and there is a chance of fire in BG panels and at other sealed off workings. The other issues for SCCL for not operating 375 kW fan is it requires construction of new fan house and purchase of fan structures. Installation of new 375 kW fan at existing return air shaft will take two to three years of time. Also, in this case total air power is 246.7 kW and power cost per year is US$ 244 203 which is very high when compared with the existing system.

In case 2, the ventilation system operates with two 225 kW fans at 17.5^o blade angle at two different shafts with three intakes and two return air ways. The overall resistance of the mine is increased when the intake shaft is used as a return air shaft. The main fan pressure for 80 m depth shaft is 946 Pa, which is in stall zone. Air delivered by these two fans is 216 m^3/s which is less than the recommended quantity of 235 m^3/s. The total air power is 196.86 kW and the power cost per year is US$ 194 867 which is very high when compared with the existing system. The cost for maintenance of two fans at different locations is expensive.

In case 3, the ventilation system operates with two 225 kW fans at 17.5^o blade angle with four intakes and one return air shaft. The air flow quantity delivered by these combinations of fans is 238 m^3/s at a pressure of 850 Pa which satisfies the recommended quantity. The total air power is 202 kW and the power cost per year is US$200 252 which is less than that of 375 kW fan. For this case an additional third fan is required as a standby fan.

In case 4, the ventilation system operates with two 225 kW fans at 15^o and 17.5^o blade angles with four intakes and one return air shaft. The total air quantity delivered by these combinations of fans is 226 m^3/s at a pressure of 790 Pa which is less than the minimum requirement of the mine. The total air power is 178.5 kW and the power consumption per year is US$176 733 which is very high when compared with the existing system.

In case 5, the ventilation system operates with two 225 kW fans at 17.5^o and 20^o blade angle with four intakes and one return air shaft. The combination of fans able to supply 242 m^3/s of air flow quantity which is sufficient for all the seams but the pressure developed by this fan is 908 Pa which is high. The total air power 219.7 kW and the power consumption per year is US$ 217 512 which is very high when compared with the existing system.

In case 6, the ventilation system operates with 150 kW and 225 kW fans at 17.5^o blade angle at two different shafts with four intakes and one return air way. The total air quantity delivered by this combination of fans is 200 m^3/s at 615 Pa pressure which is less than the minimum requirement of the mine. The total air power is 123.7 kW and the power consumption per annum is US$ 122 448 which is much less when compared with the existing system. The air flow quantity delivered by 150 kW fan is 62 m^3/s at an operating pressure of 615 Pa which may damage the fan due to its high pressure.

Table 4 and 5 shows the brief simulation results of all the cases.

Table 4 - Simulation results of existing, case 1 and 2

Sl.No	Parameter	Existing	Case-1	Case-2
1	Seam-I quantity (m^3/s)	106.10	127.67	108.47
2	Seam-II quantity (m^3/s)	26.11	31.51	27.80
3	Seam-III quantity (m^3/s)	44.85	53.93	49.13
4	Seam-IV quantity (m^3/s)	27.94	33.59	30.60
6	Total air quantity (m^3/s)	205.00	246.70	115+101 = 216.00
7	Pressure drop(Pa)	650	1000	881&946
8	Total Air power (kW)	133.35	246.70	196.86
9	Power consumption per year @ 60% Efficiency	1 945 450	3 601 820	2 874 156
10	Power cost per year @ $0.0678/kWh	131 901	244 203	194 867
11	Remarks	One 225 kW Fan at 32.5^0 Blade Angle	One 375 kW Fan	Two fans at two shafts, both with 17.5^0 blade angle

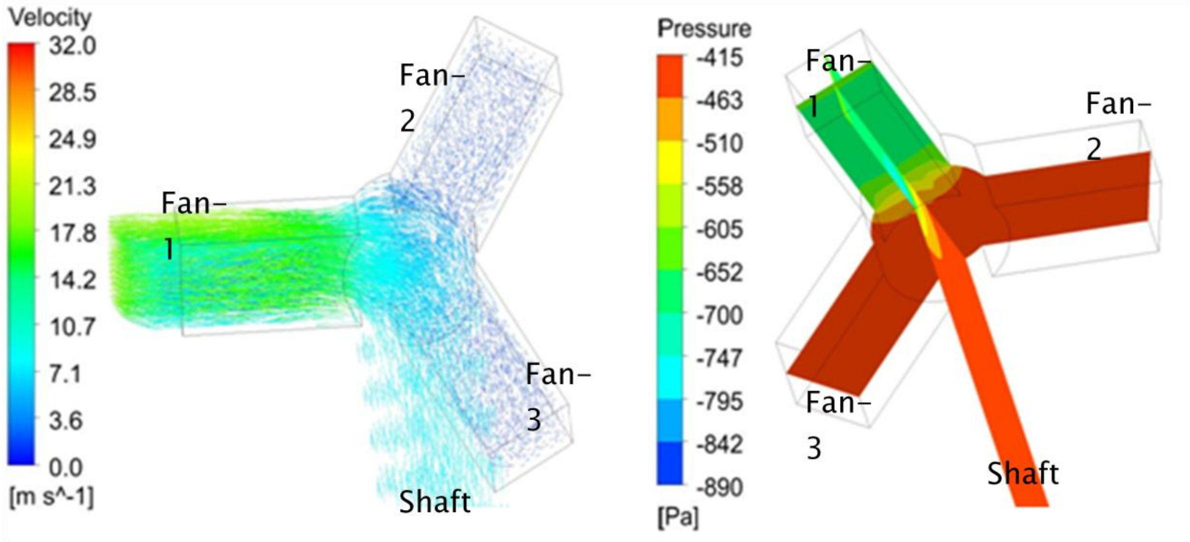
CFD models

Preliminary CFD modelling simulations were carried out for single fan, parallel fans with same capacity and blade angle and parallel fans with different capacities.

CFD modelling studies were conducted with single and/or double fans operating at different pressures. The equivalent orifice area of the main shaft inlet is about 9.7 m^2. Figure 9 indicates velocity and pressure distribution pattern for a single fan of 225 kW at 32.5^o blade angle. The pressure developed by the fan is about 650 Pa which was introduced as boundary condition in the CFD model. Modelling results indicated that air flow quantity at the fan outlet is about 206 m^3/s. The results of the ventilation simulator and the CFD model for existing condition are more or less the same.

Table 5 - Simulation results of case 3, 4, 5 and 6

Sl.No	Parameter	Case-3	Case-4	Case-5	Case-6
1	Seam-I quantity (m^3/s)	123.99	116.80	125.00	101.00
2	Seam-II quantity (m^3/s)	30.11	29.00	31.00	27.00
3	Seam-III quantity (m^3/s)	51.54	49.40	53.00	44.00
4	Seam-IV quantity (m^3/s)	32.36	30.80	33.00	28.00
6	Total air quantity (m^3/s)	119 + 119 = 238.00	124+102 =226.00	113+129 =242.00	138+62 =200.00
7	Pressure drop(Pa)	850	790	908	615
8	Total Air power (kW)	202.30	178.54	219.736	123.7
9	Power consumption per year @ 60% Efficiency	2 953 580	2 606 684	3 208 145	1 806 020
10	Power cost per year @ $0.0678 / kWh	200 252.7	176 733	217 512	122 448
11	Remarks	Two 225kW parallel fans at 17.5^o Blade Angle	Two 225kW parallel fans at 15^o &17.5^o Blade Angle	Two 225kW parallel fans at 17.5^o & 20^o Blade Angle	One 150kW and one 225kW parallel fans

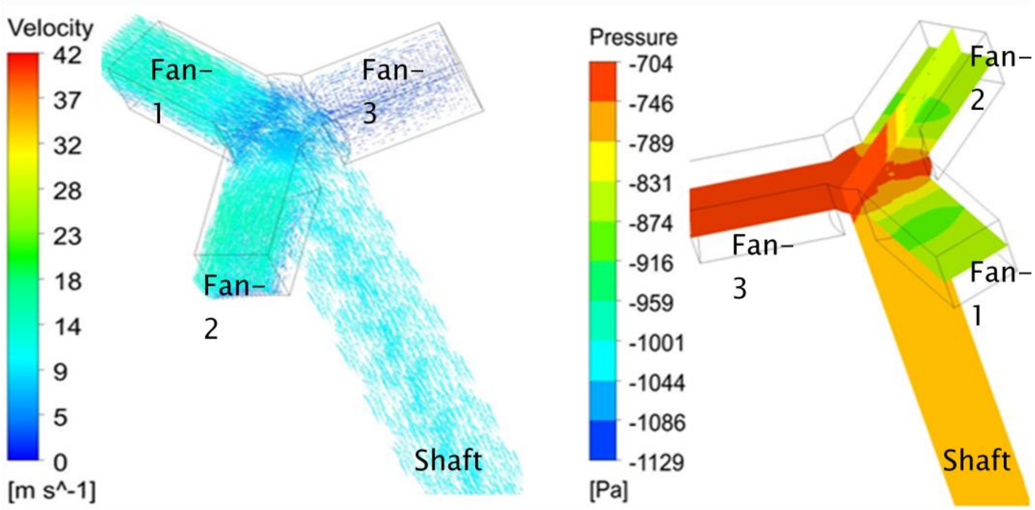


(a)Velocity vectors **(b) Pressure distribution**

Figure 9- CFD model with single 225 kW fan at maximum blade angle

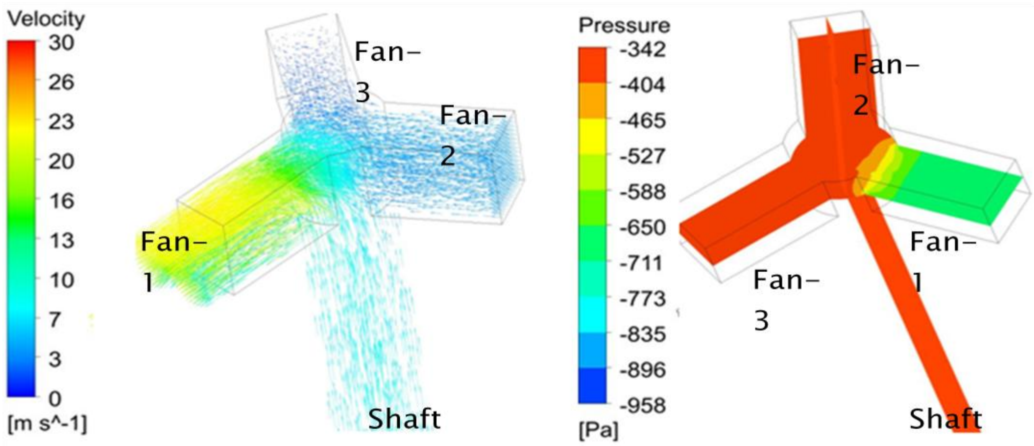
Figure 10 indicates the velocity and pressure distribution pattern for double 225 kW fans with the same blade angle of 17.5^o. The pressure developed by the fans is about 850pa which was introduced as the boundary condition in the CFD model. Modelling results indicated that air flow quantity at each fan outlet is about 120 m^3/s.

Figure 11 indicates the velocity and pressure distribution pattern for double fans of 150 kW and 225 kW capacity. The pressure developed by these fans is about 340 Pa and 650 Pa which was introduced as the boundary condition in the CFD model. Modelling results indicated that air flow quantity at the fans outlets are about 63 m^3/s (reveres flow) and 249 m^3/s. The combination of low and high capacity fans will lead to reverse flow at low capacity fan region which may damage the fan.



(a)Velocity vectors **(b) Pressure distribution**

Figure 10- CFD model with two 225 kW fans at same blade angle



(a)Velocity vectors **(b) Pressure distribution**

Figure 11- CFD model with combination of 150 kW and 225 kW fans

CONCLUSIONS

In bord and pillar mines, alteration of the intake air shaft into a return air shaft will increase overall resistance of the mine. Installation of high capacity fans leads to fire in BG panels and other sealed off area. Installation and operation of parallel fans at same capacity and blade angle more useful for achieving required quantity of air at low operating pressure. It is easy to install parallel fans at same capacity and blade angle with utilisation of the existing low capacity fans and fan houses. Parallel fans at same capacity and blade angle will give better results than different blade angles. Usage of parallel fans with different power capacities may damages the low capacity fan.

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