Chapter 2
Ventilation Network Analysis

Abstract Ventilation network analysis deals with complex working procedures to calculate the air currents flowing in the various meshes or branches of a mine network. It involves mathematical method of analyzing mine resistance to carry out ventilation planning, management, and control. Network analysis is a generic term covering group of methods that are used in cases to analyze and optimize airflow in a network of interconnected and related meshes that have some connection between one another. As central ventilation method is practiced in underground coal mines in place of boundary ventilation method, the ventilation network analysis covers large number of combinations of airway resistances, fans, and regulators that will provide a desired quantity and direction of air flow. The advances in computing techniques have made ventilation network analysis rapid, flexible, and easy to use so that various designs of experiments can be investigated and solved for selecting the optimal solution.

Keywords Ventilation network • Network analysis • Ventilation modeling • Simulation

2.1 Introduction

A ventilation analysis deals with calculation of air currents flowing in the various meshes or branches of the mine network. Ventilation planning is a continuous and routine process (Cross 1936; Hartman and Wang 1967; Maas 1950; McElroy 1954). Whenever a new underground mine or any subsurface facility is designed, it is imperative to determine the distribution of airflows by quantified planning, installation of fans, and other ventilation controls so that required environmental conditions are achieved throughout the mine (Atkinson 1854). Ventilation planning works in tandem and synergy with the mine planning so that required fans, controls, air shafts, and evasee are planned in a timely and phased manner .Ventilation planning may be treated as a dynamic system in context of any underground mine with new workings continually being developed and older ones coming to the end of their productive life.

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Any integrated ventilation system can be represented as a schematic diagram in which each line (branch) denotes either a single airway or a group of openings that are connected such that they behave effectively as a single airway (McPherson 1964; McPherson 1966). Only active and operating airways should be shown on the network schematic. Sealed-off areas having insignificant leakage and stagnant dead ends and headings that produce no induction effects on the main airflow need not be represented in the network. On the other hand, the tops of shafts or other openings to surface are connected to each other through the pressure sink of the surface atmosphere. The points at which branches connect are known simply as junctions or nodes (McPherson 1984).

The chapter is organized as follows: the next section presents various methods of carrying out ventilation network analysis. Section 2.2 concentrates on analytical method. Sections 2.3, 2.4, 2.5, and 2.6 present numerical method, Hardy Cross method, Monte Carlo method, and ventilation modeling, respectively.

2.2 Analytical Method

The analytical methods involve formulating the governing laws into sets of equations that can be solved analytically to give exact solutions. This is the most elementary of the methods of analyzing ventilation networks. If two or more airways are connected either in series or in parallel, then equivalent resistance is calculated by analytical method. This method is used with limited application, but it provides significant simplification of the schematic representation of actual subsurface ventilation systems. Once the solution is obtained quantitatively by solving set of equations, qualitative analysis is carried out in interpreting the results to find suitability of the derived solution in the real-life ventilation network problem.

2.3 Numerical Method

The prominence of numerical method has come into existence due to computers and use of high-level computer program to solve any problem reliably and quickly. Presently, simulation packages are used for carrying out ventilation network analysis. A simulation program is a mathematical model written to conform with one of the computer languages (Scott et al. 1953; Wang and Saperstein 1970; Williams 1964). Simulation is the process of generating values using random numbers without really conducting experiments. Such experiments may be undertaken before the real system is operational to aid in its design or to see how the system might react to change in its operating rules or to evaluate the system or to investigate the response to change in its structure. The simulation tool is especially valuable tool in a situation where the mathematics is needed to describe a system realistically or where it is too complex to yield the analytical solution.

2.4 Hardy Cross Method

The Hardy Cross method is an iterative method for determining the airflow in mine network systems where inputs (air quantity and pressure) as well as outputs (air quantity and pressure) are known but the flow inside the ventilation network is unknown.

The steps in Hardy Cross method may be enumerated as follows:

- Step 1: Assume the most reasonable flows for each branch of mine roadways. The continuity law should be satisfied, i.e., $Q_{\text{in}} = Q_{\text{out}}$. During the first iteration, Q_{o} may be assumed as guessed flow.
- Step 2: Apply the friction loss for each branch using

$$h = KQ^n \tag{2.1}$$

where K denotes the friction coefficients.

- Step 3: Compute the algebraic sum of the head losses around each elementary loop

$$\sum h = \sum KQ^n \tag{2.2}$$

- Step 4: Adjust the flow Q_{o} in each branch by a correction ΔQ to balance the head in the loop and give

$$\sum h = \sum KQ^n = 0 \tag{2.3}$$

$$\Delta Q = -\frac{\sum h}{n\sum \left|h\left|Q\text{o}\right|\right|} \tag{2.4}$$

- Step 5: Repeat until ΔQ becomes small.

The advantages of the Hardy Cross method are enumerated below:

(i) Convergence is achieved rapidly because of the quadratic equation.
(ii) The convergence is insensitive to the starting value.

The disadvantages of the Hardy Cross method are enumerated below:

(i) A set of loops is required to be defined.
(ii) It is time-consuming because each loop must be considered individually and sequentially.

2.5 Monte Carlo Method

Monte Carlo simulation is a simulation technique in which statistical distribution function is created by using a series of random numbers. It is a probabilistic model and dynamic model. Monte Carlo simulation yields a solution which should be very close to the optimal but not necessarily the exact solution. However, it should be noted that this technique yields a solution that converges to the optimal or correct solution as the number of simulated trails leads to infinity. Monte Carlo simulation produces distribution of possible outcome values.

The steps followed in Monte Carlo method are enumerated below:

(i) Determine the statistical properties of possible inputs.
(ii) Generate many sets of possible inputs which follow the above properties.
(iii) Perform a deterministic calculation with these sets.
(iv) Analyze statistically the results.

2.6 Ventilation Modeling

Ventilation modeling deals with formulating design of experiments matching geometry and scale of various underground structures simulating length, width, height, coefficient of friction, drag and other losses, etc. The ventilation model is designed to simulate and reflect the existing mine structure as well as the future planned extension. The boundary value condition, loading condition, and material model condition are applied resembling the actual underground geometry. By inputting quality input, the ventilation model is capable to produce the estimated output with very low error. Computaional Fluid Mechanics (CFD) is one of the popular ventilation models used in industrial domain. The evaluation of airflow in the airways is based on the Hardy Cross method, an iteration estimation method used to adjust the air quantity flow through the airways until the estimation errors lie within acceptable limits.

A very important step in designing a ventilation network is to determine the minimum airflow for different working faces of the mine. The quantity and quality of airflow must meet the airflows required by the Mining Acts and Regulations. Based on the type of system required, the ventilation model can fix the airflow on an airway. Ventilation models use built-in fan database. Each fan curve input in the database is built based on the manufacturer fan curve. Ventsim is one of the commercial softwares used for ventilation modeling.

Figure 2.1 shows an Indian case study showing the ventilation network analysis for a mine having one longwall underground panel producing 2200 tons per day, one road header underground panel producing 400 tons per day, and one bord and pillar underground panel producing 400 tons per day.

The input and output data after carrying out the ventilation network analysis for the case study mine shown in Figure 2.1 is discussed below.

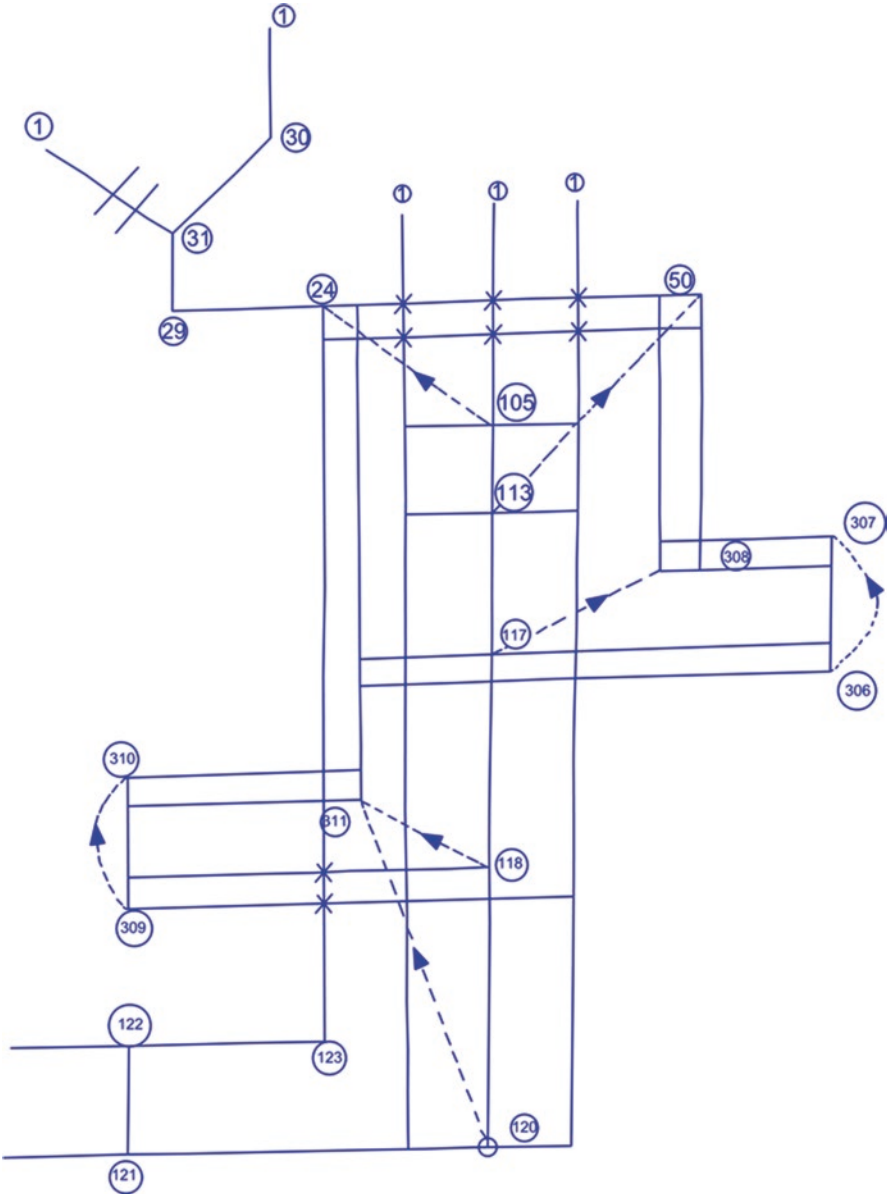

Fig. 2.1 Ventilation layout showing underground mine working

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                 **********************************
                  VENTILATION NETWORK CALCULATIONS
                 **********************************

INPUT  DATA
***********
Number of fan curves input = 1
Number of branches with fixed airflows = 3
Fan characteristic points

Fan 1

Point     Airflow    Pressure
          m^3/s      Pa

1         230.00     1400
2         220.00     2000
3         207.00     2600
4         190.00     3200
5         170.00     3800

Max., min. & presumed airflows for fans

Fan 1
Max. airflow = 400.00
Min. airflow = 0.00
Presumed airflow = 200.00

Branches with fixed airflows

Fixed       Airflow
airflow     m^3/s
branch
1           %150
2           16.00
3           16.00

OUTPUT  DATA
*************
Coefficients for fans

The form of the equation for the curve is P = a + b*Q + c*Q^2 + ...........

Fan 1

37080.36328125
-501.3621826171875
2.625705718994141
-4.871055949479342E-003

Branch  results
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Branch	From	To	Resistance Ns^2/m^8	Airflow m^3/s	Pressure drop Pa
1	30	1	0.000000	150.00	0.0
2	307	308	0.105000	16.00	26.9
3	307	308	0.105000	16.00	26.9
4	1	105	0.236400	13.86	45.4
5	1	105	0.193700	15.32	45.5
6	1	105	0.193700	15.32	45.5
7	105	113	0.060100	9.38	5.3
8	105	113	0.050100	10.27	5.3
9	105	113	0.050100	10.27	5.3
10	113	117	0.027300	5.02	0.7
11	113	117	0.022800	5.50	0.7
12	113	117	0.022800	5.50	0.7
13	117	118	0.009100	-9.51	-0.8
14	117	118	0.009100	-9.51	-0.8
15	117	118	0.010900	-8.69	-0.8
16	117	306	0.120000	16.00	30.7
17	117	306	0.120000	16.00	30.7
18	306	307	0.017500	22.01	8.5
19	118	309	0.130000	14.62	27.8
20	309	310	0.100000	20.21	40.8
21	310	311	0.130000	14.62	27.8
22	311	24	0.370000	29.57	323.6
23	311	24	0.370000	29.57	323.6
24	118	120	0.054600	-20.04	-21.90
25	118	120	0.045600	-21.93	-21.90
26	118	120	0.045600	-21.93	-21.90
27	1	120	0.003800	86.86	28.70
28	120	121	0.150000	20.52	63.20
29	121	122	0.001000	20.52	0.40
30	122	123	0.100000	20.52	42.10
31	123	311	0.030000	20.52	12.60
32	308	50	0.231500	21.87	110.7
33	308	50	0.231500	21.87	110.7
34	50	24	0.040000	28.82	33.20
35	50	24	0.040000	28.82	33.20
36	24	29	0.007000	131.36	120.80
37	29	31	0.006000	131.36	103.50
38	1	31	2.000000	18.64	694.80
39	31	30	0.007000	150.00	157.5
40	306	307	0.085000	9.99	8.50
41	309	310	0.500000	9.04	40.80
42	117	308	2.000000	11.73	275.30
43	118	311	2.000000	6.94	96.40
44	120	311	20.00000	2.43	118.30

45	105	24	2.000000	14.58	425.20
46	113	50	2.000000	13.91	386.70
47	118	309	0.130000	14.62	27.80
48	310	311	0.130000	14.62	27.80

Number of iterations = 14

Pressure drop to be adjusted in fixed airflow branch/branches

(+ INDICATES NEED OF A BOOSTER FAN. - INDICATES A REGULATOR)

Branch	From	To	Resistance Ns^2/m^8	Airflow m^3/s	Pressure drop Pa
1	30	1	0.000	%150	852.4
2	307	308	0.105	16.00	-209.2
3	307	308	0.105	16.00	-209.2

Pressures at Junctions

The following table gives the pressure relative to a Pa at junction #1.

Junction	Pressure
24	-471
29	-591
30	-852
31	-695
50	-437
105	-45
113	-51
117	-51
118	-51
120	-29
121	-92
122	-92
123	-134
306	-82
307	-91
308	-327
309	-78
310	-119
311	-147

*** NETWORK EXERCISE IS COMPLETE***
HOPE THIS EXERCISE HAS BEEN SUCCEESFUL

2.7 Summary of the Chapter

The ventilation network analysis is important in selecting the suitable mechanical ventilator considering the stage-wise mine resistance, future expansion of mine as per production planning so that requisite quantity of air quantity is delivered at appropriate pressure, and efficiency by complying all statutory obligations during the working of mine. With the development of advanced computing techniques, numerical methods, and simulation and modeling techniques, ventilation network analysis can provide an optimal solution to any underground mine by delivering desired air quantity at required head by selecting the techno-economic ventilator. Ventilation network analysis for an Indian case study has been carried out to explain the methodology and output results.

References

Atkinson JJ (1854) On the theory of the ventilation of mines. North of England Institute of Mining Engineers. No. 3, p. 118

Cross H (1936) Analysis of flow in networks of conduits or conductors. Bull. Illinois University Eng. Exp. Station. No. 286

Hartman HL, Wang YJ (1967) Computer solution of three dimensional mine ventilation networks with multiple fans and natural ventilation. Int J Rock Mech Sc 4(2):129–154

Maas W (1950) An electrical analogue for mine ventilation and its application to ventilation planning. Geologie en Mijnbouw, 12, April

McElroy GW (1954) A network analyzer for solving mine ventilation distribution problems. U.S. Bureau of Mines Inf. Circ. 7704. 13 pp

McPherson MJ (1964) Mine ventilation network problems (solution by digital computer). Colliery Guardian Aug. 21. pp 253–254

McPherson MJ (1966) Ventilation network analysis by digital computer. Mining Eng. 126(73):12–28

McPherson MJ (1984) Mine ventilation planning in the 1980's. Int J Min Eng 2:185–227

Scott DR, Hinsley FB, Hudson RF (1953) A calculator for the solution of ventilation network Problems. Trans Inst Mine Eng 112:623

Wang YJ, Saperstein LW (1970) Computer-aided solution of complex ventilation networks. Soc Min Engrs AIME 247:238–250

Williams RW (1964) A direct analogue equipment for the study of water distribution networks. Industrial Electronics 2:457–459

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