COMPUTER PROGRAM FOR PLANNING OF
MINE-VENTILATION SYSTEMS
by
R. POLLAK

ABSTRACT
Today the application of computer programs for planning of mine-ventilation and for safety-analysis of ventilation systems is widespread practice in German mining.

The computer program for network calculation, developed at the "Mine Ventilation Testing Centre of the Westfälische Berggewerkschaftskasse" allows the distribution of airflow and pressure in mines to be calculated. In a physically well-founded manner it takes into account the natural ventilation as well as changes of volume-flow in the mine, which both are dependent on pressure and temperature. Compared to an incompressible treatment of the mine air these circumstances are of increasing importance with the increase of depth, air-temperatures and fan-pressures. This especially holds for the calculation of airflows during failures of fans or for assessing the influence of open mine-fires on ventilation.

The application of the program is very easy and its structure is made to fit the requirements of practice. For instance it takes into account the fan characteristics of all fans. For each planning calculated airflows in all mine workings are compared to those of an eligible basic calculation or to measured airflows. In addition for the

simulation of mine fires any variation of temperature in selected galleries may be specified.

Finally with an additional program there is the possibility to plot the ventilation network. In this plot the main results of the calculation are recorded automatically.

Because of its comprehensive physical description of gas-flow the program meanwhile is also used successfully for planning of compressed air networks. The calculation of methane-drainage systems should be possible too.

The program has already been used for an Australian project, a commissioned study on the ventilation of the German Creek Central Colliery.

INTRODUCTION
In German coal mining, computer programs are in use since long time for calculation of air-flow and pressure distribution within ventilation system planning. Without computer aid, the calculation of a ventilation network is nowadays almost impossible because of the increased size of mine workings. In the majority of programs, the ventilation air is assumed to be an incompressible fluid and, accordingly, the programs neither consider natural ventilation air draft nor the volume flow changes occurring within the mine workings. Both phenomena, however, gain increasing importance with penetration to greater depth, increasing fan pressure rates, and increasing rock temperatures. In this context the average

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depth of coal faces in the Ruhr district increased by 220 m to 900 m in the course of the last two decades. The rock temperature increased accordingly by 8°C to 40°C. The deepest coal faces and headings are situated at present in depths of 1300 m where the rock temperatures are of 60°C.

For the above reasons a ventilation network program was developed which allows for the physical changes of the ventilation air caused by temperature and pressure, and accordingly, also for the volume flow changes and the natural draft. Particular efforts were made in view of drafting the project to the needs of practice and in view of easy application.

BASIC PHYSICS

The basic physical principles which apply to the flow of air through a mine working are

- the law of conservation of the mass,
- the law of conservation of the energy,
- the relation that describes the energy dissipated by friction,
- the equation of the state of the mine air, and
- the change of state of the mine air as a function of airway length.

According to the law of conservation of the mass the magnitude of the mass-flow $m$ of the air does not change between the inlet and the outlet point of a working:

$$m = A \cdot p \cdot v \quad \text{const} \quad (1)$$

where $\rho$ and $v$ stand for the density and velocity of the air stream respectively and $A$ for the cross-sectional area of the working.

When applying the law of conservation of the energy, the change of kinetic energy of the air flow may be neglected for mine ventilation systems. Accordingly, the following differential equation applies to mine workings without fan installations:

$$- \frac{dp}{\rho} = \frac{d\rho}{\rho} + g \cdot dz = 0 \quad (2)$$

where $\rho$ stands for the barometric pressure, $g$ for the gravitational acceleration (9.81 m/s²) and $z$ for the geodetic height coordinate.

The specific energy $\Phi$ dissipated by friction in an airway section of the length $dx$, a perimeter $U$ and a cross-sectional area $A$ is calculated by the formula:

$$\Phi = \lambda \cdot \frac{U}{A} \cdot v^2 \cdot dx \quad (3)$$

In fluid dynamics equation (3) defines the friction coefficient $\lambda$.

The air density, a function of the barometric pressure $p$ and the thermodynamic temperature $T$ is calculated quite accurately from the equation of state for an ideal gas:

$$\rho = \frac{p}{R_F \cdot T} \quad (4)$$

The gas-constant $R_F$ in this case depends on the humidity of the mine air.

Eventually, an assumption has to be made of the variation of the state of air as a function of the airway length, e.g.,

$$\rho = \rho (x) \quad (5a)$$

or $$T = T (x) \quad (5b)$$

Sufficient accuracy is obtained if the calculation is based on a linear variation in each airway. Furthermore, both assumptions are equally acceptable with respect to the possible accuracy of ventilation air measurements done underground. The solution of the differential equation 2, however, is much more complex when using assumption 5b instead of assumption 5a.

Therefore, the described set of equations...
was solved for the assumption of a linear density change in the airway.

Considering now a mesh comprising several airways and fans, if the specific fan energies are denoted by \( w \), the following may be deduced from equation 2:

\[
\delta \frac{dp}{\rho} = \Sigma w - \Sigma \psi \quad (6)
\]

For a constant density \( \rho \) the left-hand side of this equation is equal to zero. In this case, the dissipated energy is equal to the fan energy and natural draft is nonexistent. Therefore generally a natural-draft energy of a system is expressed by \( \delta \frac{dp}{\rho} \). This value is only considered if the change of the physical state of the air is not neglected either.

According to equation 7a the barometric pressure difference between the two ends of an airway results from the sum of pressure loss \( \Delta p_p \) and the static pressure \( \Delta p_s \), the latter being caused by the weight of the air column in the working under consideration.

The pressure loss \( \Delta p_p \) is calculated by equation 7b which comprises the airway resistance \( R_n \) and an arbitrarily chosen reference-density \( \rho_n \). Actually, for the mean density \( \rho_m \) the logarithmic mean of the density values \( \rho_1 \) and \( \rho_2 \) should be inserted into equation 7b. However, for practical application, the arithmetic mean assures sufficient accuracy when inserted into both the equations 7b and 7c.

The density values \( \rho_1 \) and \( \rho_2 \) at the beginning and at the end of the airway are calculated by equation 4. The resistance

\[
R_n = \lambda \frac{UL}{\ln \frac{R_n}{\rho_n}} \quad (8)
\]

is a characteristic value for an airway which depends on the friction factor \( \lambda \) and the geometric data of the airway, viz., perimeter \( U \), length \( L \) and cross-sectional area \( A \).

For constant density all relations described are reduced to the slightly different conventional laws of ventilation.

In a complete network calculation the above-mentioned equations have to be fulfilled simultaneously for every branch of the mine workings under consideration. The mathematical method for solving the resulting comprehensive set of equations is not to be discussed in this paper. For iteration, a broadened version of the cross-method was chosen.

APPLICATION OF THE PROGRAM

For a complete network calculation

- the resistance
- a required constant air quantity, or
- for fans, a required constant fan pressure
  or the fan characteristics

are to be specified for every branch of the
network.

Fan characteristics are specified by a
set of points on selected characteristic
curves available for various blade positions
of the impeller. The computer by interpo-
lation determines the correct operation condition
Corresponding to a chosen impeller blade
setting.

In addition, the following input data
are necessary for considering natural draft
and changes in volume flow:

- depths of all junctions of the network, and
- temperatures at both ends of every branch.

The results of a network calculation are
print on clearly arranged lists, including
the following quantity values for each of
the branches of the network:

- numbers of junctions on both ends of the
  branch,
- the chosen name of the branch,
- airway type; this is only indicated for
  branches with required volume flow or for
  fans,
- volume flow at the beginning of the branch,
- resistance of the airway,
- pressure loss,
- air temperatures at both ends of the branch,
- mass flow of air,
- power dissipated by friction,
- pressure at the beginning of the branch, and
- differences of depth level between both
  ends of the branch.

Moreover, the network can be plotted. On
such a graph, the main calculation results are
introduced automatically. Fig. 1 shows -
considerably reduced in scale - the perspective
representation of a medium-sized mine with
about 320 branches and 210 junctions.

The program is primarily used for venti-
lation planning. By that, the conditions for
satisfactory ventilation are determined in
advance. Thus, the program supplies the basis
for arrangement and operations of air-locks
and fans, for the network structure, and the
necessary cross-sectional areas of the airways.

Beyond that, the program is used for
studies with respect to mine safety. For
instance, it is possible to determine venti-
lation status after a fan failure. The
influence of open mine fires on ventilation is
simulated by assuming arbitrarily a fume-
temperature development in any selected airway.
In such a simulation, the program caters also
for buoyancy and throttling effect of the fumes.
In a similar way, other ventilation trouble may
be investigated thus creating the basis for
air-flow stabilisation measures to be taken
if necessary.

For all these investigations the program,
if required, supplies a comparison of the
calculated air flows against an arbitrarily
determined basic ventilation status. This
is of special importance in practice because
in this way the resulting changes in any part
of the network are recognised very quickly.

Eventually it should be mentioned that
the program because of the comprehensive physical
description of the motion of gases which
it supplies can be used for compressed-air
networks as well even though in such a case
the pressure differences are considerably
greater. For compressed-air system planning,
the program is already used successfully. In
addition, it is intended to use the program for
calculation of methane drainage systems.

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Fig. 1 Perspective Representation of a Medium-Sized Mine

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INFLUENCE OF COMPRRESSIBILITY

In order to demonstrate the influence of compressibility of air on the reliability of planning, Fig. 2 shows a comparison of network calculations wherein air is in one case treated as a compressible fluid and, in the other case, as an incompressible fluid.

The example is based on a simple network of only one mesh. The assumed air temperatures are of 5°C on the surface, rise to 30°C in the mine workings and fall to 20°C in the upcast shaft. The mine workings reach down to 1000 m of depth, and the resistances of the three branches are of 0.02 kg/m³ each. For both calculations, the required airflow at the fan was of 350 m³/s.

The results of the cases under consideration show differences of up to 17% for the volume-flows, of 20% to 52% for the pressure losses and the fan pressure, and of 28% to 55% for friction-dissipated energy and fan performance.

When summing up the energy-related data, it is confirmed that the contribution of natural draft to the airflow is catered for only when considering the compressibility of air. In the example, the corresponding value reads \( P_{\text{W}} = 170 \text{ kW} \), and corresponds to approximately 10% of the fan performance.

It is clearly shown by this example that for ventilation planning it is necessary to allow for the compressibility of air in some way or other in order to make ventilation planning acceptably reliable.

EXAMPLE: MINE-FIRE

For conclusion, a case of ventilation system calculation for a simple network comprising 17 branches and 13 junctions may be discussed. The calculation was carried out for specified resistances and temperatures of all branches and for a known fan characteristic.

Fig. 3 shows the computer-drafted ventilation network plan with automatically plotted results of volume-flow and pressure loss calculations. Table 1 contains the complete set of ventilation data. From Table 1 may be read that the operating conditions of the main fan between junction 10 and junction 12 results from a fan blade position of \( 3^\circ \), a volume flow of 251 m³/s, a fan pressure of 3440 Pa, and a fan performance of 853 kW.

By an additional calculation for the same network the influence of an open mine fire on ventilation was determined. The location of the fire was assumed to be in staple shaft 5-6 with fume temperatures gradually decreasing from 800°C to 63°C.

The results are shown in Table 2. The last column contains the comparison of the air quantity data for this case with those of the normal ventilation situation. Accordingly, in the staple shaft 5-6 with descending ventilation the buoyancy of the fumes reduces the airflow to 5%.

In almost all the other airways the influence of the fire on the stability of ventilation is negligible.

CONCLUSIONS

For the planning of mine ventilation systems the compressibility of air which depends on pressure and temperature should not be neglected. This applies in particular to deep mines, large variations in air temperatures, and high fan pressures.

The suggested method, by means of simple mathematical relations, allows very accurately for changes in volume flow and for natural ventilation.

This was the basis for development of a computer program for ventilation network calculation. All input data can be traced back to quantities measurable underground.
Fig. 2. Comparison of Network Calculations

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Fig. 3. Computer Drafted Ventilation Network Plan

<table>
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<th>AIRWAY</th>
<th>TO NAME</th>
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<th>VOL-FLOW</th>
<th>RESISTANCE</th>
<th>PRESSURE</th>
<th>TEMPERATURE</th>
<th>MEAN</th>
<th>MASS</th>
<th>DISS.</th>
<th>PRESS.</th>
<th>DIFF. OF MASS/ DEPTH</th>
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| 2      | SCH. 1  | 128.31 | 0.0015  | 36.6 | 21.0 | 22.0 | 1.276 | 206.57 | 5.8  | 1069.95 | -150.0 | 0.0  | 0.0  |
| 3      | SCH. 1  | 66.49  | 0.0086  | 248.5 | 21.0 | 22.0 | 1.282 | 71.90  | 15.1 | 1069.95 | 0.0  | 0.0  | 0.0  |
| 4      | SCH. 1  | 55.46  | 0.0018  | 5.5  | 22.0 | 23.0 | 1.293 | 71.23  | 0.3  | 1088.34 | -150.0 | 0.0  | 0.0  |
| 5      | SCH. 1  | 100.70 | 0.0340  | 343.9 | 22.0 | 23.0 | 1.290 | 129.34 | 34.7 | 1088.34 | 0.0  | 0.0  | 0.0  |
| 6      | SCH. 1  | 54.49  | 0.0019  | 96.5  | 22.0 | 25.0 | 1.297 | 71.23  | 5.3  | 1107.31 | 0.0  | 0.0  | 0.0  |
| 7      | SCH. 1  | 52.58  | 0.0450  | 120.5 | 22.0 | 23.0 | 1.268 | 64.23  | 6.3  | 1067.46 | -150.0 | 0.0  | 0.0  |
| 8      | DROSSEL | 8.46   | 33.0000 | 2334.2 | 22.0 | 23.0 | 1.244 | 10.66  | 20.0 | 1067.46 | 0.0  | 0.0  | 0.0  |

DROSSELFÜTEL = 99.2
### Table 2: Influence of an Assumed Mine-Fire in Staple Shaft 5-6

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<th>PRESSURE LOSS</th>
<th>TEMPERATURE</th>
<th>MEAN DENSITY</th>
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DROSSLANTeil = 55 %
The examples demonstrate the efficiency of the program and the possibility to plot a complete network with automatically introduced calculation results. The program may also be used for other gas networks, e.g., compressed-air networks or methane drainage systems.