The Practice of Ventilation Planning Half A Century Ago

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ABSTRACT

This is the description of ventilation planning conducted by the author in 1952 as his thesis for the German degree of Dipl.-Ing. Since the problems have not changed, most of the work done is not much different from what one would do today. Even the tools have remained the same, except for the computers, which were not around yet. To compensate for this, certain planning techniques were developed which are now in danger of being forgotten.

KEYWORDS

Ventilation Pressure Survey, Shaft Resistance, Temperature Precalculation, Ventilation Network Calculation, and Diagonal Airways.

INTRODUCTION

Looking back at almost 50 years of work in mine ventilation, I sometimes ask myself: what would I do differently today. And I come to the conclusion: Very little, in principle.

At least two conclusions offer themselves. One is that I did not learn anything in all those years. The other one is that actually very little has changed. I prefer the second conclusion.

An explanation may be that mine ventilation is such an old discipline. It cannot be much younger than mining activities in general. Underground mine workings need in many cases more fresh air than diffusion can provide. Getting the air there must always have been a major concern.

The practical application of mine ventilation seems to have developed over the past 2000 years in a rather steady way. There were no revolutionary changes and breakthroughs. There were changes of emphasis and sometimes replacements of equipment in some mining districts with those from other districts. Qualitatively, the problems never changed and the available remedies did not change much either.

We have to rely in our knowledge of the past on written records and I have to limit myself to the so-called Western World. One of the oldest technical texts is the 10-volume engineering encyclopedia of the Roman Pollo Vitruvius, which dates from the 1st Century B.C. He mentions that, if the need arose, miners established a systematic ventilation by providing intake and return air shafts.

Due to the turmoil caused by the migration of nations and due to the cumbersome business of having to copy books by hand, there are only a few records left of the following 1500 years. This changed with the invention of printing in 1436. We find in the remainder of the 15th Century two books on mining, but in the 16th Century already 20 books. One of them is Agricola's *De Re Metallica*, which presents an already highly developed mine ventilation technology.

What changed in the 500 years following Agricola paralleled to some extent the developments in other industries, an extensive use of cheap heat energy to produce mechanical work. This was at first done by producing natural ventilation drafts with coal-filled baskets in shafts, then with surface ventilation furnaces, then with underground ventilation furnaces. After the invention of the steam engine, the way was free for powerful fans, the centrifugal fans since the 1820s, the axial flow fans in the 1920s. Also in the 20s came the cooling plants.

With the beginning of the age of enlightenment, the discovery of the physical laws or principles underlying mine ventilation, and the development of the pertinent mathematics, happened contrary to the evolution of ventilation practices within a comparatively short time period. The 17th Century brought the discovery of the scalar nature of pressure in a static fluid, the development of calculus, Newton's second law, Newton's law of viscosity and the many other laws in which gradients are instrumental. In the 18th Century followed Euler's equation for ideal fluid flow which, as Euler's Turbine Equation, is still a basic tool to lay out fans. Also in the 18th Century Bernoulli developed the energy equation for inviscid fluids and Fourier established his law on thermal conductivity.

The 19th Century brought the discovery of the first and second law of thermodynamics. The combination of the two led to the energy equation. The combination of the first law and the momentum equation led to the shock loss or Borda-Carnot equation. Work on flow resistances of pipes led to the Darcy-Weisbach equation, which was in 1854 modified to the Atkinson equation. The accumulated scientific knowledge enabled Prandtl to propose, at the beginning of this century, the Boundary Layer Theory, which has given researchers a handle on answering many questions of the past.

The need for theoretical foundations for mine ventilation had been met by the end of the last century. Work in this century focused on providing experimental data as a basis for future work.

NEED FOR VENTILATION SURVEYS

Ventilation planning requires the existence of a ventilation plan, in which the existing or planned airways, their configuration in the ventilation network, and the airflow rates, which they carry, are shown. Although in principle simple, to verify such a plan for an existing mine or to establish it can be the most time consuming part of a ventilation survey. Seals have collapsed, bulkheads settled, cave-ins occurred. Sometimes older airways have simply been removed as insignificant from ventilation plans.

If a ventilation planning goes into the precalculation of airflow rates, the airflow resistances of the airways and the pressure generation of the driving forces must be known. If an existing network becomes part of a new ventilation system, the resistances of the existing airways have to be assessed. This is normally done with a ventilation pressure survey.

There has practically been no change in the approach taken and there have been few changes in the measuring instruments used during the last 50 years. The anemometers, velometers, psychrometers are still the same as they were half a century ago. If there were changes then with the barometers and manometers, although the old instruments are still popular. Some changes have also occurred with instruments to measure cross-sectional areas, although none of these ever became popular or stayed around for long.

Due to the extension of the mine, I was forced to make a barometric pressure survey. The underlying physical principles of barometric pressure surveys had by then been stated many times for several decades. It had become accepted that the same thermodynamics, which controlled the behavior of gases at the surface, controlled their underground behavior also. Psychrometric charts had been around since the mid-twenties. Since I was not provided with charts for the pressures that I had to deal with, I was told to make my own, which after a week of reading I did not find too difficult.

Measuring absolute air pressures with the accuracy required for making ventilation pressure surveys has always been a challenge. Apart from the mercury barometers, which were little suited as traveling underground instruments, 50 years ago there were aneroid barometers of the Wallace-Tiernan and Paulin type in use by different manufacturers. There were also other instruments around, which by now have almost been forgotten. There were aerostats, which essentially were manometers with one limb connected to a sealed chamber, and hypsometers, where the temperature of the boiling point of water was measured.

I was provided with several Wallace-Tiernan type barometers and with a new make, the Askania Microbarometer, manufactured by Askania Werke, Berlin-Friedenau, Germany. The pressure sensitive element in this instrument is an evacuated helical spring tube. The rotational movement of the free end of this tube, caused by variations in pressure, is magnified optically. Pressure differences can be read down to 1.3 Pa (Figure 1).

This instrument appeared on the market in 1951 and I had one of the first instruments shipped to a customer. Systematic studies of its behavior started only one year after I had already submitted my thesis. They confirmed what I had suspected and had to learn the hard way, that this was a good instrument if you knew and respected its attitudes. It became obvious to me, in particular, that the manufacturer-supplied temperature corrections could not be correct.

Since I had no second microbarometer for use as a reference instrument, and had no opportunity to have the one instrument in my possession calibrated without losing it for weeks, for the recalibration I measured every airway at least two times, once in the direction of the airflow and once against it, and then averaged the results. This, I hoped, would take care of temperature and time corrections as well as the effects of elastic creep in the instrument.

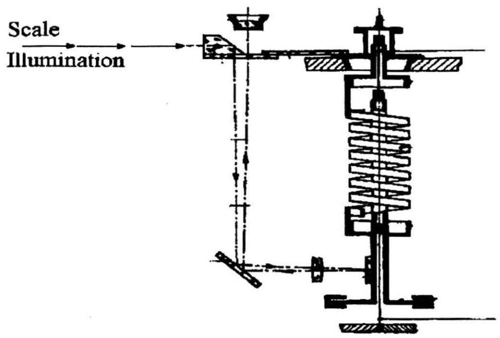

Figure 1. Askania microbarometer.

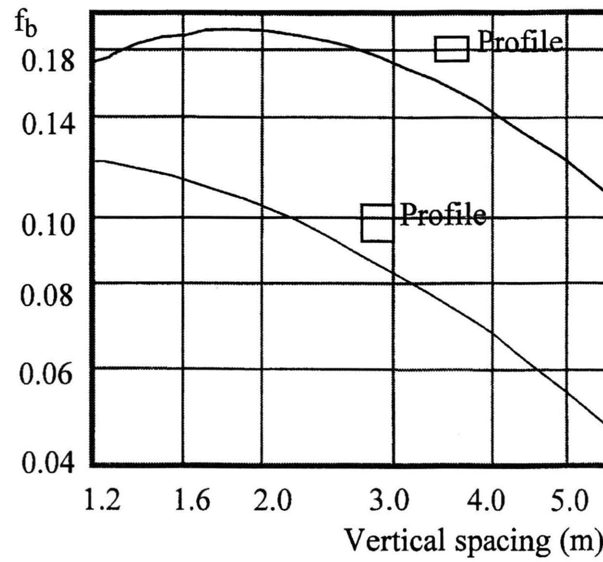

Figure 2. Coefficient of friction f_b as a function of bunton spacing.

PRECALCULATION OF AIRWAY RESISTANCES

Fifty years ago there already existed an abundance of data on airway resistances, which allowed one to precalculate the resistance of just about any airway, as long as there was any regularity in them. Resistances were measured with the help of pressure surveys then because this was the fastest way to obtain them.

My mine was a typical salt mine with large cross-sectional areas in drifts and stopes. The bottlenecks were the shafts. There were two intake shafts and one upcast shaft. I felt that there was an easy way to reduce the resistance of one of the two intake shafts. This was the product hoisting shaft, which had been converted to skip hoisting. It had square timber buntons of 0.2 m side length in 2.0 m vertical intervals. Since it was no longer used for man riding, the mandatory cage arresters were no longer needed. The statics engineers confirmed that half of the buntons could be removed, so a spacing of 4.0 m was obtained. According to my calculations this should have reduced the coefficient of friction of the buntons from 0.19 to 0.15, no dramatic change but worth more than $50,000 per year in energy savings. What I had overlooked was that the spillage from the skips had provided the buntons with a rounded front. As the miners, taking every second set of buntons out, worked their way down the shaft, they cleaned the buntons from spillage. The result was that the resistance did not decrease, it increased until new spillage provided a new rounding (Figure 2).

Temperature Precalculations

With the temperatures I had the poor luck that, in the early fifties, a large number of people in different countries worked simultaneously on refining temperature precalculations. I had, however, the good fortune that my problem was comparatively simple. With the large cross-sectional areas and the resulting low air velocities, and with the high thermal conductivity of salt, the air temperatures rapidly approached the rock temperatures. Temperature variations with time and airflow rates could only be found in the intake airways, and here as a function of seasonal and daily temperature changes of the surface air.

Temperature changes in airways with harmonic temperature variations at the airway beginnings had been calculated in the twenties using the simplification of considering the rock walls to be plane surfaces. Improved mathematics for considering the airways as hollow cylinders was provided at the time that I had to write my thesis. I could not possibly ignore what was going on.

The solutions of Fourier's equation for thermal conductivity for a hollow cylinder, which come in the form of sums of cylinder functions of the third kind and their derivatives, show that the air experiences an amplitude damping as well as a phase shift

Figure 3 shows measured temperatures at the shaft collar and the pit bottom of an intake shaft of 800 m depth and 6 m diameter. Figure 4 shows calculated phase shifts and factors for amplitude damping for the same shaft carrying an airflow rate of 100 kg/s.

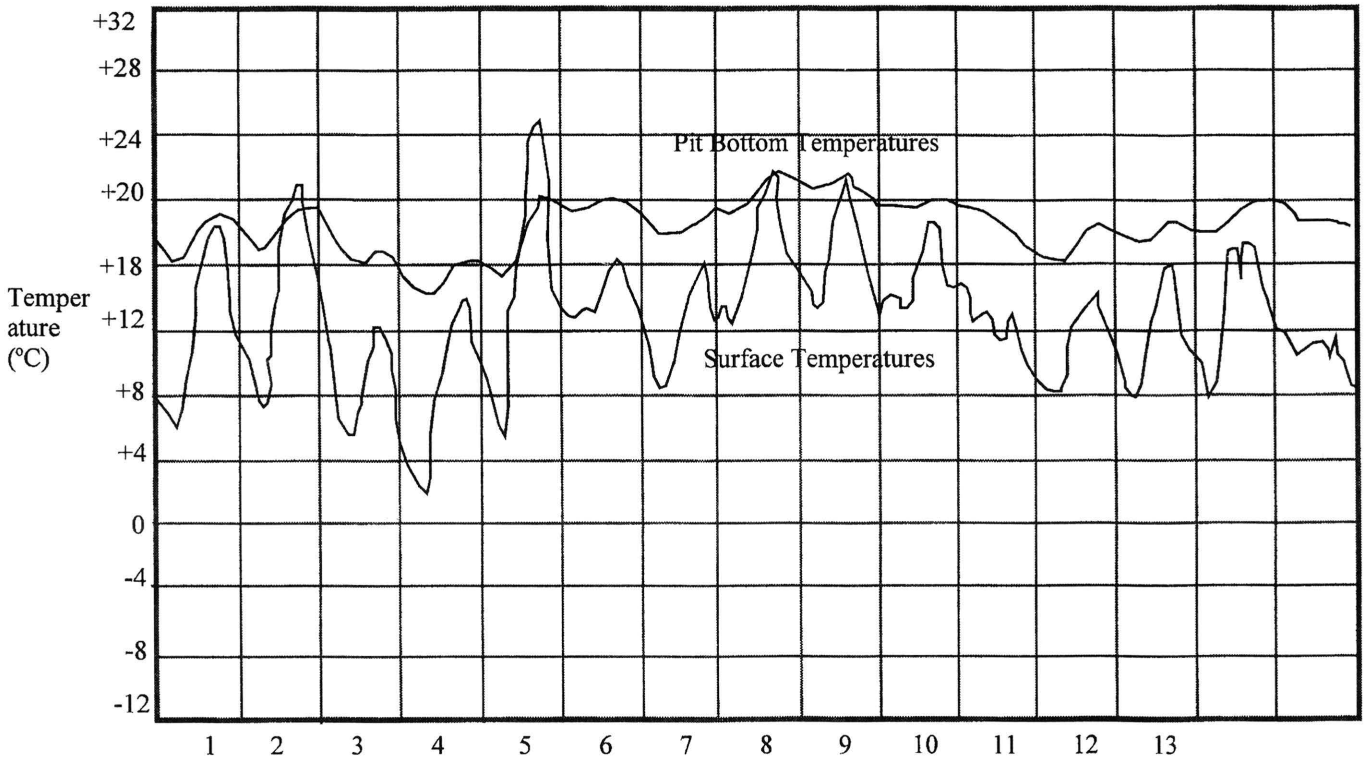

Figure 3. Temperature recordings at shaft collar and pit bottom of intake shaft.

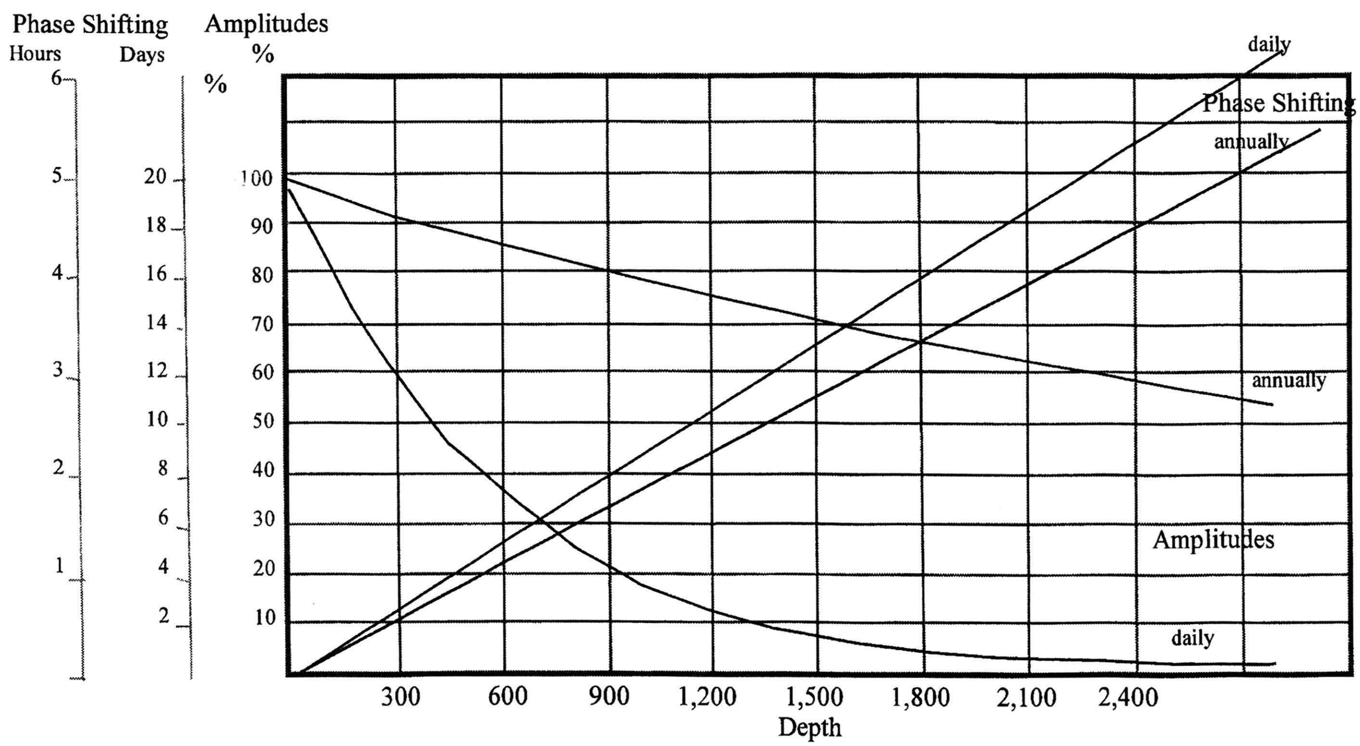

Figure 4. Amplitude damping and phase shifting of air in a downcast shaft.

Since no electronic computers were around yet, the calculations had to be performed by looking up function values in tables and processing them with a desktop calculator. This was in principle not very difficult but cumbersome.

NETWORK CALCULATIONS

Fifty years ago, network calculations did pose problems and were very time consuming. The computers available at this time were the National Coal Board Network Analyzer, which had just been introduced, a number of home-built fluid-flow models, a number of electric filament bulb analogues, and the first fully automatic electro-mechanical ventilation network computer. All of these were practically not available to the normal ventilation engineer, who had to use a slide rule and a desktop calculator.

The mathematical descriptions of ventilation networks were well known, the problems rested with the execution of the calculations. To keep the computational effort small, airways in series and parallel were combined. Substitute resistance for more common subnets could be found in the literature. The networks were reduced to the main airways. There was no rule, everybody had his own approaches and modified them to fit the network. This worked surprisingly well.

The most popular approach was a trial and error approach similar to controlled splitting. Estimates for the airflow rates were made for the main airways. Pressure losses were then calculated and compared for parallel paths. If necessary, airflow was shifted from the airways with the higher pressure losses to the ones with lower pressure losses.

The second most popular approach was the Hardy Cross method, which has become so well known that it needs no description here.

In another method, meshes were formed which ran from surface to surface through the fans. The network was considered to be a superposition of meshes, each carrying a certain airflow rate q_m. A correction factor

$$c = (p_F/\Sigma p_m)^{1/2}$$

was then applied with p_F being the fan pressure and Σp_m the pressure loss of the airways of the mesh. The pressure loss was calculated from

$$p_m = R\,(q_m{*}n)^2$$

where n was the number of meshes using the airway. The method gave a good convergence in the first corrective iterations, then its convergence became poor.

It was popular to perform extra corrections for the meshes which needed them most. If, for instance, in the Hardy Cross method several corrective iterations had been performed, new meshes were formed with the meshes, which had shown the greatest, need for corrections. Sometimes the corrections were multiplied with a factor greater than 1. Many of the things used in the manual network calculations were tried again later to speed up the digital computers, when these were in their initial stages and still slow.

VENTILATION NETWORK STABILITY

With this type of network calculation, one developed a pretty good feeling for the behavior of ventilation systems, which is of value when emergency planning is done. A particular danger was always seen in unexpected airflow reversals.

Airways which show this attitude are, in particular, connections between parallel airways. Such connections were in many countries called diagonal airways. Without any changes in fan or thermal draft-produced pressures, such airways can experience standstills or reversals as a result of resistance changes in other airways. This can have serious consequences in gassy mines when intake airways become return airways. It can also be disturbing and hazardous when, for instance, blasting fumes enter the mine rather than leaving it.

A powerful tool to recognize diagonal airways are the so - called canonical plans (Figures 5 and 6). They were introduced in Poland in the 20's, are mandatory there, and were popular in other European countries before computers. At the time of my thesis, diagonal currents were considered such a risk that they had to be marked in ventilation plans together with notes on the means provided to stabilize the airflow in them.

Drawing canonical plans 50 years ago had to be done manually. To let the result be intelligible, several redrawings frequently had to be done. Nowadays computers and plotters can be used for this purpose.

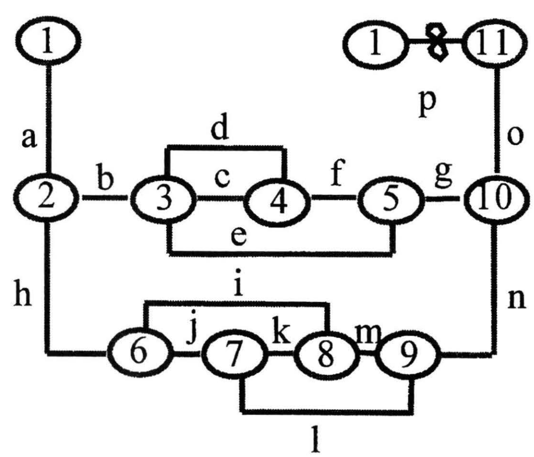

Figure 5. Schematic ventilation plan.

For a demonstration, Figure 5 shows the schematic ventilation plan of a small complex network, which can be found in many ventilation textbooks. Figure 6 shows the pertinent canonical plan. The diagonal airway k between nodes 7 and 8 becomes clearly visible.

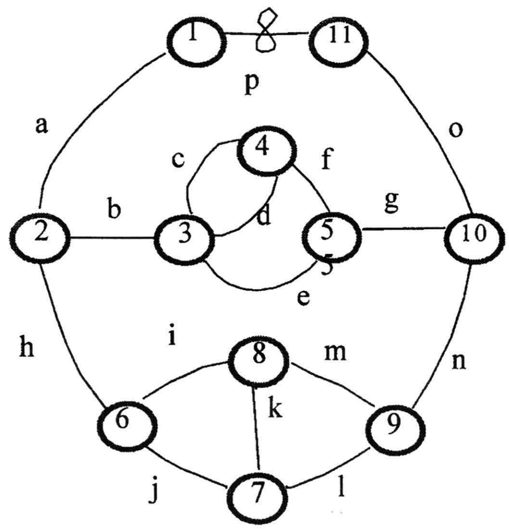

Figure 6. Canonical ventilation plan.

Before the computers became fully established in the 70's, the canonical plans were modified to the so-called Budryk plans. These allow the prediction of the stability of airflows in the presence of internal pressure sources, like fires. I did not have to do this in my thesis, although I later became quite familiar with it and liked it.

RESULT OF VENTILATION PLANNING

As a result of my measurements and calculations, I came up with a number of suggestions, and was gratified that they were accepted. Reducing resistances by removing airflow restrictions like stored material was the first of them and already provided some help.

I found an example of what can happen when ventilation is assigned to people without much interest in it. One of the two intake shafts had a nicely rounded transition from the shaft to the horizontal drift. But to protect the banksman from potentially falling material and dripping water, a roof had been built for him right into the rounded transition, and well into the cross-sectional area of the shaft.

My suggestion of making use of existing raises and widening connections between raises and upcast shaft also helped.

Still, this did not yet give the increase in airflow, which I had been told to provide. So I turned my attention to the fan. The mine had installed a new axial-flow main fan a few years before. Since I needed a fan characteristic, I set out to do fan testing. But I had to admit rather quickly that I was out of my depth. I considered myself lucky that, after just a few hours of testing, my instruments and I had survived.

So, I got a fan characteristic from the fan maker and verified it with some readings from the fan instruments. The possibilities, which the fan blade setting allowed, had already been exhausted. So I suggested a speed change. The fan had a belt drive. The speed change could therefore be easily accomplished with a new set of pulleys. As far as I remember, the mine followed the suggestion.

In summary, it looked to me, and fortunately also to my supervisor at the mine and my instructor at the school, that I had done my assignment.

The suggestions that I could come up with as a result of my measurements and calculations were not revolutionary. Just having a knowledgeable person looking into the ventilation would have helped and resulted in basically the same recommendations.

But to become a knowledgeable person, one has to go many times through the detailed calculations so that one can finally do without them. Or so one hopes.

What has basically then changed in the last 50 years? Besides the many good new instruments for analyzing ventilation properties and for their data acquisition systems, it is mainly the computers. They allow the processing of the data and the building of mathematical models to help engineers in problem solving and design. But not more than that.