A rapid method of calculating temperature increases along mine airways

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Discussion

J. de V. Lambrechts (Fellow): The author's paper is a brilliant follow-up of an earlier paper by Starfield and Dickson.[1] I have no quarrel with Dr Starfield's computerization of a complex problem, but I do not believe that he is getting quite the right answers from his programme. My impression is that his predictions about wet bulb temperature increases in very deep mines are over optimistic; in other words, that it will be hotter than Dr Starfield predicts. This is putting my views in a nutshell.

This is not the occasion on which to indulge in lengthy argument about the original paper by Starfield and Dickson, but the present paper is, after all, based directly on that earlier paper and if the one fails, the other cannot succeed. I did level certain criticisms at the first paper and cannot say that the authors' replies were very convincing.

I do not think it is a sin to admit that I belong to the old school which believes in thorough field experimentation and practical trials and no amount of mathematical manipulation or physical theorizing, no matter how excellent, can make up for inadequate practical confirmation. This, as I see it, is still the crux of the matter.

The original paper by Starfield and Dickson still rests on somewhat scanty practical evidence and I would be much happier if Dr Starfield's computer programme, based on the Starfield-Dickson model, had been checked against a large mass of observations in the practical mining situation. This is what both Wiles[2] and myself[3] had tried to do previously. What we lacked in mathematics and/or computer aids, I think the present paper by Dr Starfield lacks in practical substantiation. This is no condemnation of the author's paper which, taken by itself, is excellent but I think the final stage is still lacking, namely the bringing together of theory and empiricism in a manner acceptable to all.

This may be wishful thinking on my part but I hope, within the next year or so, to come up with a modified Starfield-Dickson model in such a way that the computer answers will agree in the majority of cases with the few hundred field observations which are already on record. It might be a case of applying the proverbial 'Cook's Law' to the Starfield-Dickson model!

REFERENCES

1. Starfield, A. M., and Dickson, A. J. 'A study of heat transfer and moisture pick-up in mine airways.' *J. S. Afr. Inst. Min. Metall.*, **68**, (5), 1967.
2. Wiles, G. G. 'Wet bulb temperature gradients in horizontal airways.' *J. S. Afr. Inst. Min. Metall.*, **59**, (7), 1959, p. 339.
3. Lambrechts, J. de V. 'Prediction of wet bulb temperature gradients in mine airways.' *J. S. Afr. Inst. Min. Metall.*, **67**, (11), 1967, p. 595.

R. Hemp (Visitor): Dr Starfield's paper has very effectively rounded off one particular aspect of the general problem of heat flow in mines. The ease with which this computer programme can be used to calculate temperature increases in horizontal airways must lead to its wider use in ventilation planning and, in developing this rapid method, Dr Starfield has indeed rendered a valuable service to the mining industry.

One could consider further instances of heat flow in airways in which the availability of a rapid computer method would be desirable, e.g. the flow of air down a shaft, where there is an increase in temperature due to adiabatic compression, as well as an increase in virgin rock temperature as the depth increases. However, this particular case would not present any new problems and would merely require an extension of the exisitng work.

I should like in this contribution to talk about an aspect of environmental control in mines which, I think, will become more important in the future. It is well known that wet bulb temperatures are subject to fluctuations underground. In some instances, particularly in stopes, the fluctuations, both with time and position, can be considerable.

The theoretical work which has been carried out on temperature increases has been aimed at the prediction of mean temperatures, and no account has been taken of fluctuations around this mean. It is questionable whether this approach will, on its own, be sufficient, particularly when temperature increases in stopes are considered.

The fluctuations in air temperatures underground arise from two causes. The first of these would be the fluctuations in surface conditions, and here one could list random, diurnal and seasonal fluctuations. The second cause is the multitude of things which vary in a mine and here one could list variations in air flow quantity, sources of evaporation, heat transfer from pump and compressed air columns and, particularly in the stope, variations in air flow patterns.

Fluctuations arising from surface temperature variations should be amenable to calculation, and here one envisages figures relating the decay of temperature variation with distance to factors such as air flow quantity. Fluctuations resulting from changes in the mine are perhaps more difficult to tackle theoretically and the best approach could well be to analyse underground observations. In this connection, there is a good case to be made for the increased use of statistical methods in the analysis of underground temperature measurements, and it might be of value to look at current air-conditioning practice.

When carrying out cooling load calculations for a particular location it is customary to use design wet bulb and dry bulb temperatures which are, on average, not likely to be exceeded for more than five per cent (or 2½ per cent or one per cent) of the time during the summer months. These design figures have been obtained from a statistical examination of many years of weather observations. An analysis of underground temperatures in a similar manner could well yield figures which would be invaluable for ventilation planning.

As an example of the type of analysis I have in mind, a set of wet bulb temperatures observed in a longwall stope over a period of fourteen months were analysed. A total of just under 1 000 measurements were involved and Fig. 1 shows the frequency distribution of wet bulb temperatures. Also shown are the temperature limits which exclude five per cent, 2½ per cent and one per cent of the measurements. In this instance, the measurements were obtained from an entire longwall stope, and covered such a long period that it is difficult to make more use of the results than to obtain the median temperature and the standard deviation. One could envisage the collection of similar data for a much smaller area, and over a shorter period. Presently available techniques for the theoretical calculation of air temperatures could be used to obtain a mean expected temperature for the area, and this could be compared with the observed values. If, in the example considered, this expected mean temperature had been 87.4°F (the median value of the set of observations), the statistical analysis would indicate that a significantly high number (±20 per cent) of observations would be made of wet bulb temperatures higher than 1°F above the median or expected value, while five per cent would be higher than 2°F above the median.

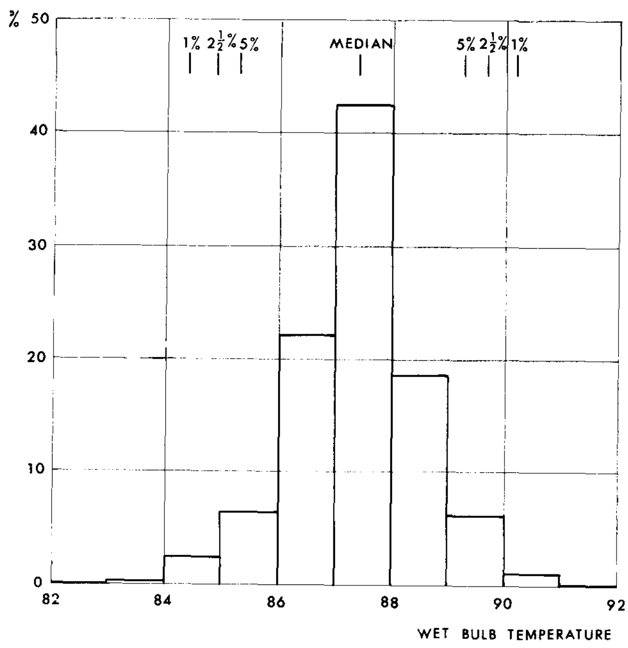

Fig. 1

A. Whillier (Fellow): My comment will deal with the the use of Dr Starfield's method of calculation and what the practical man can get out of it. This is best illustrated by reference to Fig. 5 where it was shown that a 1 000 ft long wet section in an otherwise dry airway would result in the air reaching the workings at a wet bulb temperature 2°F higher than in the case of a completely dry airway.

It is a fairly straight forward calculation to show that the size of refrigeration plant needed to reduce the wet bulb temperature of 50 000 cfm of air by 2°F, that is, to eliminate the damage caused by the wet section of the airway, is about 40 ice tons. The cost of operating this refrigeration plant would be about R4 000 per annum. Thus, in this instance, management would have to decide whether it would be cheaper to instal the refrigeration plant or to take steps to keep the wet section of airway dry by piping the water away.

The industry has already been given substantial verification that it is practical to dry out airways and that by doing so some very substantial improvement in wet bulb temperatures (with the accompanying improvement in safety and productivity) can be realized. This was on the occasion of the development of a 12 500 ft long twin haulage at Buffelsfontein[1], when by drying out the footwall and keeping it dry the development was completed with no refrigeration and only 50 000 cfm of air. It was concluded that this development could in fact not have been carried to more than 30 000 ft before thermal conditions at the development end would have deteriorated to a level where refrigeration would have been needed. The virgin rock temperature was 112°F.

This example serves to illustrate how the Starfield model can quickly provide management with an estimate of the consequences of any particular ventilation arrangement. It is inevitable, therefore, that the mining industry will find increasing use of the model in the planning of mines.

It is of interest to note that while working at the Mining Research Laboratory of the Chamber of Mines in mid-1969, Dr Starfield developed a similar computer model applicable to stopes; this model is now also available to the industry.

The computation centre at the University of the Witwatersrand has an excellent facility for using computer models such as these, using typewriters at remote terminals. With the co-operation of the Department of Mining the following computer models have been made available for use by any person at no cost, under the call names shown:

mind01 Temperature increases in mine airways
mind02 Psychrometric calculations
mind03 Temperature increases in stopes.

REFERENCE

1. Jacobs, J. C. 'Ventilation of twin haulages at depth.' *J. Mine Ventilation Society of S.A.*, Vol. 20, July 1967, p. 117-129.

Author's Reply

Dr A. M. Starfield: My thanks to Professor Lambrechts, Mr Hemp and Dr Whillier for their contributions to this paper. My reply is aimed mainly at Professor Lambrechts' remarks, but I would like to answer him in a somewhat broader context by investigating the extent to which applied mathematics can aid the mining engineer.

A mining engineer encounters problems that, by their very nature, are subject to a host of uncertainties and variations from point to point and hour to hour. In planning the design of a mine lay-out or ventilation and refrigeration system, he has to cut through these uncertainties, taking cognizance of those that might influence the details of his decision, but basing the broader outline on more fundamental principles. To make these more fundamental decisions the engineer has three tools at his disposal:—

(1) his own experience and the experience of others

(2) *in situ* measurements and empirical analyses

(3) the mathematical or computational models and analogies of applied mathematics and applied physics.

The first two techniques are the traditional tools of the mining engineer. Experience and shrewd intuition have always been the trademark of a good engineer. Measurements and empirical analyses are an attempt to define and classify this experience in somewhat more explicit terms. Both techniques are adequate when it comes to designing something essentially similar to that which has been successfully designed in the past. Once the engineer has developed a successful system or approach, experience and measurement usually enable him to hone it down to near-maximum efficiency. However, neither experience nor measurement can readily aid the engineer facing completely new conditions or novel techniques. The traditional tools of the mining engineer must therefore foster conservatism; they encourage him to stay with techniques, ideas and systems that have had a measure of success in the past.

The third tool available to the engineer is what used to be called the mathematical approach, but since the advent of computers the field has largely been taken over by computer techniques. This approach attempts to take the physical laws that basically control a process and to build up from them a model that describes the broad outline of the system under study. Once the model has been set up it is relatively easy to study the interaction of its components and the consequences of changing variables that are under the control of the mining engineer.

The applied mathematical approach is thus conducive to change and innovation. It enables the engineer to estimate, at very little cost, what the consequences of alternative actions might be. He can then choose the most promising of these alternatives and investigate it further, or improve upon it, by his more traditional techniques. Dr Whillier's contribution is an illustration of this point.

A mathematical model is always based upon assumptions. With the aid of computers these assumptions are now usually far more realistic than those that had to be made when problems were soluble by mathematical ingenuity alone. Inevitably, though, the model ignores most of the variations that characterise a mining problem. Its use is thus in the broader design context. A heat flow model aims therefore at providing an estimate of ventilation or refrigeration requirements, not at predicting precisely the air temperatures at various points in the mine. Mr Hemp's contribution has shown how futile such an attempt would be. However, because a mathematical model states its assumptions, it is often regarded as being more unrealistic than an empirical analysis. It must be emphasized that these same assumptions plague the engineer who relies on experience and measurement, only he never states them clearly. There appears to be an ingrained belief that something measured is inherently more trustworthy than something that has been calculated. Mr Hemp's contribution shows how misleading this belief could be to a ventilation engineer.

In conclusion, then, the model presented in the paper is offered as an engineering tool. Dr Whillier has highlighted the sort of information that can be obtained from it. Since the method is rapid it is open to frequent use by the engineer. It is only by *using* it that the engineer can establish its value for himself.