Research into fire fighting and fire prevention in South Africa*

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SYNOPSIS

The decisive action taken by mine managements in recent years has been the main factor in bringing about the present downward trend in mine fires. A better understanding of the fundamental factors that govern the ignition and spread of fires, obtained as a result of investigations into mine fires, has provided useful guidance to production personnel. Similar investigations into fire-fighting techniques have assisted the Rescue Training Service and mines to institute more effective fire-fighting techniques. Some of the more important findings of recent investigations in these areas are outlined.

SAMEVATTING

Die besliste stappe wat mynbesture die jongste tyd gedoen het was die vernaamste faktor wat tot die huidige dalende tendens in mynbrande gelei het. 'n Beter begrip van die fundamentele faktore wat die ontstaan en verspreiding van brande bepaal wat deur ondersoeke in verband met mynbrande verkry is, was 'n nuttige leidraad vir die produksiepersoneel. Dergelike ondersoeke in verband met brandbestrydingstegnieke het die Reddingsopleidingsdiens en myne gehelp om meer doeltreffende brandbestrydingstegnieke in te voer. Sommige van die belangrikste bevindings van onlangse ondersoeke op hierdie terreine word in hooftrekke aangegee.

Introduction

The large amount of timber used underground in mines inevitably poses a potential fire hazard and a threat to the safety of the labour force. During the seven-year period 1973 to 1979, there was a significant increase in fires on mines, costing the industry many millions of rands per annum, and a number of lives were lost. The total number of fires reported during this period, as well as the number that were of longer duration than 12 hours, are indicated[1] in Fig. 1. The period of 12 hours was selected somewhat arbitrarily to distinguish between more-serious fires and those which were extinguished quickly and hence had only a minor effect on production.

Arising out of the serious fire situation of the early seventies, the Research Organisation of the Chamber of Mines of South Africa became deeply involved for the first time in research related to fires, co-operating closely with the mines and the Rescue Training Service. Independently, the Anglo-American Electronics Laboratory embarked upon a development programme that has resulted in an excellent fire-detector system for mines[2]. The industry thus entered into what might be regarded as a three-pronged attack on the fire problem. The mines became more deeply involved in *fire-prevention*[3] methods and in development strategies to permit *rapid action*[3,4] to be taken upon any report of a suspected fire. In making their decisions, mine managements were guided by their own experience, by the views of their line management (and later, their Fire Masters), by the Rescue Training Service, and by reports arising from the research undertaken by various organizations.

In the view of the authors, it is primarily the decisive action taken by mine managements that has given rise to the present improved trend in mine fires. All the investigations in the world would have been of no value if mine managements had not accepted the guidance offered by the research (and by others as mentioned above) in implementing practical strategies on their mines to counteract the fire problem.

The concept of 'loss control' was introduced to the industry at about the same time. One outcome of this concept was that mine managements became more vividly aware of the magnitude of the financial losses that could occur if they did not take action to counteract the fire menace.

An essential ingredient of the countermeasures introduced by mines has been a better understanding of the many factors that govern the growth and spread of mine fires. Research into mine fires has thus played an essentially supportive role, supplying mine managements with information and facts that they can use to evaluate alternative countermeasures. This paper outlines some of the more important findings of the recent investigations carried out within the mining industry. Aspects that are covered in more detail elsewhere have been omitted.

Timber

Timber is the major combustible material underground in non-coal mines. Each day in South African gold and platinum mines, approximately 10 000 packs are built for roof support. The mining industry has expended considerable effort to reduce the quantity of timber since experience has shown that essentially all major fires involve timber present in the stope horizon, particularly in gullies. Thus, the density of timber used for support purposes is being decreased by the use of pipe-sticks of one or other design[3], of sandwich or composite packs of timber and concrete, and lately by mining with the use of barrier chocks at the face with no permanent support in the back areas. Notwithstanding these efforts, there are still many places such as gullies and travelling ways where there are high local concentrations of timber.

Fires started in timber packs grow in intensity very

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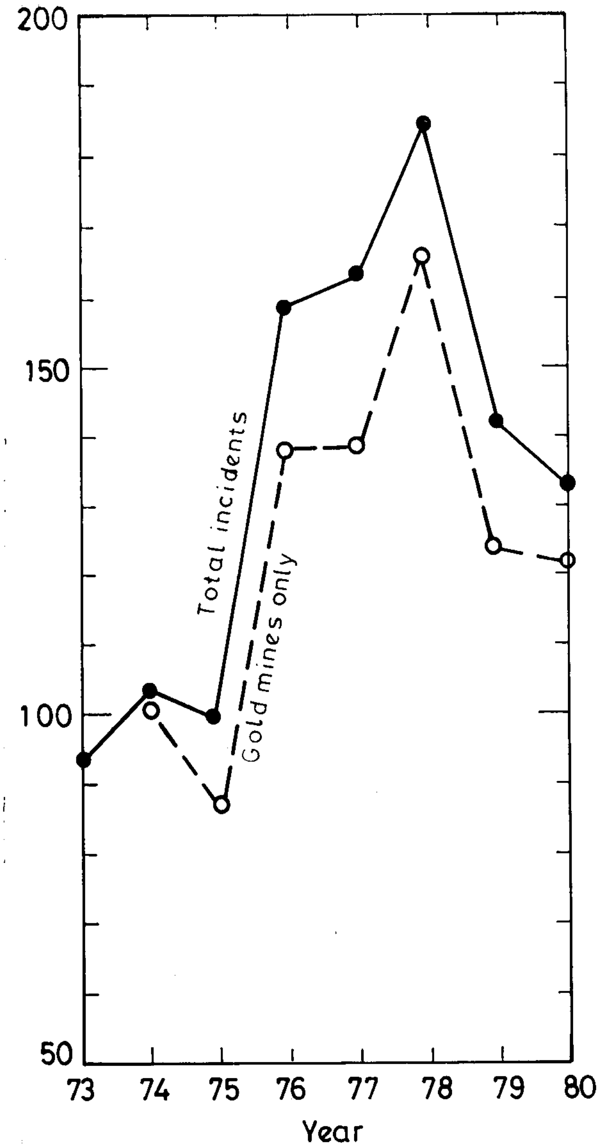

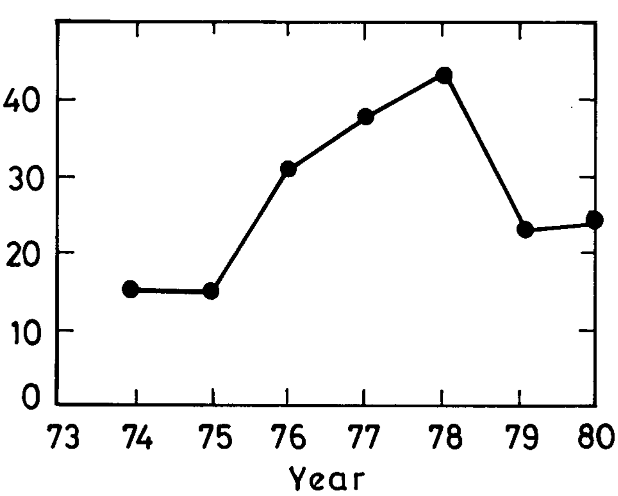

Fig. 1—Upper graph: Total number of fire incidents reported. Lower graph: Number of fires of longer duration than 12 hours (excluding coal mines).

rapidly, and tend to reach a reasonably fierce state within 15 minutes if the timber is dry, or in 40 to 100 minutes if the timber is wet. Flames from a single burning pack will engulf adjacent packs within minutes, and these adjacent packs will themselves burn out completely in about 90 minutes. A stream of very hot gases immediately beneath the hangingwall spreads from such a conflagration, enabling the fire to propagate rapidly and widely by igniting the upper timber layers in packs along the flow path of the hot gases[5]. Such fires *in unprotected timber* spread so rapidly that it is usually impracticable to take effective action before they become virtually uncontrollable, and sealing is necessary to allow the fire to burn itself out slowly.

Tests have shown[6] that the growth time of timber fires can be retarded by the adoption of any of a number of practices, such as

(1) impregnating all the timber with a suitable salt solution before the timber is sent underground;
(2) protecting the timber from the heat of the fire and hindering the access of air by wrapping, plastering, or grouting;
(3) reducing the concentration and amount of timber.

It must be emphasized that timber fires generate large amounts of heat *only when flaming combustion occurs.* Burning timber that is smouldering produces much less heat, and the rate of spreading is slower. Thus, a primary consideration in any fire-protection method is to reduce, hinder, or prevent flaming combustion, particularly in localities where there are high concentrations of timber. Certain physical protection procedures have been shown to be highly effective, and have been introduced in mines in high-hazard areas with considerable benefits.

Impregnation of Timber

Water is without a doubt a most effective way of preventing the ignition of timber and limiting the rate of spread of a timber fire. If timber is impregnated with water, its moisture content is raised to about 70 per cent from a typical value of 20 per cent. All the water present must be vaporized into steam before the timber itself can be heated to a temperature of about 280°, at which combustion can commence and the reaction becomes exothermic. The ignition source required to achieve this then becomes so large that the rate of spread through a line of packs is reduced tremendously and often ceases altogether. Thus, if the water content could be raised and maintained at the higher level, major timber fires would cease to be a problem. To increase the water content to this level, a pressure-impregnation technique must be used to ensure that the moisture penetrates all the sap wood. Dipping, spraying, or simple immersion of the timber in water or solutions results in unacceptably shallow penetrations (of the order of millimetres).

While very effective fire-retardancy properties can be imparted to timber with water, the effects are relatively short-lived since water gradually vaporizes from timber over a period of time and a final equilibrium value is reached that depends essentially on the environmental wet- and dry-bulb temperatures. Investigations are at present in progress to determine the degree of water retention in underground environments.

For greater long-term effectiveness, timber can be impregnated with solutions of various chemicals. For the mining industry, the optimum chemical formulation would seem to be based on ammonium sulphate with minor additives of other chemicals to minimize leaching, corrosion, and other possible detrimental side-effects[7]. Leaching of the chemicals under practical underground conditions does not appear to be a problem. At present, one mine is pressure-impregnating a significant proportion of the timber being used underground[3].

As chemicals rather than plant are responsible for most of the cost of impregnation, the effect on the degree of fire retardancy obtained by a reduction of the salt concentration in the mine timber is important. Leaching as a result of the simulated hosing down of mine timber packs over a period of 10 to 20 days has been shown[7] to reduce the concentration of salt in wood by about 1 per cent of the initial salt concentration per day. The concentration of salt in the wood after pressure impregnation is typically between 35 and 45 kg/m^3, where the volume is the total volume of timber. Consequently, after 10 days the salt concentration would decrease to between 30 and 40 kg/m^3 respectively, which would not affect the degree of retardancy significantly.

One of the properties of a good fire retardant is its ability to produce a marked increase in the percentage char remaining after combustion. A typical effect of salts is given in Fig. 2, from which it can be seen that, at a salt loading of about 10 per cent, the amount of char is increased from 25 per cent without salt to about 45 per cent with ammonium chloride, and to about 42 per cent with ammonium phosphate. A 50 per cent increase in char production can be achieved with about 10 kg of ammonium phosphate or 20 kg of ammonium chloride per cubic metre. A loading of about 40 kg/m^3 of ammonium sulphate (which has proved to be a very effective retardant[3]) may be in the saturation zone, and it may be possible to reduce the loadings somewhat without any marked decrease in fire retardancy. This is being investigated at present.

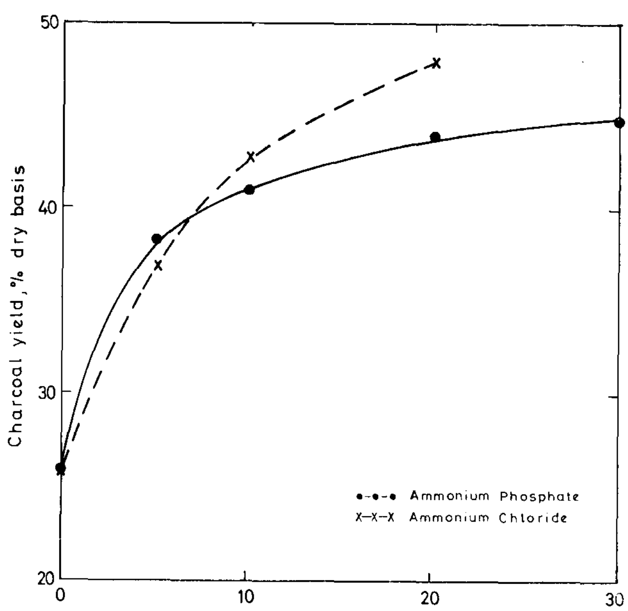

Fig. 2—Influence of ammonium salts on the formation of charcoal.

Plastics

Fires involving plastics are particularly dangerous because of the threat they pose to human life. Plastics are used underground as insulation on electric cables and cold-water pipes, and as ventilation brattices. The insulation on electric power cables is one area in which plastics is a major potential source of ignition. Isolation of electrical supplies to areas prior to blasting or when no work is taking place, coupled with improved installation procedures, are important practical measures that are taken to minimize ignitions from electrical causes. An additional safety precaution being considered is a possible modification to the composition of the insulation on power cables by the incorporation of a substantial amount of limestone filler material to neutralize any hydrogen chloride gas as it is formed. The success of such a filler would depend primarily on its fineness and degree of dispersion within the plastics.

An area in which the use of plastics can result in a greater fire hazard is the use of foam-plastics as insulation on cold-water pipes. Owing to their closed-cell structure, foam plastics possess distinct advantages for insulation, but that very fact becomes a disadvantage when material of this nature is heated by a fire. Because of its low heat conductivity, the rate of spread of flame along surfaces is very fast, and it acts as a wick to ignite combustible material ahead of the fire zone[6]. It is possible to eliminate this effect by the provision of 'fire-barriers' that would prevent, or at least retard, the spread of flame along plastics-covered pipes. One such design has an inner core of fire-retarding expanded polystyrene followed by a water-vapour barrier of annealed aluminium foil on an outer sleeve of unplasticized PVC. Alternatively, an insulation system based on glass-fibre bonded with epoxy resin can be utilized since this is relatively non-flammable. Marginally greater heat losses for similar thicknesses of insulating material must be accepted on cold-water lines if this latter type of material is used. Perhaps the best solution is a compromise between the two systems, in which short sections based on fibre-glass insulation are incorporated intermittently as flame traps into a system based on expanded polystyrene or polyurethene.

It must be pointed out that plastics often incorporate a flame-retardant chemical in their formulation. However, they generate noxious gases to variable extents when they are decomposed by heat. The gaseous pyrolysis products from halogen-containing compositions have carbon monoxide and the corresponding hydrogen halide as their most toxic components. Antimony trioxide is a very effective flame retardant, particularly with halogen-containing plastics, but about 75 per cent of this material is vaporized during fires and this very toxic compound is liberated together with the pyrolysis gases. The diversity of flame retardants makes it difficult to predict which class would be most effective. However, for mining purposes, phosphorus-based flame retardants such as the phosphate esters offer significant advantages in that their flame retardancy is adequate and the toxicity of the pyrolysis is relatively low[7].

Water Supplies for Fire Fighting

The Management of the Rescue Training Service was recently instrumental in introducing smaller, lighter nozzles and hoses as standard fire-fighting equipment. These will provide an 'adequate water supply', and ensure that water will be available for fire-fighting at many places simultaneously.

The definition of an 'adequate water supply' is difficult since adequacy depends on the severity of the fire. However, a picture can be obtained of the severity of fires in mines by the consideration of certain fundamental aspects of timber, and what might be considered to be an adequate water supply can be deduced from this[8].

In trying to arrive at this answer, it must be recognized that fire-fighting operations in stopes can be of two distinct forms: one involves a direct attack on the burning timber so as to extinguish the flames, and the other involves the use of water-sprays to cool the hot gases flowing away from a fire zone, so preventing the fire from spreading beyond check points and allowing it to burn itself out below the check points. In both cases it is *evaporation* of the water that results in control of the fire. Any water that is not evaporated will drain away and serve no useful purpose.

As the result of a series of investigations, recommendations were made to mines regarding both the service-water supply and dam system at shafts and the reticulation system to the stope horizon, so that water could be delivered to all parts of the underground workings at adequate pressure and volume for fire-fighting purposes.

Foams

Where it is not possible to attack the fire directly with water, the use of foam can be considered. Since foam is merely a means of using air to transport water from a site remote from the fire zone, it is important that as little as possible of the water introduced into the foam should drain out onto the footwall before the foam reaches the fire[9]. Clear guidelines are now available on what foams should be considered and, what is perhaps more important, when they should be considered.

Rapid Sealing

As mentioned earlier, the rate of growth of timber fires can be very rapid, and it is then impossible to fight the fire directly. The fires must then be sealed off and allowed to burn themselves out. Sealing off a fire by means of walls erected under very severe conditions, often by proto-teams in remote areas where all the services have been reclaimed, was recognized as an operation that should be simplified and made more effective and safer. The action to be taken in the event of fires is now preplanned on all mines. Mines are divided into distinct ventilation districts, and fire-doors are installed in the intake airways to each district. One mine has installed a total of 126 specially designed doors at a total cost of R70 000[4]. Any district can now be isolated quickly and efficiently in the event of a fire. With all due respect to the dangerous and exacting work carried out by proto-teams, often in appalling conditions, the seals they construct in smoke can have defects that are not readily detected, particularly close to the hanging.

Detailed preplanned fire-fighting systems have proved invaluable in controlling fires in the early stages. If no such prepared plan is available, clear thinking in the face of the many suggestions, conflicting opinions, and reports becomes almost impossible, and it is difficult for the men on hand to choose the plan of attack that will achieve the most effective results quickly and with the maximum safety.

Radio Communication

Effective rapid communication between personnel underground and the control point is imperative, and the development of an effective radio system that is able to transmit for long distances through rock has proved to be extremely beneficial when used both by proto-teams and by mine personnel[10]. In fact, a potentially disastrous fire on a mine was recently stopped in an early stage as a result of radio communication.

Conclusions

It is generally agreed that the success of mine management in countering fires is the outcome of many factors, some of which are indicated below. The list is not necessarily complete.

- Improved investigation of all fires.
- Preplanning of the action to be taken.
- Better understanding of the factors governing the spread of fires.
- Fire protection of high-risk areas.
- Knowledge, based on past experience, of when to seal.
- Fire masters.
- Fire rating of every underground section.
- Better housekeeping.
- Better awareness.
- Better availability of water.
- Changes in support practices.
- Concept of loss control.
- Better detection.
- Quicker response.
- Better use of proto-teams.
- Better communication (radios).
- Improved standard practices.
- Enforcement of adherence to standards.
- Improved discipline.
- Better use of fire patrols.
- Isolation of electric power to scrapers during blasting.

Acknowledgements

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Pipe lines and pipe fittings

Vanadium has been an essential element in many specifications for higher-strength steel pipelines for oil as well as gas, and is indeed involved in several of the developments for the latest requirements. It is therefore appropriate that a conference on steels for pipelines and pipe fittings, which are of obvious interest in the light of general developments in pipeline construction should take place in 1981 and form part of the celebrations for the 150th Anniversary of the Discovery of Vanadium.

Accordingly, The Metals Society is sponsoring, with the support of The Welding Institute, a three-day conference on pipelines and pipe fittings to be held in London from 21st to 23rd October, 1981, but the conference will not be restricted to vanadium steels.

The programme will include the following:

- The design of pipelines and steel property requirements for line pipes and pipeline fittings in the 1980s and 1990s.
- Advances in the physical metallurgy of pipeline steels, and fracture problems.
- Developments in the production of pipeline steels to meet the demands of the 1980s.
- Steels developed to meet requirements of pipelines in the 1980s and 1990s.
- Steels for pipeline fittings.
- The welding of pipeline steels.

Further information is available from Conference Department, The Metals Society, 1 Carlton House Terrace, London SWIY5DB, England.

Applied mineralogy

The National Institute for Metallurgy and the Geological Society of South Africa, in collaboration with the Chamber of Mines of South Africa and the South African Iron and Steel Industrial Corporation Limited, are arranging the first international conference dealing with the application of mineralogy and mineralogical techniques to many activities in the mineral industry. The Conference, ICAM 81, will cover the complete spectrum of mineralogical activity in the exploitation of

- base metals
- precious metals
- base minerals
- industrial minerals
- building and construction materials
- carbonaceous materials.

Mineralogy today finds application not only in mining, extractive metallurgy, and economic geology, but also in the investigation and development of refractories, ceramics, cements, alloys and many other industrial materials. It is the aim of ICAM 81 to stimulate technical interchange on all those aspects of mineralogical activity, not only between applied mineralogists but also between them and other workers in the mineral industry, thus giving each an insight into the problems of the other.

ICAM 81 is to be held in Johannesburg in June, 1981, immediately before the Third International Platinum Symposium, which itself will form part of the two-yearly Congress of the Geological Society of South Africa (Geocongress 81). Delegates to ICAM 81 will therefore have an opportunity of taking part in both these important meetings during one visit to South Africa.

The dates for ICAM 81 are as follows:

15th to 22nd June	Pre-conference excursions
23rd June	Check-in of delegates, and opening function
24th to 26th June	Technical sessions
29th June to 3rd July	Post-conference excursions

All correspondence and enquiries should be addressed to The Secretariat, ICAM 81, National Institute for Metallurgy, Private Bag X3015, Randburg 2125. Further information about Geocongress 81 is obtainable from The Symposium Secretariat S.217, CSIR, P.O. Box 395, Pretoria 0001.