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A literature review of the ignition of methane–air mixtures by coal-cutting picks

by R. TRUEMAN*

SYNOPSIS

Past work on the ignition of methane-air mixtures by coal-cutting picks is reviewed, with special reference to the factors that contribute to ignitions and ways of reducing them. The main conclusions obtained from this review are outlined for the following aspects: mechanisms of ignition, methane concentrations, and the roles of rock types, cutting parameters, cutting tools, and water. However, many of these factors have been investigated on a qualitative, rather than on a quantitative, basis.

A considerable amount of effort over a long period has been expended in this area of research. It is shown that a number of the factors influencing ignitions by machine picks have been researched adequately, but that there is still work to be done. Research is continuing in this area, being concentrated primarily upon the ignition potential of the coal-cutting pick.

SAMEVATTING

Werk wat in the verlede in verband met die aansteek van metaan-lugmengsels deur steenkoolsnyerpikke gedoen is, word in oënskou geneem met spesiale verwysing na die faktore wat tot ontbrandings bydra, en maniere om hulle te verminder. Die hoofgevolgtrekkings van hierdie oorsig word met verwysing na die volgende aspekte uiteengesit: ontbrandingsmeganismes, metaankonsentrasies, en die rol van rotstipes, snyparameters, snygereedskap en water. Baie van hierdie faktore is egter op 'n kwantitatiewe basis ondersoek.

Daar is oor 'n lang tydperk baie werk gedoen in verband met navorsing op hierdie gebied. Daar word getoon dat 'n aantal van die faktore wat aansteking deur masjienpikke beïnvloed, reeds voldoende nagevors is, maar daar is nog werk wat gedoen moet word. Die navorsing op hierdie gebied gaan voort en word in die eerste plek toegespits op die aansteekmoontlikhede van die steenkoolsnyerpik.

Introduction

The ignition of methane–air mixtures by machine picks has been of interest to mining engineers for many years. Work was done in this area as early as the 1920s by the Safety in Mines Research Establishment (SMRE) in the U.K., and continued up to the Second World War. There was an intensification of interest in this field after the Second World War by the SMRE, and research was carried out in this area up to the 1970s. The U.S. Bureau of Mines (USBM) started investigations in the 1970s and is actively involved in research in this field at the present time.

The investigations have concentrated upon the following aspects: the mechanism of ignition, the concentration of methane, and the role of rock type, cutting parameters, cutting tools, and water. This research has been aimed at identifying the factors that contributed to ignitions and ways of reducing them. There has been some repetition of research between the SMRE and the USBM, although it is clear that the two organizations have also built on each other's work. The research carried out by the USBM has been biased towards the continuous miner, while that at the SMRE has been concentrated upon the longwall shearer. However, the experimentation that has been done by both organizations is of a sufficiently general nature that the results can, and have been, interpreted for the full range of machines that operate with coal-cutting picks.

In countries such as the U.K. and the U.S.A., where most of the coal is mined by longwall shearers and continuous miners, coal-cutting picks are a major contributor to the ignition of methane–air mixtures. With the increasing use of these machines in South African collieries, there is an obvious need for mining engineers in this country to understand the causes of ignitions and methods of reducing their frequency. It is the intention of this literature review, by summarizing the work already done, to provide South African mining engineers with the current knowledge in this area.

Mechanism of Ignition

The sparks produced by frictional rubbing or impact were thought at one time to be a major cause of ignition. However, Blickensderfer *et al.*[1,2] and Burgess and Wheeler[3] found in the laboratory that it is very difficult to ignite mixtures of methane and air by the mechanism of sparking. Methane has a high ignition temperature (650 °C), and sparks do not usually possess an adequate combination of life time, temperature, and surface area for ignition. Gases with a lower ignition temperature, such as hydrogen, are ignited fairly easily by sparks from machine tools.

Wynn[4] thought that piezo-electricity resulting from picks impacting rock was a possible source of ignition, but Powell *et al.*[5] observed that, when ignitions occur, the delay between the machine tool striking the rock and ignition was too long for ignition to be caused by an electrical discharge.

Several authors[2,5-7] have concluded that a major cause in the ignition of methane–air mixtures by machine picks is a hot spot on the rock. As early as 1929, Burgess and Wheeler[3] referred to a stationary spark at the contact between the pick and the rock, which can be equated to

* Formerly Research Fellow, Department of Mining Engineering, University of the Witwatersrand; now Rock Mechanics Officer, Amcoal Research and Development, Private Bag X555, Vandyksdrift, 2245 Transvaal.

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the hot spot described by later authors. This hot spot is composed of a surface layer of either molten rock or metal, and is caused by frictional sliding. The layer normally consists of the material with the lowest melting point, and the maximum temperature does not normally exceed this value. It is suggested that the area and the temperature of the hot spot, together with the methane concentration, determine whether ignition can occur, as will be discussed in a later part of this literature survey.

In rocks containing iron pyrite, the mechanism of ignition is thought to be the burning of finely ground pyrite, rather than a hot spot on the rock[8]. Frictional sliding between the machine tool and the rock is responsible for the initial heating.

Rae *et al.*[9] and Cutler[6] conclude that the area and temperature of a hot spot will have a marked effect upon the ignition potential. Different areas of metal foil were heated rapidly in a 7 per cent methane–air mixture in an explosion chamber, the temperature at ignition being measured by an optical pyrometer. They all concluded that the temperature for ignition decreased as the area of the heated surface was increased. However, because they used metal foil, they did not take into account the possible effects of the thermal conductivity of different rocks, and of variations in the thickness of the hot spots. Wynn[4] noted that the thermal conductivity of a rock influences the role played by the dissipation of heat. The rate of heat dissipation could, in turn, influence the area required for ignition. The thickness of the hot spot could also influence the heat dissipation.

Blickensderfer[10] noted that the maximum temperature of a hot spot is the melting point of either the tool material or the rock. The maximum width of the hot spot is the width of the tool. The length of the hot spot above a certain temperature varies with the speed of the tool and the cooling rate of the molten rock or metal. (The effect of pick speed will be discussed later.)

It is implied in the literature that, as the temperature of the hot spot caused by frictional impact increases, the area needed to cause an ignition of methane decreases. However, the possible effect of the thermal conductivity of the rock and the thickness of the hot spot upon the area required for ignition have not been investigated. The maximum temperature of the area heated by frictional impact depends upon the melting point of the tool and the rock. The area of the hot spot depends upon the width of the tool and the speed of cutting.

Concentration of Methane

Two different methods for the determination of the methane concentration that is most easily ignited are given in the literature. These are based on laboratory experiments conducted in an explosion chamber, and on statistical analyses of ignitions that actually occurred in coal mines.

Rae *et al.*[9] heated metal strips in 6, 9, and 12 per cent concentrations of methane within an explosion chamber. The temperature at ignition was measured by an optical pyrometer, and it was noted that the minimum temperature required to ignite the gas mixture increased with increasing methane concentration.

Cutler[6] completed experiments similar to those of Rae *et al.*, but the increments were more closely spaced. Cutler concluded that a methane concentration of 7 per cent was most easily ignited. If Cutler's results for 6, 9, and 12 per cent mixtures of methane in air are observed in isolation, the same conclusions as those of Rae *et al.* are reached. This indicates that the increments in methane concentrations used by Rae *et al.* were spaced too widely, and that the greater definition used by Cutler between the 6 and 9 per cent concentrations was necessary to permit the observation that a 7 per cent concentration appears to be the most incendive.

Explosion-chamber tests carried out by the SMRE in which the methane concentration was not included as a variable normally used a 7 per cent mixture of methane in air. The USBM used a 7 per cent concentration of natural gas, which equates to 6,5 per cent methane. Presumably these mixtures were used as a direct result of Cutler's work.

Bakke *et al.*[11] attempted to develop a relationship between the risk of ignitions on longwall faces, and both methane concentration and airspeed. As a consequence, a statistical analysis was carried out of all ignitions on longwall faces in British coal mines between the periods January 1958 and June 1965. Many sources of igniting the gas, not just those attributed to machine picks, were included in the analysis. The statutory measurements of general body methane concentrations and air speeds in the return roadways were used as a basis for the analysis. It was concluded that the ignition risk was proportional to $(C^2/F)^{0,9}$, where C is the methane concentration and F is the Froude number. The Froude number is expressed as

$$F = U^2 p / gA\Delta p,$$

where U is the airspeed, g is the gravitational acceleration, Δp is the difference in density between air and methane, p is the density of air, and A is the cross-sectional area of the roadway.

The analysis made by Bakke *et al.* did not take into consideration other factors that have an influence upon the risk of igniting methane, such as rock types when cutting with machine picks. It cannot be assessed whether the methane concentration and air speeds when ignitions occurred were the same as the statutory measurements from which the analyses were made, which must have been taken some time previously remote from the point of ignition. There were also variable sources attributed to igniting the methane. With so many uncontrolled variables, the accurate assessment of the ignition risk attempted by Bakke *et al.* appears to be unjustified. However, the analysis does appear to indicate that the methane concentration must be linked to the Froude number when the risk of ignition is assessed.

It can be concluded that a methane concentration of 7 per cent is the most easily ignited within an explosion chamber. At the coal face, however, the indications are that the Froude number, and not just the methane concentration, has an effect upon the risk of an ignition occurring. It is clear, therefore, that work in an explosion chamber does not accurately model actual conditions with regard to methane concentrations. However, for accurate quantification of the effect that the Froude number has upon the ignition potential of methane, laboratory experimentation in which the variables can be controlled is necessary.

Methane concentrations are, on average, lower in South African mines than in Europe and North America. A recent methane explosion in a South African mine, however, highlights the fact that concentrations of this gas can reach dangerously high levels.

Rocks Likely to Cause Ignitions

An attempt is made within the literature reviewed to identify, from a knowledge of petrology, the ignition hazard associated with a particular rock. The mechanism of ignition when these rocks are impacted by machine picks is important in this respect, and two general categories of rocks can be identified (as already pointed out): those where a hot spot develops on the surface when impacted, and those that are liable to self heat on impact owing to the presence of pyrite.

Burgess and Wheeler[3] noted that rocks with a high quartz content are an ignition hazard when impacted. Rae[12] concluded that only rocks with a high melting point, such as those containing appreciable quantities of quartz, are likely to cause ignitions by the mechanism involving a hot spot. Blickensderfer *et al.*[2] suggest that the quartz content and particle size are important parameters affecting ignition potential.

Powell *et al.*[5] conclude that the following general characteristics of rocks are most likely to cause ignitions from a hot spot developing on the surface:

(i) a quartz content greater than 30 per cent,
(ii) a particle size greater than 10 μm and usually greater than 70 μm, and
(iii) the rock remaining 'strong' at temperatures of at least 1250°C.

Powell and Billinge[7] carried out petrological analyses of twenty-four rocks from sites where ignitions had occurred in British coal mines. These tests tended to confirm the above conclusions.

Allsop and Wheeler[8] noted that the impacting of nodules of iron pyrite by machine picks can result in ignitions of methane because of the self-heating of small accumulations of dust from the rock. The picks had to be blunt or badly worn before ignition could occur. The cutting of iron pyrite with sharp picks did not result in any ignitions of the gas. Blickensderfer *et al.*[2] could not ignite methane, even under the most adverse circumstances, when impacting a rock containing 10 per cent iron pyrite. The indications are, therefore, that rocks containing a relatively small percentage of iron pyrite are not a major contributor to ignitions. The literature contains no record of tests on rocks that contain iron pyrite in concentrations of between 10 and 100 per cent. It is not clear, therefore, what percentages of iron pyrite in a rock, below that of the pure state, will increase the risk of igniting methane.

Wynn[4] and Titman[13] considered that an investigator's knowledge of the petrology of a rock was not sufficient for him to make a judgement of its incendivity. Other factors were also thought to be important. In particular, the thermal conductivity of the rock was considered to have a substantial influence. Wynn noted that quartz had a low thermal conductivity, and it was thought that this could be one of the reasons why rocks containing appreciable quantities of this mineral have a high ignition potential when impacted. No experimentation has, however, been done regarding the effect of thermal conductivity on the ignition potential of rocks.

The rocks that are most likely to cause ignitions when impacted by machine picks as a result of the formation of a hot spot are those having both a relatively large quartz content and particle size. The strength of the rock at a temperature of 1250°C also appears to be important. Nodules of iron pyrite are an ignition risk owing to the self-heating of dust generated from an impact. It is not clear, however, whether iron pyrite disseminated within a rock increases the risk of an ignition of methane. Some authors consider that the thermal conductivity of a rock has a substantial influence upon the incendivity, although this has not been established through experimentation.

There are seams currently being mined in South Africa that have, as the immediate roof, materials that fall within Powell's definition of a high quartz content and particle size. Included stone within some seams falls into the same category. Iron pyrite is also present within the coal in some mines.

The Cutting Tool

Several parameters regarding the ignition potential of the cutting tool have been investigated, these being pick material, wear, heating, geometry, and rotation. Studies are continuing in some of these areas at the present time.

Material of Pick Tool

Early work suggested that the material of the cutting tool contributed little to the cause of ignitions of methane–air mixtures. More recent work states that the material of the pick tool does have an influence upon the probability of ignitions.

Burgess and Wheeler[3] carried out experiments in which various steels were held with an edge in contact with a rotating wheel of quartzitic sandstone in an explosion chamber. Ignitions were obtained from all the steels, and there was no significant difference between them. In tests on machine picks made from both carbon and tungsten steels, there were no appreciable differences in the time taken to ignite methane between the two pick materials.

Allsop and Wheeler[8] carried out experiments in which blunt picks made from carbon steel and tungsten steel impacted iron pyrite. There appeared to be no difference in the incendivity of the two steels.

Rae[9] noted that soft metals, such as copper and brass, that have a melting point lower than the ignition temperature of methane can cause ignitions as a result of a hot-spot mechanism when impacted on quartz rocks. Particles of rock embedded in the metals were observed. The hot spots produced were molten rock, rather than molten metal, and were thought to have been due to the friction of rock on rock. No tests were carried out on the relative incendivity of these soft metals, steels, and tungsten carbide.

Blickensderfer *et al.*[1] tested several metals and metal alloys for ignition potential. They concluded that tungsten carbide was considerably less incendive than commercial carbon steels of the types that are used for pick shanks.

It was therefore concluded that the steel shanks of cutting tools, rather than the tungsten carbide tip, were primarily responsible for face ignitions. Stainless steel was found to be less incendive than commercial carbon steels, but more prone to ignitions than tungsten carbide. The mechanism of ignition in these tests, however, was stated to be that of sparking. It was noted that methane mixed with air was very difficult to ignite by sparking, and a hydrogen–air mixture, which ignited easily, was used.

In further tests, Blickensderfer *et al.*[2] noted the applicability of the results obtained with the hydrogen–air mixture to ignitions caused by hot spots in methane–air mixtures. In addition, a hard metal alloy, TiB_2–CuNi, was found to have a lower ignition potential than tungsten carbide. No reasons were given for the differences in ignition potential between the various metals or metal alloys.

Blickensderfer[10], in a theoretical approach, developed an energy-balance equation for the mechanism of ignition by hot spots on rock. The formula implied that the melting point of the tool had an effect upon ignitions. The lower the melting point of the tool, the less energy would be required to form a metal smear on the rock. For a given energy input, therefore, the easier it would be to form this molten layer, which is a major contributor to ignitions as discussed previously. Conversely, the lower the melting point of the metal, the lower would be the temperature of the hot spot. In the tests described above, none of the authors attempts to explain the differences in incendivity, or otherwise, between different pick materials by comparing their respective melting points.

On the basis of tests with pick-body steel and tungsten carbide, Roepke and Hanson[14] suggested that the ignition potential depends upon the back clearance of the tool, rather than on the material. When the back-clearance angle was positive, neither of the materials ignited a methane–air mixture. With a negative back-clearance angle, ignitions readily occurred with both materials. The authors did not attempt to give an explanation for these effects.

It can be seen that there are contradictions in the literature surveyed. The very early work indicates that the pick material does not influence the likelihood of igniting methane–air mixtures. The later literature implies that tungsten carbide tips are considerably less incendive than the body steel of a pick. It is also suggested that, if the material of a pick is changed, for example to a tip of the hard-metal alloy TiB_2–CuNi and a body of stainless steel, a tool could be designed that would be less likely to produce ignitions. Very recent work implies that the effect of the back-clearance angle, rather than the material from which a machine tool is made, influences its incendivity. The normal forces acting on picks increase dramatically as the back-clearance angle is reduced to less than about +5 degrees, which has an effect on the rate of heating at the rock–pick interface. However, no authors attempted to equate their experimental results with a mechanism of ignition. It is clear, therefore, that the effect of the material of a cutting tool upon the risk of ignitions has not been researched adequately.

Pick Wear

Many authors agree that worn picks are considerably more incendive than sharp ones. Some aspects of the effects of wear on the ignition potential of machine picks have been investigated only very recently.

Powell *et al.*[5] and Blickensderfer[10] conclude that ignitions will not occur while picks remain sharp. During ignition tests, Powell *et al.* noted that the duration of cutting for a 50 per cent probability of ignition was considerably more for sharp picks than for worn picks. These authors considered that the extra time was needed for wear of the cutting tool to occur.

A marked increase in the ignition potential of picks was noted by Cheng *et al.*[15] when the wear flat extended to the steel shank. The reason for this was thought to be the greater incendivity of commercial carbon steel relative to tungsten carbide.

Roepke and Hanson[14] concluded that the mechanisms of ignitions caused by frictional impact appear to be largely controlled by the back-clearance angle of the pick. The back clearance can, of course, be influenced by the wear of the cutter tool.

The literature implies that worn picks are considerably more incendive than sharp ones, particularly if the body steel comes into contact with the rock being impacted. Recent investigations suggest that the incendivity of a coal-cutting tool may be greatly increased if wear occurs so that the back-clearance angle becomes negative.

Pick Heating

Experimentation has been carried out recently into the effect upon the potential to ignite methane of a pick that was heated before cutting. An earlier theoretical approach implied that there is an initial pick-temperature effect.

Larson *et al.*[16] pre-heated worn picks to a temperature of between 120 and 150 °C to simulate a machine tool that has been heated as a result of cutting coal, and compared their ignition potential with that of cool picks having the same degree of wear. No justification was given for the range of temperature to which the tools were preheated. It was found that, at pick speeds of 58 and 115 m/min, the ignition potential for the hot picks was considerably more than for the cool ones.

In the energy-balance equation developed by Blickensderfer[10], an initial tool-temperature effect is implied. It is implicit from the equation that, the higher the initial temperature of the pick, the less energy is required to form the metal smear on the rock. For a given input of energy, therefore, the easier it will be to form this molten layer, which is a major contributor to ignitions of methane–air mixtures.

Comparing pre-heated worn picks with cool ones at a speed of 172 m/min, Larson *et al.*[16] deduced that their incendivities were essentially the same. The reason for this was thought to be cooling of the pick by air.

It is suggested in the literature that, as machine tools become hot, their potential to ignite methane–air mixtures increases. However, at pick speeds of more than approximately 170 m/min, the indications are that there is little difference in incendivity between hot and cool cutting tools. A possible explanation for the higher speed effect was thought to be that air cooling of the picks reduces their temperature between successive impacts.

Pick Geometry

The work relating to pick geometry has tended to concentrate upon the tip area and diameter of the shank. This is because previous experimentation concluded that the tungsten carbide tip was less incendive than the body steel, and that wider picks increased the area of the hot spot.

Larson *et al.*[16] compared a commercial tool of plumb-bob shape with a bullet-shaped pick of smaller diameter. The angles of the carbide insert and body cone in both tools were essentially the same. It was found that, as the pick diameter increased, so did the ignition frequency. Hanson[17], in comparing plumb-bob with pencil-type picks, reached similar conclusions. In addition, he noted that, if the diameter of the tungsten carbide tip and the immediate shank was smaller, the ignition potential was reduced.

Three types of conical picks were compared for ignition potential by Roepke and Hanson[14]. All these cutting tools had a tip angle of 90 degrees, but the size of the tungsten carbide tips in relation to the end of the shank was different in all cases. A widely used commercial pick, which was used as a reference, had the smallest tip, which did not cover the end of the shank. The tip of the second pick covered the end of the shank. The third tool was a non-commercial type, which was termed the 'mushroom-tip pick', in which the tungsten carbide tip had a greater diameter than the end of the shank.

It was found that the reference pick was considerably more incendive than the other picks. The mushroom-tip pick had the next greatest ignition potential. The authors did not expect the latter result, because they thought that the larger tip, by protecting the steel shank, would prove to be less incendive. They therefore carried out additional tests on tungsten carbide and coal-cutting steel to monitor the effect of back-clearance angle, since this factor was thought to be responsible for the anomalous results.

Two radial-type picks were also tested, one with a cutting tip that was larger than normal. Both these tools had the same ignition potential as the least incendive conical pick tested.

For the conical picks, it was found that shanks of larger diameter increased the ignition potential of the tool. The cutting tip of this type of pick also appears to be important. If the tungsten carbide covers the tip of the shank, this has an adverse influence on the incendivity of the machine tool. The geometry of the pick can influence the wear, which in turn may have an effect on the back-clearance angle. It is suggested by the literature that the back-clearance angle has a marked influence upon the ignition potential of machine tools. It appears from the few tests that have been carried out that radial picks have a relatively low incendivity.

Pick Rotation

In testing conical-type picks for the effect of rotation within the pick block, Larson *et al.*[16] noted that no ignitions occurred when the tool rotated, but the incidence was high when the pick was locked. The authors stated that this type of tool will rotate when unbalanced side loading overcomes the resistance friction between the shank and the block, and they therefore recommended an angle of skew to induce rotation. The authors did not give any reasons why rotation should influence the ignition potential of a tool.

Hanson[17] also carried out experimental studies in this area, but concluded that conical picks that rotate can produce ignitions. However, the rotating cutting tools could be subjected to considerably more wear before becoming incendive. It is suggested, therefore, that pick rotation influences incendivity, and that incendivity is related to wear.

It is clear that, if conical picks rotate within the block, the ignition potential of the tools will be reduced. This is probably due to geometrical considerations; by rotating, the picks tend to be subjected to unbiased wear.

Cutting Parameters

Several aspects have been investigated that relate machine cutting parameters to the risk of ignition of methane–air mixtures. These are the speed of cutting, the rate of advance of the machine tool, the depth of cut, and the cutting forces.

Speed of Cutting

The effect that the speed of the pick has upon the ignition potential of the tool has been investigated by several authors. The influence of this parameter on sharp, blunt, and pre-heated picks has been looked at.

When considering sharp picks, Blickensderfer[10] concluded that, by increasing the cutter-tool speed, a greater area of the hot spot, which is capable of igniting methane, is produced on the rock. An example is used to illustrate this point. The hot spot is considered to be a molten smear of carbon steel at an initial temperature of 1450 °C. The smear will cool with time. At a pick speed of 90 m/min, part of the smear would have cooled to below a temperature of 1200 °C at a distance of about 0,7 cm behind the pick. If the speed were increased to 272 m/min, however, the pick would have travelled a proportionately longer distance before the hot spot cooled to 1200 °C or less, this length being approximately 1,6 cm. The length of the hot spot at or above a temperature that will ignite methane therefore increases as the speed of the pick is increased. The area of the hot spot, which has a marked effect upon ignitions, will also be greater, since the width is a constant.

Powell and Billinge[7] and Larson *et al.*[16] concluded that the probability of igniting methane with sharp picks increases with speed. Larson *et al.*, noted that the ignition potential of worn picks was greater when the speed of cutting was increased. The difference in the ignition potential between the speed increments was not, however, as great with worn picks as it was with sharp picks.

Larson *et al.*, in tests on worn picks that had been pre-heated, found that the probability of ignition was reduced when the speed of cutting was increased, which was the opposite effect to that found for cool picks. The authors thought that this was probably due to air-cooling of the machine tool.

It can be concluded that, when picks are not pre-heated, the effect of increasing the speed is to produce a greater length, and therefore area, of hot spot on the rock. This, in turn, leads to an increased probability of ignition. For pre-heated machine tools, the opposite effect can be expected. The picks become less incendive as the speed is increased, which may be due to air cooling.

Rate of Advance

Blickensderfer *et al.*[2,10] noted that the advance rate of a pick into rock had little or no effect upon the ignition potential. Larson *et al.*[16] concluded that, as the advance rate during a cutting sequence increased, the number of cuts to ignition decreased. When the advance per cut was plotted against the cut depth, however, it was found that the depth of cut at ignition was the same for all advance rates.

The implications are that the rate of advance of a machine tool into rock has no direct influence on the probability of ignition. It is suggested that the governing factor is the depth of the cut, rather than the rate of advance.

Depth of Cut

Several authors have paid attention to the depth of cut, but only Powell *et al.*[5] and Larson *et al.*[16] have carried out experiments to evaluate the effects of this parameter. They noted that, as the depth of cut increases, so do the forces and rate of heating of the rock and tool. Both these factors can increase the probability of ignition.

The literature suggests that the depth of cut has a great effect upon the ignition potential of machine cutting picks. The implications are that this parameter has an obvious and central role in ignitions. As indicated later, depth of cut is interrelated with cutting forces.

Cutting Forces

Powell and Billinge[7] concluded that there is no direct relationship between the probability of ignition and the cutting forces. It was found that ignitions were not associated with the sudden force of an impact. These authors appear to regard the depth of cut, rather than the cutting forces, as the controlling parameter in ignitions.

There is an obvious interrelationship between the depth of cut and the cutting forces. In order to cut deeper, larger forces are required both in the direction of cutting and normal to the pick. Although the literature emphasizes the depth of cut, from a mechanistic point of view the cutting forces, particularly the normal force, appear to be more important. With increasing normal force, the friction between tool and rock increases. Authors consider that this friction causes the hot spot to form on hard rocks, and is responsible for the self-heating of pyrite. It seems logical to assume, therefore, that the cutting forces, rather than the depth of cut as implied in the literature, is the major factor affecting ignitions. The effect on ignitions of a reduction in the back-clearance angle of picks is also probably due to an increase in normal forces.

The Effect of Water

Powell *et al.*[5] and Powell and Billinge[7,18] noted that water could be effective in reducing ignitions, but that the direction of application is important. Water can be used best when directed onto the freshly cut rock behind the pick, parallel to the instantaneous cutting direction. If supplied normal to the rock behind the pick, ignitions would be decreased, but not as effectively. When water was directed in front of the pick, which is equivalent to pick flushing, no noticeable reduction in ignition potential was apparent. Sprays rather than jets were found to be the most effective form of applying the water.

Wilson[19] described ignition tests carried out by the USBM on a modified coal-cutting pick for use on longwall shearers that allowed water to flow through a channel in the tool. The water was directed to a point where the pick struck the rock or coal, i.e. immediately behind the cutting tip. With the correct water pressure it was possible to suppress ignitions completely, even in the most adverse circumstances.

It is evident that the application of water can reduce, or even eliminate, ignitions of methane–air mixtures. The most effective way in which water can be used is in a spray directed onto the rock immediately behind the pick. The implication is, therefore, that the water must be directed onto the hot spot as it is formed, which has the effect of either cooling the hot spot to below the ignition temperature of methane–air mixtures, or of preventing the formation of the hot spot.

Conclusions

A considerable amount of effort over a long period has been expended in the area of ignitions by coal-cutting picks. However, several factors have been investigated on a qualitative rather than on a quantitative basis. Although mechanisms of ignition have been discovered, many of the authors do not make any attempt to explain their results using these mechanisms.

The main conclusions obtained from the review of the relevant literature regarding the ignition potential of coal-cutting picks can be summarized as follows.

(1) The most common mechanism of ignition is a hot spot on the rock caused by frictional impact of the pick. When iron pyrite is impacted, ignitions can occur by the self-heating of small accumulations of dust from the rock.

(2) The ignition potential increases with the area and the temperature of the hot spot.

(3) A 7 per cent methane concentration in air is the most incendive mixture in an explosion chamber. The Froude number could have an effect on the ignition potential of methane in a working environment. However, the effect of the Froude number has not been researched adequately.

(4) Rocks that have a high risk of igniting methane when impacted include those with a quartz content of more than 30 per cent and a particle size usually larger than 70 μm. Nodules of iron pyrite also have a high potential to ignite methane. It is not clear from the literature whether disseminated iron pyrite affects the risk of ignitions. Some authors consider that the thermal conductivity of a rock is an important factor, but this factor has not yet been investigated.

(5) In regard to the material of the pick, there are marked contradictions in the literature. Very early work suggests that the material has no effect; but later work indicates the opposite, and more particularly that tungsten carbide is considerably less incendive than the body steel of the pick. The latest work in this area suggests that the back-clearance angle of the cutting tool, rather than the material from which it is made, is the most important aspect.

(6) For sharp picks, the ignition potential becomes greater as the speed of the pick increases. The same

trend can be noted for worn picks, but the increase in incendivity is not as great. With worn picks that are hot, the trend is reversed: the ignition potential decreases as the speed of the tool increases.

(7) As the depth of cut, and therefore the cutting force, increases, so does the potential for the cutting tool to ignite methane–air mixtures.

(8) The rate of advance of picks into rock has no apparent effect upon the ignition potential.

(9) Worn picks are considerably more incendive than sharp picks. It is not clear whether the reason for this is that the body steel tends to be exposed to the cutting process, or that the back-clearance angle is changed.

(10) For pick speeds lower than about 170 m/min, hot picks are considerably more incendive than cool ones. At higher speeds, pre-heating of the pick does not appear to have any appreciable influence upon the ignition potential.

(11) For conical picks, the larger the diameter of the shank, the more incendive is the tool. If the tungsten carbide covers the shank tip, the cutting tool is less incendive than otherwise. If the tungsten carbide is too large, this has an adverse influence upon the ignition potential of the pick.

(12) If conical picks rotate, they are less incendive than locked picks.

(13) Radial picks appear to have a relatively low incendivity. However, very few tests have been carried out on this type of cutting tool.

(14) The application of water, particularly in the form of a spray, can substantially reduce the potential for methane–air ignition. To be most effective, the water must be directed onto the rock immediately behind the pick.

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AIME Annual Meeting

Papers are invited on alumina and bauxite for the 115th AIME Annual Meeting, which is to be held in New Orleans from 2nd to 6th March, 1986. The following deadlines apply:

1st August, 1985: Titles, authors, and abstracts
4th October, 1985: Final manuscripts.

Any paper of significant technical or economic interest in the alumina and bauxite field is acceptable. For presentation, papers will be grouped into broad topics, which in 1986 may include

- Equipment and Process Development
- Process Control, Process Simulation, Analytical Techniques.
- External Forces and Internal Reactions:
  Optimization of Existing Plants
  Cost Reduction/Energy Conservation
  Environmental Developments — Red Mud Disposal
  Safety Hygiene
- Special Chemicals.

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Waste management

Seven annual symposia were held on this topic at Colorado State University from 1978 to 1985. The first symposium dealt primarily with uranium-mill tailings, and the last two included low-level and hazardous wastes. The Eighth Annual Symposium which is to be held at Fort Collins, Colorado, from 5th to 7th February, 1986, will focus on geotechnical and geohydrological aspects of all areas of waste management including

- Uranium-mill Tailings
- Low-level Waste
- Hazardous Waste
- Other Mine Wastes.

Papers are being solicited in the general areas of geotechnical and geohydrological aspects of tailings and waste management, both during operations and as applied to reclamation and long-term stabilization. Papers dealing with regulatory aspects, social concerns, and risk assessment are also encouraged. Sessions dealing with each of the above areas will include keynote presentations by the following:

- *Uranium-mill Tailings*
  Mark L. Matthews, 'UMTRA Project: Implementation of Designs', U.S. D.O.E.
  'Review of the National Academy of Sciences, Report on Uranium-mill Tailings', by a panel member to be announced.
- *Low-level Waste*
  Keros Cartwright, 'Geohydrological Experience at a Low-level Waste/Shallow Land Burial Site', Illinois State Geological Survey, Champaign, Illinois.
  Vern C. Rogers, 'Low-level Waste: The Nature of the Beast', Rogers and Associates Engineering Corporation.
- *Hazardous Waste*
  William A. Murray and James G. Dragun, 'Impact of Soil Chemistry on Contaminant Migration from Hazardous Waste Areas', E.C. Jordan Company, Portland, Oregon.
  Larry A. Holm, Brad J. Berggren, and Jim R. Schneider, 'Methodology to Evaluate the Geotechnical and Geohydrological Aspects of a Hazardous Waste Site', CH_2M Hill, Redding, California, Milwaukee, Wisconsin and Portland, Oregon.
- *Other Mine Wastes*
  Andrew M. Robertson, 'Mine-waste Disposal: An Update on Geotechnical and Geohydrological Aspects', Steffen, Robertson & Kirsten, Vancouver, British Columbia.

Abstracts of papers must be submitted by 17th July, 1985. Abstracts will be reviewed and authors will be notified by 20th August, 1985, whether their papers are accepted. Manuscripts will be due 15th November, 1985, in order to be included in the Proceedings.

Abstracts or inquiries should be directed to
Eighth Annual Symposium on Geotechnical and Geohydrological Aspects of Waste Management,
Geotechnical Engineering Program,
Civil Engineering Department,
Colorado State University,
Fort Collins, Colorado 80523, U.S.A.
Telephone: (303) 491-6081.

Gold and silver recovery

The date and venue of 'Gold & Silver Recovery 85' have been changed to avoid clashing with other conferences. It will now be held in Santa Fe, New Mexico, U.S.A., on 14th and 15th October, 1985.

The main themes are as follows:

- The Processing of Refractory Gold and Silver Ores
- New Horizons for Heap and Vat Leaching.

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IPMI calendar

The International Precious Metals Institute (Government Building, ABE Airport, Allentown, Pennsylvania 18103, U.S.A. Telephone: 215/266-1570) announces the following calendar of events.

Platinum-group Metals Seminar
6th to 9th October, 1985
Westin Hotel, Washington, D.C.

Financial II Seminar
12th to 14th March, 1986
Copley Plaza Hotel, Boston, MA.

IPMI 10th International Precious Metals Conference and Exhibit
9th to 12th June, 1986
Hyatt Hotel, Lake Tahoe, NV.

Silver Seminar
12th to 15th April, 1987
Colonial Williamsburg, VA.

IPMI 11th International Precious Metals Conference and Exhibit
14th to 18th June, 1987
Hilton Hotel, Brussels, Belgium.