ALOK VARDHAN
YASH KUMAR
AJIT KUMAR
and
K. DASGUPTA

Development of dust control methodologies in continuous mining operation

Workers in mining industries face a serious health threat of exposure to respirable dust. Over-exposure to respirable coal mine dust generally leads to coal workers' pneumoconiosis (CWP). CWP is a lung disease that causes disability and may also prove to be fatal in serious cases. Along with this, the miners may also get exposure to extreme levels of respirable silica dust, which is known to cause silicosis, another agent leading to disability and/or fatal lung disease. Regarding this issue, a major challenge is to reduce the amount of respirable dust which exists in underground mining industry.This paper aims to design new methodology and discuss the various processes for dust control in underground coal mining operations. The goal involves optimizing the use of water spray as well as evaluating emerging control technologies, design criteria and methods.

Keywords: *Respirable dust, CWP, silicosis, underground coal mining, dust control.*

1. Introduction

Coal is a prime source of energy for India and it will continue to maintain its lead for the foreseeable future. Throughout mining and processing of minerals, mined ore undergoes number of process like drilling, blasting, haul road and coal cutting by continuous miner (coal mining machinery), conveyor belt and crusher houses. With an increased level of mechanization and pressing demand to boost production for minimising the supply gap, generation of air borne respirable dust is increasing necessitating more effective dust control practices. Being a labour intensive industry, coal mining wants extra effort to mitigate dust pollution.

Dust is broadly defined as small solid particle created by the breaking up of larger particles. Depending on their size these particles can become hazardous to worker health, particularly when suspended in air. The largest size particle that can be suspended in air for long periods of time from wind velocity acting upon it is about 60-2000 micro-meter (μm) can also become suspended in air, but they only reach heights up to approximately 3 feet about ground before they fall back to surface. Particles more than about 2000 μm generally creep or roll along surface due to wind velocity acting upon them [1].

Prolonged exposure of coal mine dust is known to cause various respiratory diseases like pneumoconiosis, silicosis, bronchitis, asthma, fibrosis of lungs and tuberculosis (TB), depending upon the nature of the dust. Free silica/quartz present in the dust of mine air has been identified as a main cause of these health hazards to miners. Indian coals are considered to be of 'drift' origin and therefore contain high mineral matter intermixed with coal matter. Quartz is one of the major minerals present in coal and therefore miners are exposed to health risks arising from inhalation of quartz laden coal dust generated in the coal mines. Dust with quartz content of up to 14.49% has also been reported in coal mines of Bharat Coking Coal Limited, Dhanbad [2].The health risk to the miners varies depending upon the nature of coal and its mineral content, condition of the mines, nature of job handled by the miner and finally the quality and the efficacy of the safety measures adopted by management.

Air-borne dust from mining activities spreads over nearby populated areas and crops causing harmful effects in many ways to the people, vegetation, forests, animals and water resources. The corrosive effect of the dust shortens the life of lubricants of heavy earth moving machinery (HEMM), increases maintenance costs and reduces its operating efficiency. The dust impedes visibility thereby reducing production capacity. It is also a potential safety hazard.

The major part of excavation carried in underground mine involves heavy mining machinery equipment i.e. continuous miner. Continuous miners, which were designed for increasing productivity, have also increased the concentration of respirable dust in the mines. The amount of silica and respirable dust generated by excavating coal and cutting roofs with continuous miners is the major concern for the industry. Typically, respirable dust is controlled by water sprays mounted on the continuous miner (CM). This method has been an effective means of controlling respirable dust for CM

Messrs. Alok Vardhan, Yash Kumar, Ajit Kumar and K. Dasgupta, Department of Mining Machinery Engineering, Indian School of Mines, Dhanbad. E-mail: alok.or.monu@gmail.com, chaudharyyash20@gmail.com, ajit.ism185@gmail.com, dasgupta_k2001@yahoo.co.in

operators for many years, but the increase in the incidence of overexposure suggests that the use of water sprays is no longer consistently providing protection to operators. As new methods of controlling face hazards are developed and adopted by the mining industry, their potential for controlling respirable dust will continue to be evaluated.

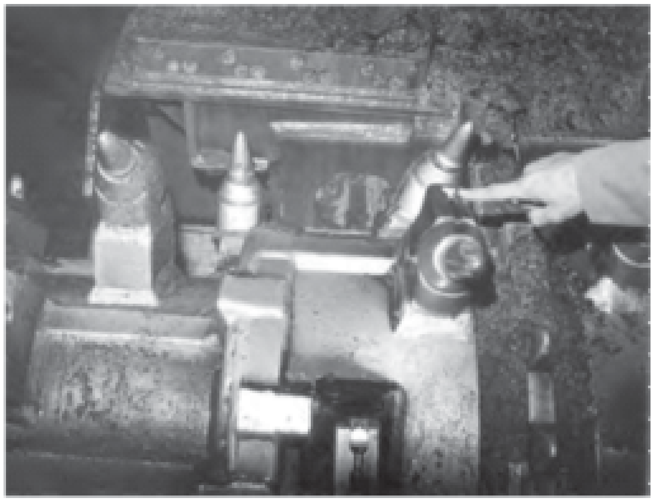


Fig.1 Water sprays on continuous miner head

Thus this paper aims to provide probable alternatives for suppression of dust generated by underground mining equipment i.e. continuous miner, depending upon cutting geometry factors including bit tip angle, angle of attack, bit penetration and bit spacing.

2. Dust control on continuous mining operation

To understand the methods for the suppression of dust based on tool geometry and the bit spacing it is important to understand the basic mechanics of coal cutting.

2.1 Basic mechanics of coal cutting

When a pick cuts across the surface of a block of coal, it is seen always to produce a groove that is much wider than the width of the pick. Also, the depth of the groove is sometimes greater than the depth of the pick.

As illustrated by Fig. 2 the excess lateral breakage occurs as sides play and, although its surfaces are usually irregular, it can be represented by an equivalent angle of inclination to the vertical. This is termed the 'breakout angle', and for a given coal it remains fairly constant for all depths of cut. The production of excess coal is variable and depends mainly on the direction of cutting in relation to the cleat and bedding of the coal, pick shape also being of some significance in this context.

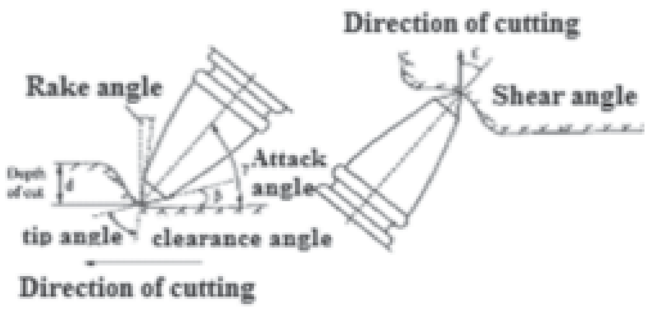
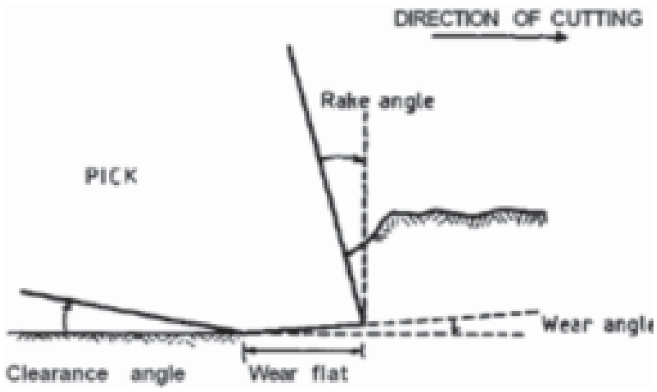


Fig.2 Coal cutting by pick

The cutting of coal is characterized by a rapid linear increase in the force acting on the pick as it penetrates. Eventually this force exceeds the strength of the coal, and a coal fragment or chip is produced with an attendant and instantaneous reduction of pick force. The coal chip extends ahead of the pick, the latter then advancing under zero or negligible force until it re-engages a fresh coal surface, after which the chip-formation process is repeated.



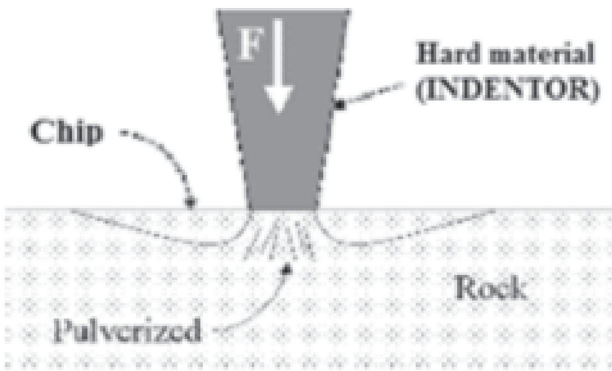


Fig.3 Interaction of pick with coal

This leads to a typical saw-tooth shape of force-distance diagram for a pick, with peaks that are irregular in magnitude and frequency owing to the heterogeneous nature of coal. Although coal is known to have time-dependent stress-strain properties, these are of no practical significance when cutting, even at the slowest speeds. From this standpoint, coal can be regarded as a brittle material. Evans's model provides a valuable analytical insight into the mechanics of coal-chip formation by a wedge [3]. The recognition that breakout angle θ remains constant with depth of cut is significant, since it leads to what is probably the most important fundamental principle of coal cutting. Evans's theory, which is fully consistent with laboratory experience, shows that the cutting force acting on a pick is linearly proportional to the depth of cut. A low specific energy (i.e., the work done or energy consumed to produce unit volume or mass of coal) implies a high efficiency. The generalized cutting force "F" acting on a pick can be resolved into two mutually perpendicular components: FC, the cutting force that acts in direction of cutting and FN, the normal force acting perpendicular to the direction of cutting. The mean cutting force FC multiplied by the distance cut gives the amount of work done. The normal force FN is the force required to maintain the prick at a constant depth of cut. It has zero or negligible displacement in its direction of action and does not contribute to the work done in cutting the coal depending on the pick shape and some other factors, a sideways or lateral forces can sometimes be generated, when it does not exit, it is always of low magnitude and can therefore easily be ignored at this stage.

The effects of cutting depth on work done to cut the coal and its relationship to the quantity of coal produced are as follows.

Work done to cut the coal = $F_c l = k_1 dl$ ... (1)

where,

F_c = mean cutting force

d = depth of cut

l = distance cut

k_1 = a constant (depending on the shape of the pick and coal strength)

Volume of coal cut = $(W.d + d^2 \tan\theta)l$ ... (2)

where,

θ = breakout angle

l = pick width.

Specific energy = $F_c l/(W.d + d^2 \tan\theta)l$

$= k_1 d/d(k_1 + k_3 d) = k/(k + k_0)$ ... (3)

Where,

$K_0 = k_1/k_2$ and $k = k_3/k_2$

Equation (3) indicates that specific energy decreases (i.e. the energy efficiency improves) as the depth of cut increases. It also shows that as d tends to zero, the specific energy approaches a maximum finite value of k_0/k.

These considerations relate to a single pick cutting unrelieved; a mining machine uses an array of picks disposed on some form of cutter head, drum, or jib in which the picks are required to interact. The effect of spacing between picks on their cutting efficiency is important.

If two adjacent picks array are placed a large distance apart(s), they will each require the same specific energy. If the picks are now brought closer together, a position will be reached at which they start to interact, the groove cut by the leading pick providing relief for the following pick. If the spacing between the picks is further reduced, the specific energy will continue to fall but not indefinitely so. Indeed, as the spacing tends to zero, the depth of cut of the following pick tends to zero since it is then cutting exactly in the 'shadow' of the leading pick. At that position, the specific energy is at a maximum, as indicated by equation (3). The effect of spacing on specific energy indicates a value of spacing at which the specific energy can be expected to be minimized. In fact, a family of curves can be drawn, each showing a minimum specific energy for a different depth of cut and consistent with the general level of specific energy, being lower at the high depths of cut; also, that a wider pick spacing is appropriate when the depth of cut is larger.

The interaction starts when adjacent grooves just touch (i.e., $s = 2d.\tan\theta$), the geometrical similarity implicit in the family of curves can be normalized the spacing, s, is divided by the depth of cut, d. Now, on the basis of spacing expressed as a multiple of cutting depth, interaction between the grooves will occur at $2\tan\theta$, which is the same for all depths of cut. Similarly, if geometrical similarity persists, the s/d ratio at which the specific energy is minimized will be the same for all depths of cut. Fig.4 shows how specific energy is expected to vary with s/d ratio, the value of the minimum specific energy reducing at the higher cutting depths.

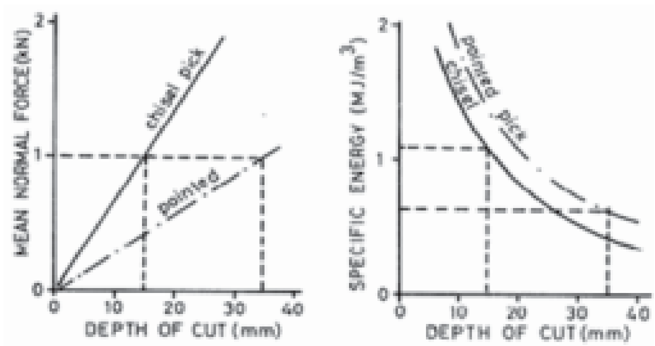


Fig.4 Variation of different shapes of pick with depth of cut

2.2 Processes for dust control in continuous mine operation

The process that involves the dust control in continuous mine operations are as follows:

- Blowing face ventilation
- Exhausting face ventilation
- Proper bit design and maintenance
- Modified cutting method
- Water spray system
- Flooded bed scrubbers.

The continuous mining machines which were introduced in the 1950's, now account for more than half the production of coal from underground mines. Unfortunately, these continuous miners, which were designed for increasing productivity, have also increased the concentration of respirable dust in the mines. Improving the fragmentation process by understanding the mechanisms of coal/rock breakage will not only reduce respirable dust at the face, but it will also decrease the amount of respirable dust that is liberated during the secondary handling such as loading and transportation etc.

The problem in continuous miner head/drum is mainly associated with bit/tool and drum geometry. The bits/tool tips and the bodies are not designed properly, resulting in inefficient performance of machine and tools, producing high levels of noise and fine particles and generating enormous amounts of respirable dust. In a typical continuous miners drum, the bits cut face randomly and their cutting abilities mainly depend on the geometry of the bits.

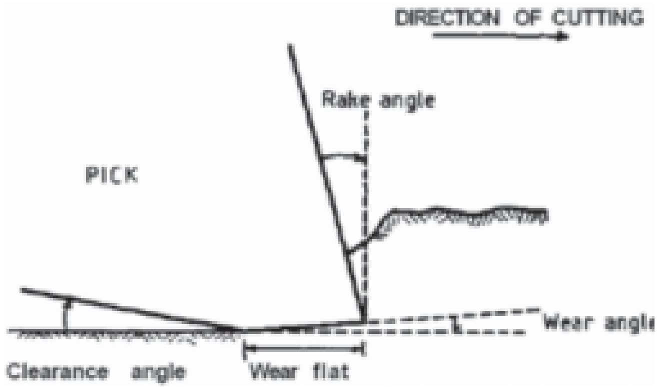
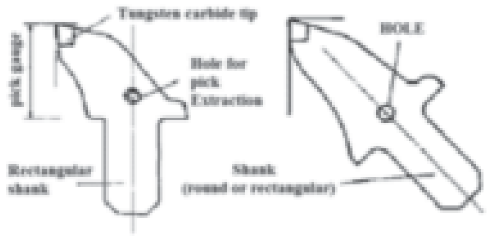


Fig.6 Different tool geometry



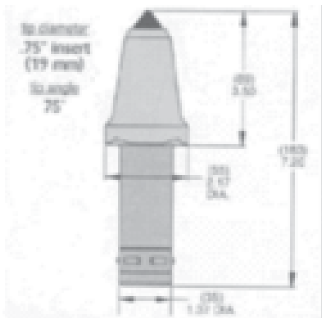


Fig.5.(a) Wedge type pick Fig.5.(b) Point attack pick

There are two shapes of cutting bits commonly utilized, namely, wedge type and point attack type. Although point attack type bits are used most frequently in the US, research indicates point attack bits suffer a lot of bit tip wear and damage. This is largely due to their inefficient rubbing contact with the wall of the cut groove (ridges/lands) [4].

2.3 Tool bit wear

Bit wear can be defined as the removal of material from the surface as a result of mechanical action. The mechanism of bit wear can be adhesion, abrasion, oxidation, or diffusion depending on cutting conditions. The mechanism of bit wear can be adhesion, abrasion, oxidation, or diffusion depending on cutting conditions. Chain saw machines, surface miner, continuous miner, shearer, plough etc. are used for coal cutting. A study was carried out by the researchers to study the principles of bit wear and dust generation [5]. In their study they found, four types of point attack/conical used bits were obtained from different underground coal mines. The same study showed that worn bits with 15% weight loss generated about 26% more dust than the new bits. So thus we can say that bit wear is one of the factors contributing to dust generation and work has to be carried out to reduce bit wear.

Reason of bit wear: Heat generation during cutting is considered to be a major factor in advancing the process of wear of bits. During the process of cutting, bits interact with different material having different strength and frictional properties which provide frictional resistance against the movement of the bit. In order to overcome this resistance energy is spent to overcome friction which results in heat being generated as a form of energy transfer between the interacting surfaces. When the heat is conducted by the bit, its material property is affected and the onset of wear takes place.

The major problems in the cutting action of the rotary cutting drum, which excavates the cutting face, are the following:

(1) Non-uniformity of the cutting depth for each individual bit along the cutting path,

(2) Generation of secondary dust, which may be much more than the primary dust generation due to cutting action.

(3) Excavating material in a confined state/solid face without pre-cut free faces or slots.

In a rotary cutting action the shape of the groove along the path of an individual bit resembles a crescent moon. Each bit on the drum starts the cutting face from zero depth of cut and as the bit penetrates further into the face, the depth of cut increases to a maximum at the center line of the path of each cutting bit, then the depth of cut decreases to zero when the bit exits the cutting face.

The dust generation by regrinding depends on the size of the particles being cut during primary excavation (i.e., cut by the first line of bits). Higher dust concentration coefficients are obtained by regrinding finer particles. Increasing depth of cut creates less fine particles and reduces dust generation by regrinding. Dust generation also significantly depends on hard grove grind ability index. The coal with higher grind ability index has higher dust concentration coefficients. Higher velocity of cutting head causes higher dust concentration. Concentration by regrinding is linearly proportional to the amount of coal left for regrinding [6]. Study conducted by researcher's recommends that loading the entire coal removed/excavated in each cutting cycle will help to reduce regrinding. Also it has been said that "using blunt, high speed bits, (continuous mining machines) probably are the best machines for forming dust that could be invented, except for a grinding stone" [7].

3. Occurrence of fracture in rock or coal cutting

Fracture process in coal/rock by rotary cutting showed that the dynamic forces causes fracture formation and fracture extension, while the quasi-static forces are responsible for grading the fracture surface. The rotational velocity of cutting head slows down after it induces certain fracture (different intensities, magnitudes, and lengths). When the bit enters the coal it indents and compresses the coal under it and shears off the fragments. This process yields coal fragments, coarse and fine, and dusts particles. Crushing and subsurface cracking will produce fine fragments and dust.

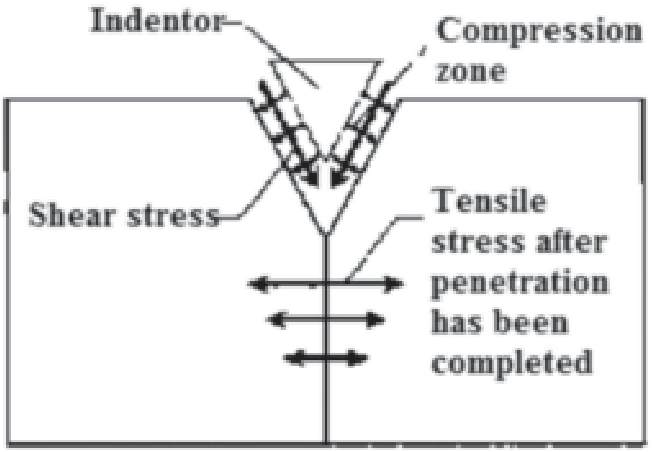


Fig.7 Stress during indentation

The important cutting parameters of rock/coal cutting are:

3.1 Bit attack angle

The study carried out by researchers utilizing four different attack angles, 15°, 30°, 45°, and 60° found that the most ideal condition for force transmission by the bit to the coal would be a 30°-45° attack angle [8], where the area of contact between the bit and coal is at a minimum and causes a high stress concentration in the coal block. As a result, less force is required to break the coal. The smaller attack angle will not only require a larger normal force (thrust) to penetrate the coal, consequently resulting in more friction heat, especially during the quasi-static loading condition(grading). The 60° attack angle is similar to the 15°; however, in this case the front portion of the bit will have a larger surface area of contact with the coal. Its influence on fragmentation will be during the dynamic loading cycle and the larger area of contact will make the bits behave as if they were blunt.

3.2 Bit geometry

Conical bits are commonly used in the mining industry. In regards to bit geometry, there are two elements associated with bit geometry, namely:

1. Bit tip
2. Bit body

Variation in bit geometry i.e. bit tip angle, and size, bit body geometry and stream linear of bit tip and body can lead to efficient fragmentation and considerably change respirable dust generation.

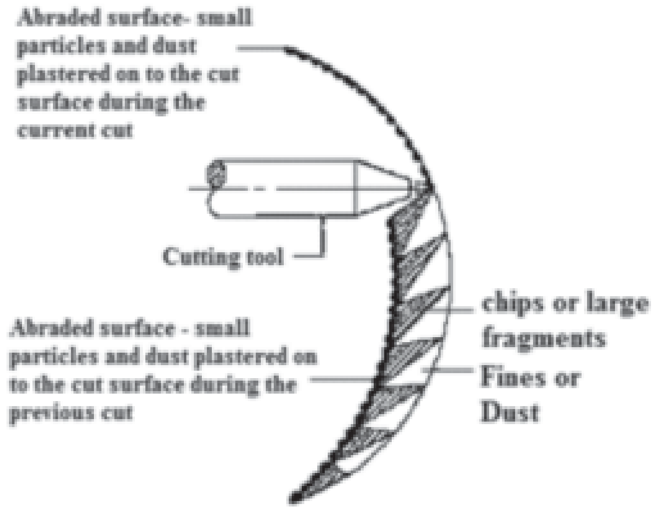


Fig.8 Crushing and chip formation when cutting coal with continuous miner

3.3 Depth of cut

Past research indicated that as the depth of cut increases the specific respirable dust is reduced. Deeper cutting enable interaction between adjacent cuts and help produce larger chips of material. The average cutting force increases with increase in depth of cut while the specific respirable dust and specific energy decreases with depth of cut [9]. It is known that a proper depth of cut to bit spacing ratio reduces specific dust generation. This ratio depends on machine cutting parameters and physical and mechanical properties of rock.

3.4 Bit spacing

The researchers carried out study of the influence of bit spacing on the energy consumption and amount of noise produced during cutting [10]. Their results indicated that the noise levels usually increase with an increase in the cut spacing to depth of cut ratio for individual bits There is an increase in the noise level and energy consumption of 4 5% and 24 1% respectively when the bit spacing to cut depth ratio was increased from 1 to 2. Optimum bit spacing reduces confinement and provides free space, which results in less energy consumption and reduced dust generation. Experiments conducted by the researchers indicated that energy consumption and specific respirable dust reduces as the bit spacing to depth of cut ratio decreases from 2 to 0 3 m [11] ,and the amount of respirable dust produced increases as the bit tip angle increases from 60° to 75° and it reduces from 75° to 90° [12].

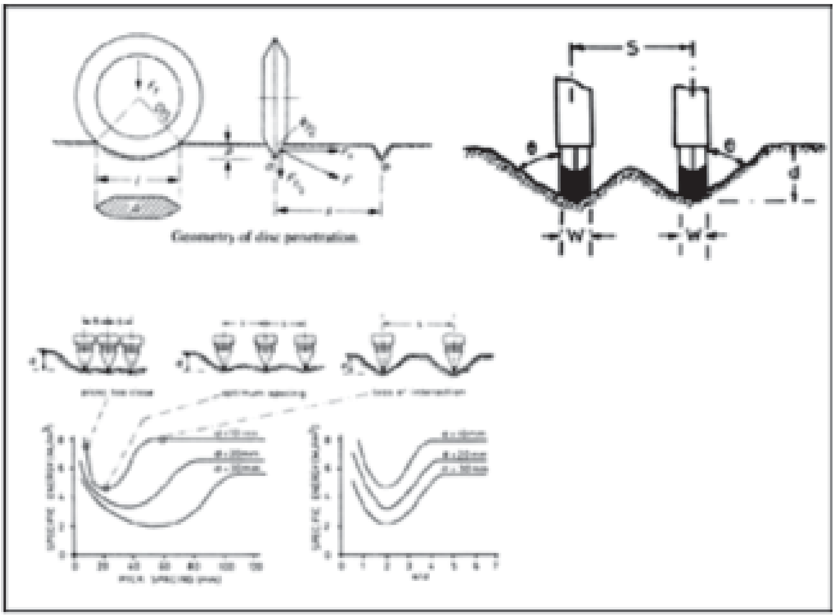


Fig.9 Effect of pick spacing and s/d ratio on specific energy

4. Enhancement

Continuous miners of today are the boon for underground mining which are highly advanced in hydraulic, electrical, electronic, and mechanical technology than the ones built a decade ago. But unfortunately the cutting head of continuous miners need to improve coal/rock fragmentation, reduce dust and increase efficiency of the machine. There are many types of cutting tools with different bit geometry shape, size, and tool tip available to cut materials of different strength and abrasivity. Polycrystalline diamond compact (PDC) bits could be used for hard and abrasive materials; however, the use of such a bit in the field is restricted by cost. Unfortunately, cutting tools' geometries are not optimized to reduce respirable dust and specific energy. The important elements for cutting tools are deep penetration with least wear and energy consumption. In a research work by Khair (1996), recommendations in regards to optimum bit geometry were presented. Following these recommendations, a series of new cutting tools were developed by two major tool-manufacturing companies. Research on optimization of cutting tool, for cutting different geological materials, is underway by the authors. During sumping process, where most of the regrinding takes place, scrolls, similar to the longwall shearer machine, will help to transport material from the sump to the gathering arms. The scrolls on the cutting head of some continuous miners, used for trona mine are implemented and the results are highly favourable. The productivity of the continuous miner has increased significantly by increasing depth of cut. However, if the depth of cut to bit spacing is not optimized it results in excessive amount of respirable dust generation and high energy consumption. If the ridges between the bits were not broken or fragmented during bit penetration there is crashing of these lands/ridges by the bit blocks. The use of water jet assisted cutting has been implemented in a number of continuous miners in relatively dusty coal mines. Of course water jet assisted mining not only suppresses dust generation, it also helps retard ignition, facilitates rotation of bit in bit block, and increases efficiency of the cutting tool and cutting head. Perhaps the most inefficient cutting of continuous miner drum is lack of free face. The geometry of the drum is not modified to cut material toward free the face.

5. Conclusions

This article concludes that for an efficient use of underground mining machinery in order to sustainable growth in areas of productivity and also to set up a benchmark to achieve low dust generation during coal-bit interaction, special attention needs be taken in this regards instead of moving with outdated process. Economical as well as physical benefits of the process should be considered along with its side by side impacts. For low dust generation, some processes such as blowing face ventilation, exhausting face ventilation, water spray system and flooded bed scrubbers are used. Cutting tool geometries mounted on cutter head of the continuous miner play an important role for low dust generation and high productivity. Basic cutting tool geometries include pick attack angle, bit geometry, depth of cut and bit spacing are some important parameter which need to properly determined or specified.

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