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मनोज कुमार
अध्यक्ष सह प्रबंध निदेशक
Manoj Kumar
Chairman-Cum-Managing Director

Message

Coal is the most important and abundant fossil fuel in India. It accounts for 55% of the country's energy needs. The country's industrial heritage was built upon indigenous coal. Considering the limited reserve potentiality of petroleum & natural gas, eco-conservation restriction on hydel project and geo-political perception of nuclear power, coal will continue to occupy center stage of India's energy scenario. In the long term, India needs to focus at coal to gas i.e. more clean energy sources.

Creation of a sound technological base depends to a large extent on Research & Development activities. Recognizing the needs for coordinated and sustained R&D work in coal sector, Ministry of Coal through S&T scheme and CIL through its R&D scheme support research endeavors to provide renewed scientific impetus to address mining challenges, broaden the participation of stake holders, to make the research in mines more productive with high safety, to focus cleaner energy and to promote innovation & indigenization etc. Research efforts should not only focus on immediate requirements of coal & lignite sectors, but also address long term goals for the benefit of future generations.

I am glad that CMPDI is publishing special issue of 'Minetech' to disseminate the outcomes of some research projects among the mining community for their wider application in actual field.

It is hoped that this special issue of 'Minetech' will serve its purpose for further and wider application of these findings for the benefit of the industry.

I extend my greetings and best wishes to the authors and the officials of S&T Division,CMPDI for their dedication and hard work put in to bring out this special R&D issue.

This publication will also provide impetus for intensifying future research efforts.

(Manoj Kumar)

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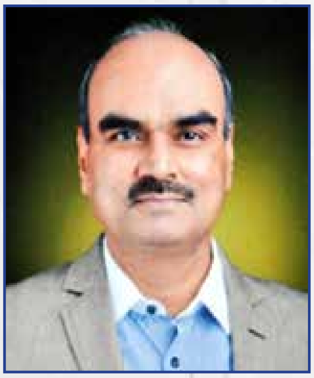

रबीन्द्र नाथ झा
निदेशक (तकनीकी/आरडीएण्डटी)
Rabindra Nath Jha
Director Technical (R,D &T)

Message

Ministry of Coal started Coal S&T Grant and Coal India Limited R&D Grant to intensify research work for indigenous development of technologies suitable for Indian coal & lignite industries to meet the rising energy demand of country in sustainable manner.

CMPDI is the nodal agency for coordination & monitoring of research projects. Besides co-ordination of R&D works by various academic & research institutes, CMPDI with its well established scientific laboratories actively participate in research in key areas.

Over the years, many research projects have yielded notable benefits to coal industry. Efficient management and sustainable development are two key elements, which needs to be addressed for optimal utilization of natural resources. The challenge for development of mining & fuel sectors includes scientific mining, conservation and proper utilization of low grade mineral resources, clean coal initiatives, management of mining waste and above all the environmental protection. In Indian context, coal is the mainstay of the energy mix. Hence, it is equally important to address the issues related to efficient and optimal utilization of coal, exploitation of alternative cleaner fuels as well as livelihood generation of the project affected peoples through R&D works.

I am extremely happy & proud that S&T Division, CMPDI felt the need of highlighting the issues and concerns of technological advancement through R&D efforts in coal & lignite sectors on one collated documents, i.e special R&D issue of ‘Minetech’.

I am sure the publication will be of interest to the professionals engaged in coal & allied industries and enable widespread use of the findings for the benefit of the industry.

(Rabindra Nath Jha)

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एस. के. गोमास्ता
निदेशक (तकनीकी/सीआरडी)
S. K. Gomasta
Director Technical (CRD)

Message

Coal forms the backbone of India's energy system as it contributes to nearly 55% of the country's energy needs & coal based power generation contributes more than 70% of the power generation in the country. It can be said that country's industrial heritage has been built upon indigenous coal. It will remain the most viable fuel for driving economic growth for many years to come.

Coal is the most abundant fossil resources in the country. India, currently stands fifth in terms of the total world resources, whereas, it is 2nd from the point of view of coal production. Considering increase in complexities with depth of coal deposit, climate change, mechanization and application of modern tool in mining, there is an urgent need of introduction of innovative exploration and mining technologies. For long time sustainability of coal & lignite sector, continuous efforts should be made in R&D endeavor.

Ministry of Coal through S&T Grant & Coal India Limited through R&D funding support research work in coal & lignite sectors to meet the rising energy demand of the country in long time sustainable manner. Over the years, many research projects have yielded considerable benefits resulting in operational improvement, safer working conditions, better resource recovery and protection of environment. Some research projects have produced tangible impact on the industry directly, some have strengthened mine planning, design & technical services required by operating mine & future mining projects.

This special R&D publication of 'Minetech' from CMPDI illustrated the outcomes of some completed research projects. It is hoped that this special issue will prove useful in disseminating the outcomes of the projects amongst the professionals engaged in coal & allied industries.

I congratulate S&T Division CMPDI for bringing out this special publication of 'Minetech'

(S. K. Gomasta)

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शंकर नागाचारी
निदेशक (तकनीकी/ईएस)
Shankar Nagachari
Director Technical (ES)

Message

World over coal has been recognized as the most important fuel resources, which can be relied upon to meet the global energy demand for many decades and it is felt that it will remain the prime source of energy in future also. The adverse effects of using this fossil fuel on the environment are also being increasingly realized. India, rich in coal resources, has to take the lead in employing clean coal technologies, carbon capture utilization & sequestration and other issues, which involve use of coal on sustainable basis in the long term perspective. Development of suitable technology for beneficiation of coking coal to make them metallurgical use is a green area where more thrust should be given through R&D. This will save huge foreign reserve, which are being siphoned out today.

We should increase our outreach by involving R&D in innovative tools and machinery for mining and allied operations, strategic technology management and system development, innovation in alternate source of energy, energy efficient process/equipment, use of AI and IoT etc. to fulfill the aspiration of country to make it Atma-nirbhar.

Recognizing the need for coordinated and sustained R&D work in coal & lignite sectors, Ministry of Coal and Coal India Limited initiated coal S&T Grant and R&D Grant in 1975 and 1995 respectively. Since then large nos of research projects have been completed. Many of these projects have yielded considerable benefits resulting in operational improvement, safer working conditions, better recovery of resources and protection of environment etc.

It is hoped that this special R&D issue of ‘Minetech’ will prove useful in disseminating the outcomes of the projects amongst the professionals engaged in coal & allied industries.

I congratulate S&T Division CMPDI for this special publication of ‘Minetech’.

(Shankar Nagachari)

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अजय कुमार
निदेशक (तकनीकी/पीएंडडी)
Ajay Kumar
Director Technical (P. & D.)

Message

Research & Development for any industry is important because it provides powerful knowledge and insights, leads to improvements to existing process, where efficiency can be increased and cost can be reduced. It also allows industries to develop new products and services for long term survive and thrive in competitive markets.

Ministry of Coal through S&T scheme & CIL through R&D scheme promoting R&D activities in coal & lignite sectors for improvement in production , productivity , safety, coal beneficiation and utilization, protection of environment & ecology, clean coal technology, creation of wealth from waste and other allied fields.

CMPDI, apart from the activities of exploration, planning & development, mining related consultancy has been acting as the nodal agency to coordinating research activities under the S&T Grant of MoC and R&D Grant of CIL. Besides co-ordination of different R&D works, CMPDI with its well established laboratory is undertaking research in key areas.

In India, coal & lignite are the most important energy resources and also the main contributor to the basket of commercial energy of the country. As such, continuous R&D efforts are essential for its long term sustainable growth.

It is heartening good to know that CMPDI is publishing special R&D issue of the ‘Minetech’ to disseminate the findings of some research projects among the stake holders for wider application.

I am sure that this publication will be dwelling on promotion of innovations and technological breakthroughs and mining industry will be benefitted.

I express my greetings and best wishes to all authors and officials of S&T Division, who put their best efforts in this endeavors.

(Ajay Kumar)

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Optical Fiber Based Solar Illumination of Underground Mine with Simultaneous Communication Potential

Sarbojit Mukherjee[1], Dushasan Kundu[2], Shivakiran Bhaktha B. N.[3], R.N. Jha[4], A.K. Mishra[5], Arun Kumar[6]

Abstract

A novel solar energy driven illumination system for underground mines is developed and installed at Jhanjra underground coal mines, Eastern Coalfields Limited. With the help of this system bright illumination greater than 50 Lux has been achieved without the use of any electrical components in the underground mine. At the mine surface, sunlight is coupled into multimode optical fiber with the help of a lab-built solar tracker and a Fresnel lens. The ~ 300 m long optical fibers are inserted into suitable conduits and the output end of the optical fiber is lowered to the pit-bottom through the mine shaft for illumination. During cloudy days and nights, the energy generated by the photovoltaic cells is used to drive high power light sources that are coupled into optical fibers at the mine surface. The potential of this illumination system for simultaneous Li-Fi communication has also been tested. Effectively, the hybrid illumination system completely driven by solar power without the use of any electrical components in the underground mine will have immense utility.

Keywords: Optical Fiber Based Illumination, Li-Fi Communication, Light Coupler

Introduction

For generations the underground mining industry has struggled to provide adequate lighting for workers at reasonable costs [1,2]. Poor illumination in the underground mines is an occupational hazard faced by the miners and has been understood to lead to serious illness and loss of efficiency of the miner. Moreover, optimum illumination in the mines can also bring down the accidents that frequently occur in the mines due to poor lighting [3]. Today, thanks to optical fibers, mining operations can be handled in a much better and safer way by the use of solar lighting coupled through optical fiber cables resulting in improving productivity and safety.

When light enters a fiber, it travels (confined within the fiber) by total internal reflection process until it leaves the fiber at the other end. The concept of optical fiber based illumination of underground mine is illustrated by a block diagram in Figure 1. This system does not use electrical energy for illumination in the underground mines. As there is no electrical current flowing through the optical fiber cables, Corona discharge effect is also not expected to occur. An optical fiber is a flexible transparent communication medium made up of glass or polymer [4]. It is used to transmit data (light) between its two ends over long distances with minimum attenuation and higher bandwidth with no electromagnetic interference. Nowadays these fibers are playing a very important role in

[1,2,3]Indian Institute of Technology,Kharagpur, [4]Director(RD&T), [5]GM(S&T),[6]CM(S&T), CMPDI(HQ),Ranchi

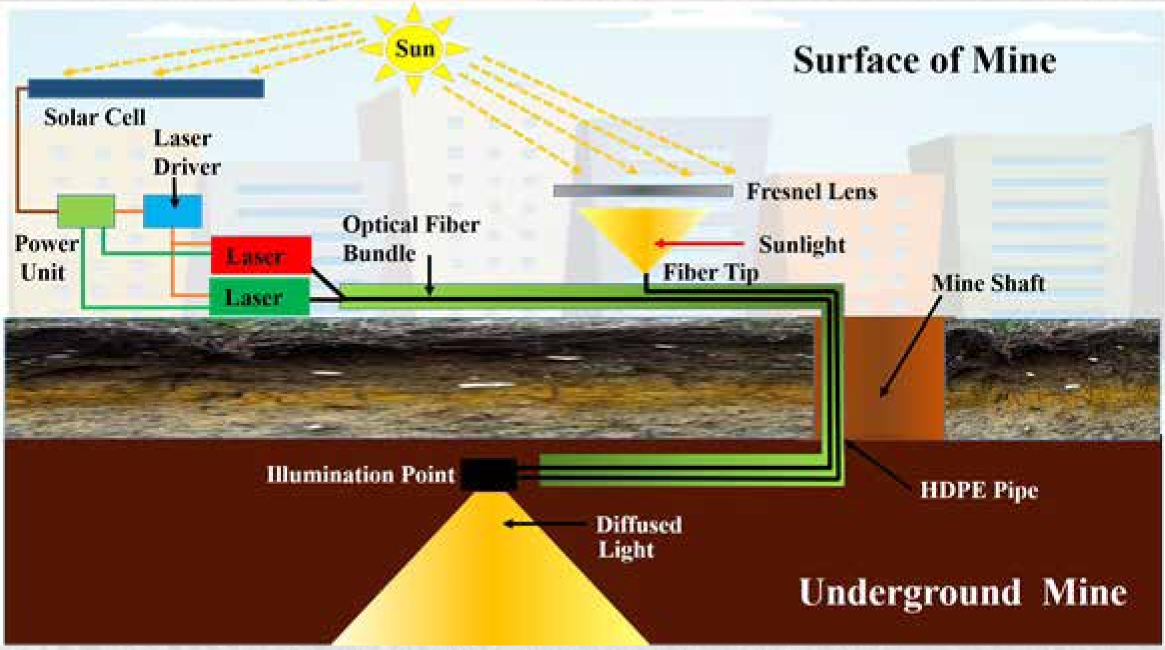

Figure 1. Schematic diagram of solar powered system designed for illumination of underground coal mine.

optical communication systems which make them superior over conventional wires. In fact, optical fibers can be used for transmitting light from a source to a remote location for illumination as well as communication [4]. The optical fibers are not only made to transmit light but also to glow along the fiber itself for lighting purposes [5]. Applications for fiber optic lighting are many, generally based on utilizing the special attributes of the fiber as well as its unique characteristics.

Optical fibers are very light in weight, easily twistable and have low attenuation (low power loss and hence low information loss). Since it is made up of cylindrical silica which is non-conductive and non-radiative, there are no possibilities of cross talk. Fibers are also resistive to high temperature as the melting point of silica is very high, i.e. ~ 1900^{o}C [6]. In summary, optical fibers are attractive for lighting remotely accessible areas.

In the context of mining too, optical fibers have played an important role. Underground coal mining automation has been quite successful by the implementation of fiber optic cable for leg pressure monitoring and performance analysis of shield supports [7]. In modern times optical fibers are used for reliable communication to monitor, analyze, and control the equipment and facilities during the normal mining process [8]. Moreover, fiber optics also serves as temperature sensors in underground coal mining [9].

Internationally, fiber optic lighting has gained importance in recent years. It is currently being used mainly for museum lightings and interior decorations as they offer tremendous flexibility as well as are the safest method of lighting valuable artefacts. Some of the museums where fiber optic lighting is in use include, The Tower of London, Kilmainham Gaol, Dublin, and the Asian Civilisation Museum, Singapore [10]. By using a remote light source located in an accessible position the need to enter a showcase is eliminated. At the Tower of London, the projectors are located in the top of the showcases. Should a lamp require replacing it can be done without opening the case and exposing the crowns to dust, moisture and most importantly risk of theft. Because fiber optics uses a lens and other optical elements to collect or to diffuse the light, it is possible to control the light distribution and intensity with a precision no other lighting system can match. Thus, the visual impact of the exhibit is further enhanced in the museums.

Finally, the use of solar fiber lighting for corporate offices and homes is being extensively researched upon and can drastically bring down the expenses involved in habitat lighting [11]. In the current context, this technology will be of immense use for underground mines wherein electrical lighting is hazardous.

The optical fiber based mine lighting function both, during the day and the night. During the day, the visible solar radiation is coupled into the optical fibers using optical couplers. To avoid heating effects in the fiber and damage of the fiber during optical coupling, wavelength selective filters, lenses and mirrors are used to filter out the infra-red radiation. The coupled visible light is transmitted to the underground mines. However, artificial illumination with the help of high-power lasers coupled to optical fibers is necessary on cloudy days and during nights, and is implemented in the study presented here.

Experiments and Results

Efficient illumination of the underground mines involves several design challenges and requires optimization of various components: (a) optical fibers, (b) light sources, (c) light couplers and (d) light diffusers. The optimization process has been carefully carried out for each of these components.

The studies were carried out on various optical fibers of varying core diameters and numerical apertures. The results obtained for coupling of sunlight using a Fresnel lens assembly comprising of a lab-built solar tracker are presented in Table 1. The light coupling efficiencies were calculated by:

$$\text{Efficiency (\%)} = \frac{\text{Output Lumen} \times \text{Area of Lux meter sensor}}{\text{Input Lumens} \times \text{Area of the lens}} \text{x}100$$

Table 1: The output characteristics exhibited for coupling of sunlight into various optical fibers, illumination efficiency and lumen per dollar per meter are compared

Fibre Core Diameter (μm)	Numerical Aperture	Efficiency (%)	Output Luminance (Lux)	Lumen /$/m
1000	0.39	4.2	210.0	9.66
1000	0.50	3.4	170.0	7.18
600	0.39	1.2	61.6	8.64
600	0.50	1.2	59.4	7.91
400	0.39	0.7	34.7	10.19
400	0.50	0.6	29.4	8.60
200	0.39	0.4	21.0	15.36

It is to be noted that the choice of the optical fibers is also determined by the longest available length in the market. The use of shorter fibers with multiple splices can lead to losses at the spliced locations.

Based on the laboratory experiments, optical fibers of core diameter 400 μm were chosen for the installation at Jhanjra underground coal mine.

Figure 2. Photographs of the optical fiber bundles embedded in HDPE pipes being spliced together in the laboratory (left), and the fiber cables being lowered through the mine shaft to the pit-bottom at Jhanjra underground coal mine (right).

The optical fiber bundles of length 150 m were procured and spliced together (Figure 2 (left)) to obtain a single optical fiber of length 300 m. Three such fibers were put together to form an optical fiber cable bundle. The fiber bundle was inserted into a high-density polyethylene (HDPE) pipe for mechanical protection. These fiber cables were thoroughly tested under laboratory conditions and then carefully lowered to the pit-bottom through the mine shaft at Jhanjra underground coal mine as shown in Figure 2.

The light from artificial illumination sources comprising of red and green lasers of wavelengths 632 nm and 532 nm respectively, were coupled into optical fibers with the help of lens assemblies. The light sources and the optical coupler unit was assembled in an enclosed box to avoid degradation of optics due to dust as shown in Figure 3 (right). However, proper ventilation was provided to the light sources in the box to avoid their malfunctioning due to heating.

Figure 4 shows the photographs of the illumination achieved using artificial light sources. Figure 4 (left) shows the image taken at the mine surface, before the optical fiber cable was installed in the mine. The yellow light which is a combination of green and red laser sources appears at the output end of the 300 m long fiber bundle. A diffuser is

Figure 3. Photographs of the solar-powered artificial light coupling system installed at Jhanjra coal mine (left). The lasers and the optical coupler assembly used for illumination are shown (right).

Figure 4. The researchers from IIT Kharagpur test the illumination system on the mine surface (left) and at the pit-bottom (right) at Jhanjra underground coal mine.

attached at the tip of the optical fiber to achieve illumination over a larger area. The Figure 4 (right) shows the photographs of the illumination achieved at the pit-bottom using the illumination system. The lumens measured at 7 feet distance from the source was ~ 50 Lux.

A light-fidelity (Li-Fi) communication module was also developed and tested so that communication can be achieved simultaneously with illumination. A working model of the optical fiber-based Li-Fi system is shown in Figure 5.

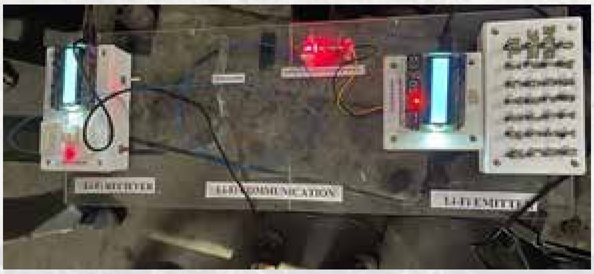

Figure 5. The Li-Fi communication setup comprising of the emitter module which transmits signal and the receiver module which receives and displays the signal are shown.

Conclusion

Solar powered optical fiber-based illumination and simultaneous Li-Fi communication system was designed for underground coal mines. The use of optical fiber-based illumination eliminates the use of electrical contacts in underground coal mines, which is advantageous for mines rich with combustible gases. Illumination of over 50 Lux at workplace was achieved using the developed hybrid illumination system. The laser sources were powered by photovoltaic solar cells mounted on the surface of the mine, leading to the development of solar-powered all-optical hybrid illumination system for underground mines. The developed optical fiber-based illumination system will be very cost effective once India starts manufacturing the large core diameter optical fibers indigenously. The developed system can also be used for illumination of underground parks, inside water reservoirs and multiple storied buildings and offices.

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NOTICE TO THE AUTHORS

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Indigenous Development of Portable Wireless Communication System for Underground Coal Mines

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Abstract

A prototype development of a communication system, having transmitter and receicer modules, for an underground coal mine is described in this article. The communication system is portable and easy to carry. The primary objective of the proposed system is to develop a wireless link from the outside of a mine to the inside in an emergency. The proposed system works in the lower VHF frequency of operation. The portability of the proposed communication system is defined based on the developed antenna at the lower VHF frequency. The communication system is tested in an operational underground coal mine and the results are recorded. The communication system is intrinsically safe as per IEC 60079-11 standards. In addition, we have followed all the necessary guidelines suggested by the Directorate General of Mines Safety (DGMS) for system development and measurement.

I. Introduction

Nowadays, wireless communication is an integral part of all most day-to-day activities for an individual and industries as well. It is a core infrastructure component of an industry that improves productivity, safety, and convenience. This wireless communication system varies based on the environmental conditions i.e., the communication system required for a deep space environment (for satellite communication) differs significantly from a free space environment (for commercial wireless communication). Similarly, the communication links (or the electromagnetic signal) are also get affected based on the type of application environment. Some application environments inherently pose challenges to develop this electromagnetic link for wireless communication. For example, wireless communication in a contemporary urban environment faces multi-path reflection and refraction, signal attenuation, distortion, and electrical interference that affect communication performance. Similarly, certain application environments demand high reliability in communication in case of accidents and emergencies. Combing these two situations is called a high-stress environment; one such environment is the Underground (UG) mine. Specifically, this article discusses communication aspects in the UG coal mine.

Before going into wireless communication in the UG coal mine it is also essential to know its importance. Mining is one of the oldest ventures of mankind. In the modern world mining still retains its importance by supporting the energy need of a country. Among all mines, coal has

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special importance in a country like India. Coal is the predominant energy source for power generation in India which supports approximately 70% of India's domestic electric production. This coal production takes place in two ways such as open cast mining and underground mining. However, UG mining is one of the most extreme situations due to the very hazardous environment. Roof fall, fire breakout due to flammable gases, wall collapse, and eruption of toxic gases are some major hazards. Any of these situations may lead to serious fatalities and in any serious accident that happens in a UG coal mine emergency communication system is required. The available wired communication would not be a suitable solution because the wire connection may get damaged during accidents and therefore it is less reliable. A wireless electromagnetic link would be a more suitable alternative in this situation, whereas it is restricted to the size of antenna dimension at lower operating frequencies and transmitted power based on the type of the UG mine environment to avoid fire breakout due to high power radiation.

Here, we have developed a portable wireless communication system having a compact antenna with low transmit power. The communication system complies with the radiated power limit as per the IEC 60079-11 standard. The system is tested initially at ISL Lab IIT Bombay at various frequency points starting from 20 MHz to 48 MHz and observed the radiated power to satisfy the intrinsically safe limit. Further, the testing of the developed system is conducted at a UG coal mine according to DGMS guidelines, and data of received signals are collected. The details of the developed communication system and test results are as follows.

II. Development of the Wireless Communication System for UG Coal Mine:

The developed communication system has two modules as transmitter and receiver. The transmitter module consists of an RF signal generator with an antenna and the receiver module consists of an antenna followed by signal analyzer as shown in Fig, 1. The schematic shown in Fig. 1 is for the laboratory testing purpose at IIT Bombay where the measurement setup for the field trial has additional power supply equipment with safety concerns. The measurement setup for field testing is discussed in the subsequent sections. The list of equipment used for the testing of effective radiated power measurement is provided in Table 1, where the antenna is designed at the IIT Bombay.

II.I. Antenna Design

The schematic of the antenna along with the fabricated prototype are shown in Fig. 2. Fig. 2(a), (b), and (c) show the front, top and side views of the antenna along the y-z, x-y and x-z planes respectively and Fig. 2(d) shows the front view of the fabricated antenna. The antenna has two layers of hemicylindrical conductive sheets providing

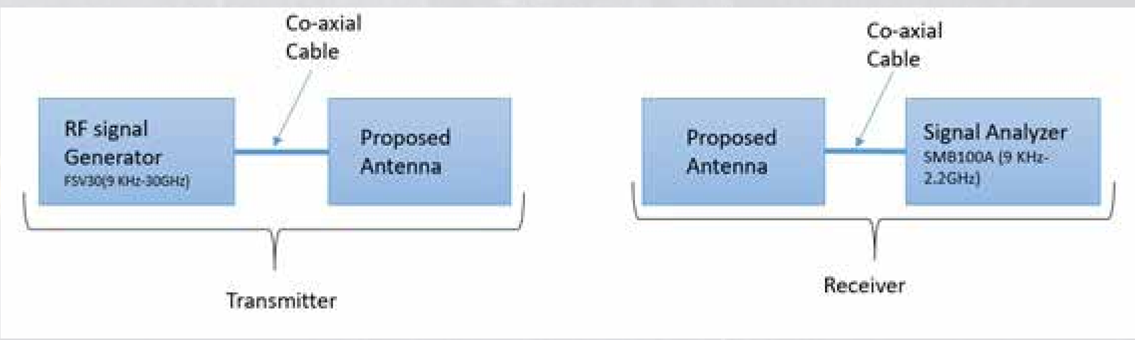

Fig. 1 Schematic representation of laboratory setup transmitter and receiver module of the developed communication system.

Table 1: The List of equipment used for laboratory testing to observe effective radiated power.

Equipment	Make	Model No.
Signal Analyser	Rodhe and Schwarz	FSV30(9 KHz-30 GHz)
Signal generator	Rodhe and Schwarz	SMB100A (9 KHz-2.2 GHz)
Software Defined Receiver	WinRadio	WR-G33DDC (9 KHz-49.995 MHz)
Two Antenna	Developed at IIT Bombay (Fig.10)	NA

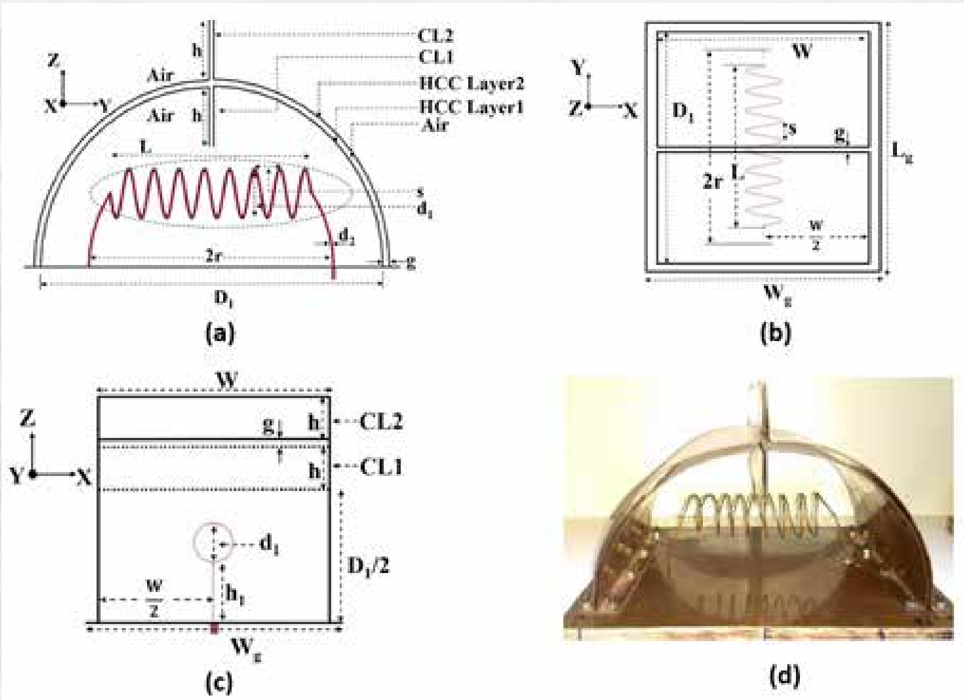

Fig. 2 ESMA antenna (a) Front View (b) Top View (c) Side view (CL= Capacitive load, HCC= hemicylindrical copper, MTL= multi-turn loop), and (d) Front view of fabricated antenna.

capacitive loading CL1 and CL2. The CL1 and CL2, as shown in Fig. 2(a), are oriented along the positive and negative z-axis respectively. The metal used for the antenna is electrolytic tough pitch copper has a conductivity of 58 MS/m. The thickness of a single conductive sheet is 1 mm. The capacitive loading CL1 and CL2 are high enough to scale down the resonant frequency sufficiently. The primary radiator is a multi-turn loop (MTL) solenoid placed at a height of h1= 38 mm (along the z-axis) over a finite metallic ground at a distance of W/2 from one of the edges as shown in Fig. 2(c), here W is the width of the hemicylindrical sheet. The solenoid is connected to a 50-ohm coaxial cable feed line. The purpose of using a multi-turn loop (MTL) is that it provides higher radiation resistance and resonant inductive coupling. The optimized design parameters for 58.27 MHz are given in Table 2. However, the antenna can work in the frequency range of 20-48 MHz by using the proper coil and loading effect without increasing the antenna effective volume.

Fig. 3 shows the specific absorption rate (SAR) evaluation, for the antenna placed near a human body voxel model, using the HFSS electromagnetic simulator. SAR value is 0.06 W/kg, which is below the threshold value of 1.6 W/kg defined by FCC i.e., the radiation from the antenna is not harmful to the human body.

Table 2: Optimised design paramater

Parameter	D_1	L	h	d_1	d_2	g	r	W	L_g	W_g
Dimension (mm)	290	165	48	38	2	4	100	240	300	300

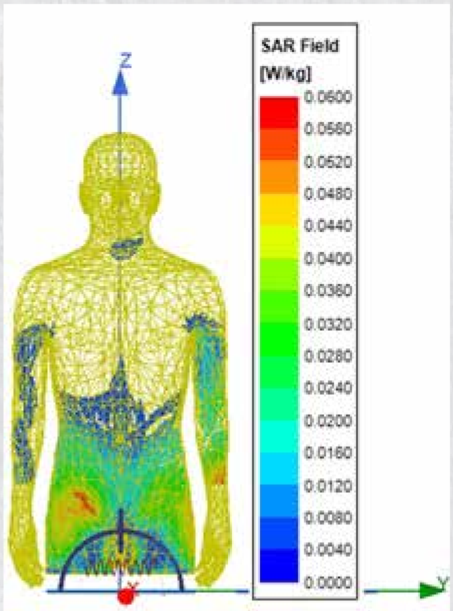

Fig. 3 Evaluation of SAR value when the antenna is placed near a human voxel model using HFSS.

II.II Measurement Procedure to compute Effective Radiated Power:

The complete communication system has been tested at IIT, Bombay. Initially, the transmitter and receiver are placed at a distance of 1 meter apart and the received power level was measured. Then, a similar procedure is continued for several distances as shown. Tables 3 and 4 provide the measured received power for various frequency points having a transmitter and receiver distance of 1m for brevity. From the measured data, we found that the radiated power is far below the threshold as per the IEC 60079-11 standards and defines the developed system as intrinsically safe.

1. Overall Antenna Volume: 300x300x190 mm^3
2. Maximum output power of Signal Generator: 1 watt =0 dB= 30 dBm
3. The noise floor level of signal analyzer/ Win-Radio SDR: -110/-120 dBm
4. Cable Loss: 0.02 dB/m (negligible)

Table 3: Measured and Calculated Parameters (Using Signal Analyser (FSV30(9 KHz-30GHz)

Frequency (MHz)	Measured ERP in receiver (P) (dBm)	Calculated ERP in receiver ($P_{milliwatt}$) (mW)
20	-23.46	$5.011x10^{-3}$
32	-10.00	100×10^{-3}
34	-30.02	$9.54 x10^{-4}$
40	-20.32	9.28×10^{-3}

Table 4: Measured and Calculated Parameters (Using WinRadio WR-G33DDC (9 KHz-49.995 MHz)

Frequency (MHz)	Measured ERP in receiver (P) (dBm)	Calculated ERP in receiver ($P_{milliwatt}$) (mW)
24	-91	7.943×10^{-10}
28	-66	2.511×10^{-7}
36	-61	7.943×10^{-7}
40	-68	1.584 x 10-7
44	-63	5.001×10^{-7}
48	-60	1×10^{-6}

Fig. 4 Laboratory measurement setup for voice/audio transmission and reception (a) Transmitter module, and (b) Receiver Module.

II. III Voice/Audio Testing in Laboratory

Further, we have conducted the wireless voice/audio testing of the complete transceiver setup. Fig. 4 and Fig. 5 show the transmitter and receiver modules respectively indicating the important equipment. An audio signal and after that a voice signal were transmitted via wireless media from the transmitter using FM modulation and the respective audio and voice outputs are received at the receiver section successfully.

Fig. 5 Inspection of mine map to locate the positions in mine map for testing.

III. Field Trial

The field trial of the developed communication system is conducted at Bhurkunda Colliery, UG coal mine of CCL after taking approval from the DGMS. Accordingly, the field trial is conducted in two phases. In the first phase, the transmitter was kept outside the mine and the receiver was kept inside the mine. In the second phase, the field was conducted by replacing the transmitter andre-ceiver positions. The test setup for each field trial and their corresponding test results are as follows:

III.I Test Setup for phase 1 field trial

1. Transmitter module (Surface station)
   - Antenna
   - Co-axial cable
   - N-type male to SMA female adaptor
   - N-type male to SMA male adaptor
   - Transmitter (RF Signal generator)
   - Connecting wires
   - Power supply
2. Receiver Module (Underground Station)
   - Antenna
   - Co-axial cable
   - N-type male to SMA male adaptor
   - Software-defined radio (SDR) with display
   - Connecting power cable
   - DC to AC converter
   - Battery

III.I.II Test and Observation:

- The transmitter was placed at the surface station and the receiver was placed at various positions w.r.to the surface station.
- The signal was transmitted from the transmitter and the corresponding signal was received at the underground station. The details of the testing done are mentioned in the result and discussion section.
- The dimensional variation of the entry of the mine was observed. The UG mine entry was gradually tapered towards the position of actual coal seems to start. A continuous fall of water was observed at the mine entry.
- The UG mine was in tunnel shape with wooden supports to provide mechanical strength to the mine.
- The roof and walls of the UG mine tunnel were very rough. The mine was continuously inclined towards the end.
- Wooden pillars are kept every 25-30 meter distance apart starting from the entrance of the mine toward the end.
- Fig. 5 depicts the pre-testing inspection of the mine map to locate the location inside the mine for testing.

Fig. 6 Measured signal level at an approximately 60-meter distance from the entrance (at the 2nd pillar).

Fig. 7 measured signal level at an approximately 90-meter distance from the entrance (at the 3rd pillar).

Fig. 8 measured signal level at approximately 120-meter distance from entrance (at the 4th pillar).

Fig. 9 measured signal level at approximately 150-meter distance from the entrance (at the 5th pillar).

Result and Discussion

Fig. 6 to Fig. 9 show the received signal level at various locations inside the UG test mine. The transmitted power from the transmitter was kept at 0.5 watts (maximum instrument limit). The irregular variation of received signal power levels is observed and it can be seen in Fig. 6 to Fig. 9. This irregular variation of the power level indicates that this EM wave transmission is a completely different form through the air or free space condition where the received signal level decreases monotonically with path length i.e. received power is inversely proportional to the square of the distance. It can be inferred that the EM wave propagation was affected by UG coal seems property and UG environmental conditions. The proposed communication system was designed considering the North American coal mine conditions as there is no such study on the electrical property of Indian coal mines available. The received signal was a very narrow band noisy signal, which needs an advanced signal processing algorithm to get clarity. The developed system is portable, lightweight and low cost, and most suitable for Indian coal mines.

III.II Test Setup for phase 2 field trial:

1. Transmitter module (Underground station)

- Flameproof box (FLP)
- Antenna
- Co-axial cable
- N-type male to SMA female adaptor
- N-type male to SMA male adaptor
- Transmitter (RF Signal generator)
- Connecting wires
- Power supply using UPS

2. Receiver Module (Surface Station)

- Antenna
- Co-axial cable
- N-type male to SMA male adaptor
- Software-defined radio (SDR) with display
- Connecting power cable
- Power supply

III.II.I Test and observation

Initially, the test setup has installed at the underground (UG) station and the surface station. The test setup has two modules i.e. the UG transmitter module and surface receiver module. The underground station contains the FLP, power supply using UPS, RF signal generator, cable, and antenna. The input supply voltage to the RF signal generator was 240V. The stable rechargeable UPS power supply was used to give input to the RF signal generator. Except for the antenna all other transmitter equipments were kept inside the FLP. The underground test setup is shown in Fig. 10. Similarly, the surface station contains a power supply from the surface, an antenna, a win-radio high-sensitive receiver, and a laptop for display. The receiver was kept outside the mine. Fig. 11 shows the surface station test setup.

Fig. 10 Transmitter setup for the underground station (the photograph is taken outside mine before installation inside mine) (a) Complete transmitter setup with FLP(b)FLP containing RF signal generator and power supply (UPS) (c)Side view of FLP showing the cable.

Fig. 11 Receiver setup for a surface station

Result and Discussion

The testing of the developed communication system was started from the 2nd pillar (approx. 60 m) and moved up to the 5th pillar (approx. 150m) inside the UG mine. Fig. 12 to Fig. 15 show the received signal level at various locations inside the UG test mine. The transmitted power from the transmitter was kept at 0.5 watts (maximum instrument limit). The received signal strengths were respectively -100 dBm, -91 dBm, -90 dBm, and -101 dBm from the 2nd pillar to the 5th pillar as shown in Fig. 12 to Fig. 15. The signal strength at the 2nd pillar was found weak. This is because of the two reasons such as bending of path at 2nd pillar and the mine strata structure. The irregular variation of received signal power levels is observed and it can be seen in Fig. 12 to Fig. 15. This irregular variation of the power level indicates that this EM wave transmission is a completely different form through the air or free space condition where the received signal level decreases monotonically with path length i.e. received power is inversely proportional to the square of the distance. It can be inferred that the EM wave propagation was affected by UG coal seems property and UG environmental conditions.

Fig. 12 Measured signal level when transmitter at the 2nd pillar (approx. 60 meters).

Fig. 13 Measured signal level when transmitter at the 3rd pillar (approx. 90 meters).

Fig. 14 Measured signal level when transmitter at the 4th pillar (approx. 120 meters).

Fig. 15 Measured signal level when transmitter at the 5th pillar (approx. 150 meters).

Conclusion

The project is completed successfully with a series of discussions, documentation, lab tests, and field trials. In this project, a novel electrically small portable antenna for underground coal mine communication is developed. Two of such antennas are integrated with the transmitter and receiver module. Various lab testing of the developed prototype is conducted at IIT Bombay. The lab testing includes the transmission and reception of electromagnetic signals as well as the audio/voice signal using the developed prototype. The developed communication system is intrinsically safe and developed as per the DGMS guidelines. Rigorous testing and documentation are prepared to get the DGMS approval for field testing of the developed communication system. As a result, DGMS approval is received for the testing of the receiver module inside the mine to detect the signal transmitted from the outside of the mine and vice-versa. The test results were satisfactory and the receiver which was placed inside the coal mine could able to receive the signal transmitted from the outside of the mine. Similarly, satisfactory results were obtained while keeping the receiver outside and the transmitter inside the mine.

The developed communication system targets the application of emergency mine communication. The complete system is portable, and the miners can easily carry it inside the mine. The database generated out of this work such as portable antenna design technique for UG mine, lab testing of the transmitted and received power for the various operating frequencies to justify intrinsic safety of the system as per the DGMS guidelines, system integration, and the field measurement, etc. would help to study them and develop a more advanced communication system concerning the Indian coal mines.

Enhancing the Life of De-watering Pipes in Coal/Lignite Mines by Prevention of Erosion-Corrosion with Nano-Crystalline Surface Engineering Treatments

Dr. C. Sendil Kumar[1], Dr. S.P.Kumaresh Babu[2], Milan Sen[3], Arun Kumar[4], Somesh Kumar[5]

Abstract

In this project many surface engineering treatments were explored for enhancing the life of pipeline under mining conditions. Systematic Corrosion and Erosion studies simulating the mining environment were created. A total of nine different coatings where chosen for study based on literatures and field experience. These nine coating on the pipe material were coated using the best practices available on the field. The coated specimen was subjected to the simulated mild to harshest mining environmental conditions. The behavior of the coated specimens to the harsh environment were studied using best evaluating technique known in the material science like electro chemical analysis, scanning electron microscopy etc. The results were taken and optimized for lowest cost condition both in implementation and maintenance as the net outcome would imply for the entire pipeline used within the service range of coating. The cost optimization leads to field trial of the resulting coating.

The three stage field trial were executed and evaluated. First field trial of coating was performed on a single length pipe. The single compound polyurea coatings were developed and used for phase-I field trial. Due to its higher setting time and heavy texture coating showed signs of sagging defects of the coating. Even with these defects the coating was found to perform satisfactorily in evaluation and showed no sign of wear. Learning from the first field trial two compound systems were developed to avoid the setting time lag. The phase-II field trial coatings were performed on three pipe length and came out very satisfactorily after coating and evaluation. Similarly, third Field trial coating was performed with two compound systems with additional TiO2 additive for enhanced wear resistance by the laboratory tests. A total of 13 length of pipeline were coated satisfactorily and deployed in mines.

Phase-I field Trial coating:

Single component moisture curable polyurea on the inside surface of a 4.0 meters length of Fe410 grade 24” dia SWC pipe coating was performed on 8/12/2014 at Mines -II/pipeline yard by M/s. Nistala Pvt Ltd, Hyderabad. The coating thickness was measured throughout the inside surface of the pipe and found in the range of 250-350 microns and tabulated in the table.1

[1]NLCIL,Neyveli, [2] NIT-T,Trichy, [3,4,5]CM(S&T), CMPDI(HQ),Ranchi

Evaluation of phase-I field trial:

The evaluation was carried out for the coated pipe deployed in Mines. The inspection was done on 13.05.2015. The Coating was found intact with no reduction in thickness of coating even after 151 days of service. The results of the evaluation are tabulated in table: 1 to 3.

Phase-II field trial coating:

Two component system polyurea coating was carried out in 24” dia pipe and deployed in Mine-II at different location during Oct-2015. This work was carried out at Neyveli site. The coating was carried out from 3/07/2015 to 12/07/2015 on 24"dia. 2 No’s of pipes of length of 2.75 m and 5 m length. Ends of pipes were welded and fitted with 16 mm thick MS flanges with 24" inner dia, as per pipeline welding procedure with stiffeners. The coating composition and mixture were monitored and prepared as per the literature to form two component system and were blended in 2:1 ratio.

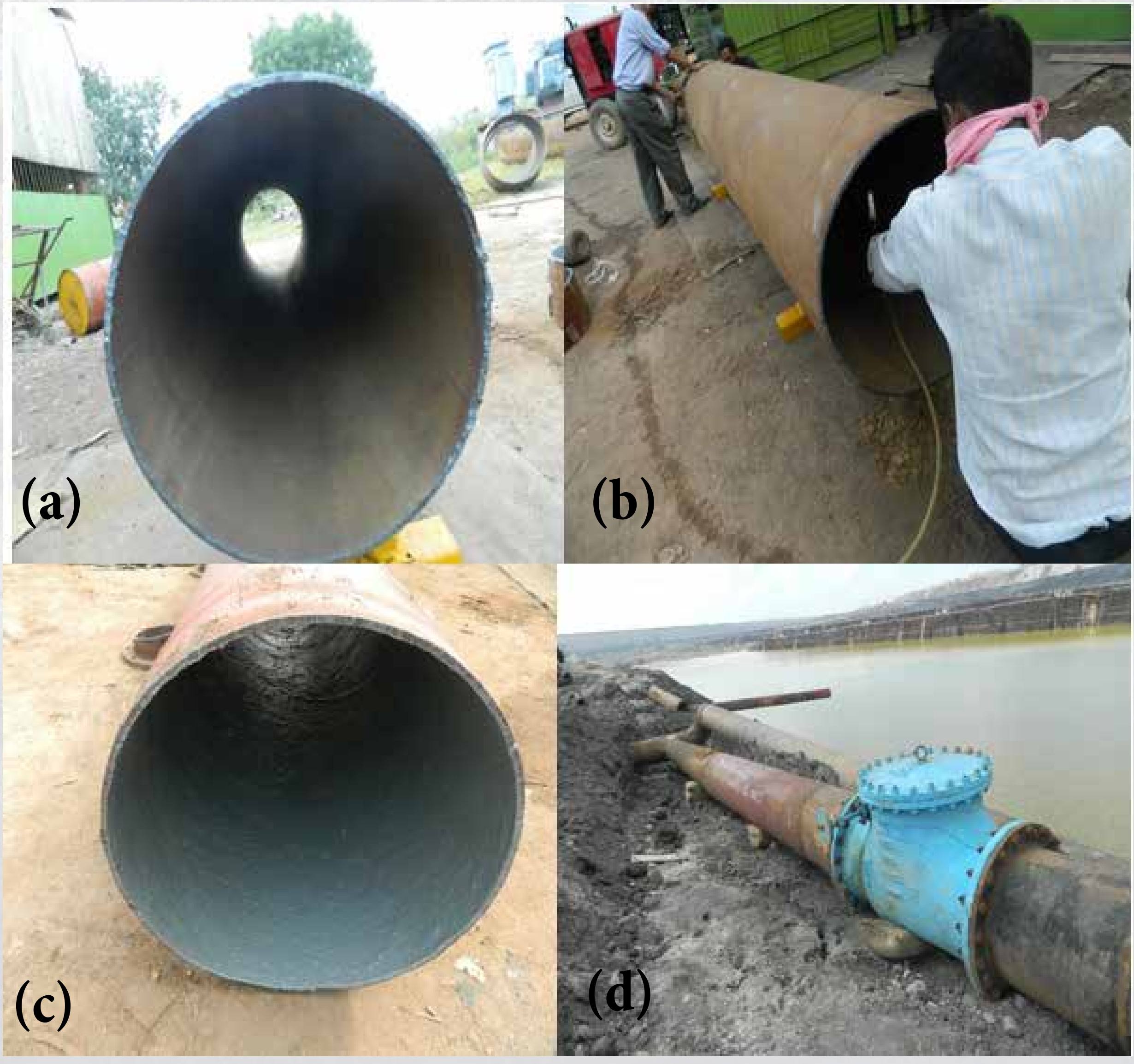

Fig. 1 Phase-I field trial: (a) Before coating (b) spray Coating (c) after coating (d) pipe being deployed in mainline

Table: 1 Field Trial Phase-I pipe coating evaluation after 151 days in the field service in microns.

Ends of the pipe \ Readings	1	2	3	4	5	6	7	8	9	10
Left end	290	278	288	358	318	250	272	265	280	310
Right end	252	321	248	298	322	305	310	300	288	322

Table: 2 Field Trial Phase-II pipe-I coating evaluation after the field service in microns.

End of the pipe \ Readings	1	2	3	4	5	6	7	8	9	10
Left end	390	383	378	358	338	352	388	369	370	374
Right end	282	321	348	299	322	291	325	355	277	379

Table: 3 Field Trial Phase-II pipe-II coating evaluation after the field service in microns.

End of the pipe \ Readings	1	2	3	4	5	6	7	8	9	10
Left end	340	298	288	353	368	345	371	381	364	370
Right end	354	321	348	294	352	286	311	358	298	312

Fig. 2 Phase-II field trial :(a) Before coating (b) After Coating (c) Pipe-I being deployed in mainline (d) Pipe-II being deployed in mainline

Fig. 3 Phase-II field trial :(a) Pipe-II taken out from mainline for inspection (b) Pipe-II is being washed and cleared of debries (c) the coating was found intact (d) Pipe-II is being deployed back to the mainline

Table: 4 The coating thickness values in microns.

Sl. no.	Left end	Mid end	Right end
Pipe-1	1027	982.14	1068.66
Pipe-2	1029.3	1102.4	1082.7
Pipe-3	971.7	1031.5	1035.4
Pipe-4	1048	1031.66	1006.81
Pipe-5	988.72	995.90	948.58
Pipe-6	998.83	852.63	996.09
Pipe-7	1063.5	931.7	1056.7
Pipe-8	963.5	984.16	1013.2
Pipe-9	930.8	999.66	1007.5
Pipe-10	970.77	968.2	1021.6

Evaluation of phase-II field trial:

The coated pipe of length 2.75 m and 5 m were deployed in mines-II on 13.10.2015 at 2500 and 2800 Bunds/Mines-II respectively. The evaluation of the coating was conducted on the pipe-I, pipe-II on 22 & 23.01.2016. Pipe-I & II results are tabulated in table: 4.

Fig. 4 Phase-III field Trail:(a) polyurea III coated pipes (Internal),(b) polyurea III coated pipes (Internal and external), (c) Movable Spray gun,(d) polyurea III coated pipes deployed in pipeline system

Phase-III field trial coating:

For further evaluation to establish the results, Phase-III coating are planned in the month of July 2016. The tender was floated during April 2016, as per the specification given in table 5. The contract was awarded to the successful bidder for carrying out Polyurea Phase-III coating (about 120 m). The coating work was completed on 05.08.2016 for 10(Int)+3(Ext) pipe lengths. The coating thickness was measured on 5th August 2016 and the average thickness of the coating was around 1000 microns. The coated pipes of each 5 numbers were deployed in Mines-II at 2900 bund and Mine-1A at 600 bund during 8th to 10th August, 2016.

Cost Benefit Analysis:

NLC is operating with three lignite mines at Neyveli. The total pipeline systems running for dewatering purpose are about 125 km length. The average life of the pipes comes around for 2 years. The 20% of existing pipes are being replaced every year which leads to huge replacement cost. The recommended coatings are used for dewatering pipes will enhance the life of the dewatering pipes. The Cost Benefit was estimated as Rs 480/- per meter per year.

Recommendation from the project:

The polyurea coating was developed keeping harsh mining environment in consideration, hence it is a robust coating to resist corrosion attack. Neyveli mining environment had a range of mild to harsh conditions. The coating is found very satisfactory in service. This coating is being recommended to be used in all de-watering steel pipeline under wide range of 2 to 12 pH conditions and 3-5% slurry condition.

The Polyurea coating specification is given in the table below:

Table: 5 Detail specification of Polyurea coating, Part A- Polyisocyanate+ TiO_2; Part B- Polyamine

Product Specification- Two component product		
Characteristic	**Specification**	
	Part-A	**Part-B**
% of Solids by weight	100%	100%
Mix Ratio	1:1 by Ratio by volume (A&B)	
Application	Two component spray equipment	
Properties		
Property	**Value**	**Test Method**
Tensile Strength	15 n/sq.mm	ASTM-D 638
Adhesion	8 n/sq.mm	ASTM-D-4541
Recoverable elongation	50%	ASTM-D-638
Surface Hardness	50 (Min)	Shore D
Operating Temperature	-55 deg c to +55 deg c	Passes
Impact Resistence	252 kg cm	ASTM-G-14
Tear strength	181 pl 1	ASTM-D-624
Abrasion resistance (taber abraser h-10)	39 mg	ASTM-D 4060
Flexibility	Passes	ASTM-D 1737

Additive TiO_2 particles 2-6 wt % enhances hardness to wear

Study of Techno-Commercial Efficacy of ANFO with Low Density Porous Prilled Ammonium Nitrate for Blasting in Overburden of Coal mines

Rajat Mukherjee[1], R.K. Singh[2], Manoj Kumar Jha[3], Arun Kumar[4], Somesh Kumar[5]

ABSTRACT

In CIL, over 80% of the total coal production is achieved through opencast mining which requires large overburden removal. This operation consumes large quantity of explosives. Out of the total explosive consumption, 85% share is that of Bulk Explosives (SME) & the balance requirement is met using non-permitted large diameter explosives. However, ANFO (with porous, low density, thermally stabilized, prilled ammonium nitrate) is not used in CIL mines. Very limited use of ANFO was done in the past in Indian coal mines but no techno-economic feasibility studies were conducted. ANFO basically consists of prilled Ammonium Nitrate (94.2%) intimately mixed with Fuel Oil (5.8%) by weight. Several significant technological advances in the properties of prilled AN have been incorporated in recent time.

Worldwide ANFO is extensively used (around 70%) in various forms of mining to achieve techno-economic efficiencies. However, the complexity of the modern ANFO explosive requires good understanding of its various technical aspects, which needs to be systematically investigated to parameterize their physical & chemical properties on the overall blasting operation. The knowledge of the relevant properties of the ANFO explosives & its raw material plays a pivotal role to achieve the best blast performances.

In the absence of any published systematic research study done with ANFO explosives in CIL Mines, a thorough study/research was initiated to realize the efficacy of ANFO explosives particularly in Indian geo-mining condition, vis-à-vis SME explosives.

1. Introduction

The breakage of rock to excavate minerals is done mostly by using blasting. The consumption of explosives has increased from 7,22,021 Metric tons in the year 2011-12 to 12,11,727 metric tons in 2016-17 (Source: PESO annual reports), which is almost a 67% increase over a five year period. The demand of explosive for blasting is witnessing a tremendous increase in mining industry.

In CIL, over 80% of the total coal production is achieved through opencast mining which requires large OB removal. This operation consumes large quantity of explosives. Out of the total explosive demand, 85% is met through Bulk Emulsion

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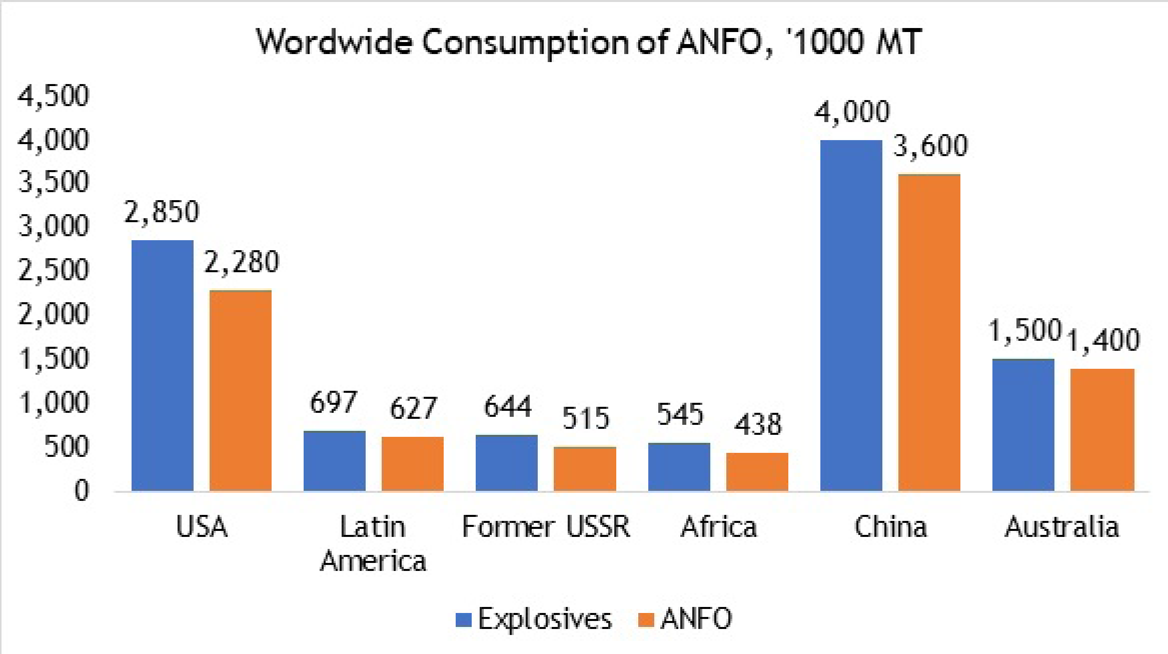


Explosives (SME) & the rest through non-permitted large diameter explosives.

However, ANFO (with porous, low density, thermally stabilized, prilled Ammonium Nitrate) is not used in CIL mines on a wider scale. ANFO has been used in Indian coal mines in a limited manner in the past, but no techno-economic feasibility studies were conducted.

ANFO basically consists of prilled Ammonium Nitrate (94.2%) intimately mixed with Fuel Oil (5.8%) by weight. Several significant technological advances in the properties of prilled AN have been incorporated in recent time.

Worldwide ANFO is extensively used (around 70%) in almost all forms of mining to achieve optimized blasting because of its techno-economic efficacy. However, the complexity of the modern ANFO explosive requires good understanding of the same & its various technical aspects which are required to be systematically investigated to parameterise their physical & chemical properties on the overall blasting operation with standard quality ANFO.

The knowledge of the relevant properties of the ANFO explosives & its raw material plays a pivotal role to achieve the best blast performances. A good knowledge of explosive characteristics of the ANFO to be used for blasting is essential for optimum blast results with due regard to safety.

In the absence of any published systematic research study done with ANFO explosives in India, a thorough study/research was required to realise the efficacy of ANFO explosives particularly in Indian geo-mining condition of CIL mines, vis-à-vis SME explosives. In this context, ANFO explosives is successfully & widely used in all types of mines, namely iron ore, manganese, limestone, chromite, bauxite, phosphate, copper, zinc, uranium, aggregate (building stone), ballast, etc.

1.1 Objective

The purpose of this R&D project was to find out the techno-economic efficacy of ANFO explosives, with low density, porous, thermally stabilized, Prilled Ammonium Nitrate in CIL mines, vis-à-vis other conventional explosives like SME (Slurry Mixed Emulsion - column charge explosives), in terms of Powder Factor (PF), post blast analysis etc. for its tangible and intangible benefits with field trails in dry blast holes. Accordingly, the main objectives of the project are listed below.

- To develop a new blasting process with ANFO, having lower cost and better fragmentation.
- Reducing the overall effort and cost involved in blasting in coal mine.
- To quantify the benefits of ANFO with respect to fragmentation & cost, utilizing modern measurement methods
- To measure and compare other blast related parameters such as vibration & noise.

1.2 Scope

This R&D project was to find out of techno-economic efficacy of ANFO explosives, with low density, porous, thermally stabilized, prilled Ammonium Nitrate in CIL mines, vis-à-vis other conventional explosives like SME (Slurry Mixed Emulsion - column charge explosives) on the dry benches of large opencast coal mines in India in term of cost, vibration, time consuming, burden relief rate, Velocity of detonation etc. Accordingly, the main objectives of the project are listed below:-

- Adequate number of trial blast with ANFO & SME, in similar blast design and geo-mining conditions.
- In-hole VOD measurement (to find out confined VOD of explosives) & run-up speed and time (in-hole VOD profile), both for ANFO & SME column explosives.
- Primer sensitivity & run-up VOD against differentprimer percentages, both for ANFO & SME.
- Blast analysis by high-speed photography.
- Near-field & far-field vibrations for typical blast designs.
- Collection, analysis & compilation of existing blast data.
- Tangible & intangible benefits

1.3 Introduction of Mine

Durgapur O/C mine is situated in Chandrapur district of Maharashtra state about 160 Km from Nagpur city, DOC Mine is well connected by rail & road, being located very near to district town of Chandrapur. Tadoba road passes through the western side of DOCM. The nearest railway station is Chandrapur on Delhi-Chennai broad gauge main line, central railway is approx. 7 KM from DOC Mine. The DOC Mine is bounded by Latitude of 19°-59'-41'' to 20°-01'-14'' and Longitude of 79°–19'-16'' to 79°-19'-58''as per Topo sheet no 55 p/8- 56m/5 Survey of India. Durgapur O/C Mine is bounded by Durgapur Rayyatwari Colliery on South, Padmapur O/C Mine on North, forest land on East, & Durgapur village on the West.

2. Overview of Study

Explosives are vital and indispensable in the mining of every mineral, whether it is coal, iron ore, copper, bauxite, or any other. Worldwide explosives demand is driven by economic development, energy and base mineral requirement. The mining industry is heading towards a technology driven optimisation process. This process is expected to continue and accelerate further in future under the pressure of competitive environment of global market. The development and advancement of innovative technology is essential for the mining industry to become cost effective so that information can flow back in order to ensure continuous improvement in the blasting process. The last decade has also seen a dramatic progress in the advancement of blasting technology as well as the quality and performance of explosive products. Monitoring instruments, measurement technique and computing tools have become indispensable in the blast design exercise. The performance and reliability of explosives and initiation systems have reached such a level that allows distribution and sequencing of explosive energy to be carefully controlled. Emulsion explosives have been accepted globally as one of the safest and efficient explosives. Performance of explosives are dependent on numerous factors. Some of the factors are internal such as chemical composition while few are external during processing, manufacturing, storage, handling and usage.

Ammonium nitrate (AN)-based explosives exhibit non-ideal detonation behavior, and their physical properties can vary greatly for the same production process at the same facility. This combination makes analytical solutions nearly impossible and limits the ability to obtain repeatable experimental results. The importance of ANFO as an industrial explosive due to cost and ease of use has prompted a large amount of work attempting to quantify the influence of physical properties (parameters of the explosive) to the detonation properties (parameters of the explosion).

Blasting is the controlled use of immense energy of explosives to break the rock for its efficient excavation. The explosives is a reactive chemical substance that contains a large amount of potential energy that on sudden release can produce an explosion, usually accompanied by the production of kinetic energy, light, heat, sound, and pressure. (Ammonium nitrate fuel oil (ANFO), Slurry and Emulsion explosives). Sanchidrian et al. (2007), Ouchterlony et al. (2003), Hamdi (2008) conducted extensive work in an attempt to quantify the energy components in rock blasting. In doing so, some useful equations were identified. The first equation, and likely the most important, is the energy balance equation expressed as:

$$E_E = E_F + E_S + E_K + E_{NM}$$

Where as:

E_E is the total explosive energy,

E_F is the fragmentation energy,

E_S is the seismic energy,

E_K is the kinetic energy and

E_{NM} is energy forms not measured such as air blast and heat

Understanding the basic principles of rock fragmentation by explosive charges is crucial for ground vibration assessment and optimizing successful blasting operation. According to Persson (1978), 1-20% of the energy of a detonated explosive charge, and also according to Langefors and Kihlstrom (1963), Duvall (1966) 5-15% is transferred to the surrounding rock as shock waves. The remaining part of the explosive energy released as very high pressure and temperature gaseous products of the reaction. Kutter and Fairhurst (1971) indicated that there are three zones of varying destruction and deformation around the explosion.

These zones are-

- the strong shock zone or hydrodynamic zone,
- the non-linear zone, and
- the elastic zone.

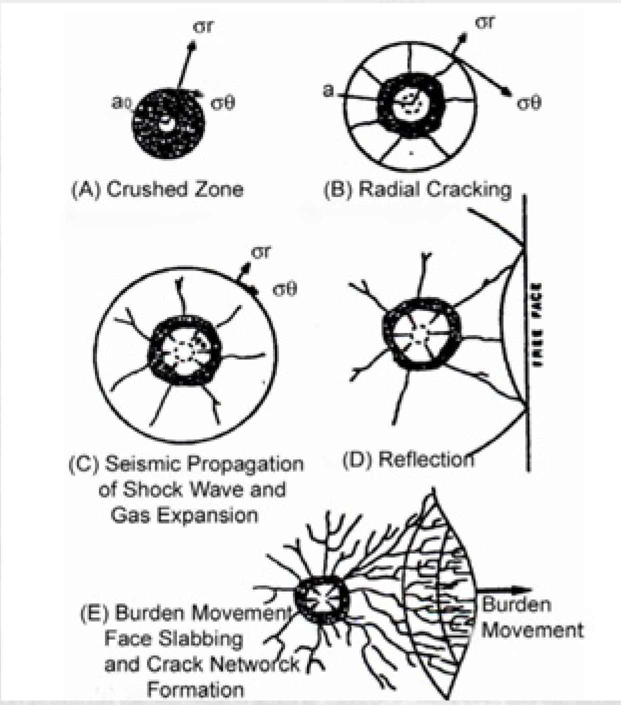
In the first zone, the radial compressive stresses generated from the shockwave exceed the dynamic compressive strength of the surrounding rock and develop complete crushing as rock fail in compression. In the second zone, fracturing is due to the tangential stress. Since the tensile strength of the rock is not very high, the tangential tensile stresses create fractures. When the strain wave reaches the free surface of the rock, it is reflected and may cause spalling.

2.1 Mechanism of Rock Breakage

Blasting theory is one of the most challenging, and astonishing areas of Explosives engineering. Rock mass damage due to blasting is directly related to the level of stress experienced by the rock mass and its pre-blasting condition. The damage due to blasting is the combined effect of stress wave and gas pressure. This type of damage is a function of blast design characteristics as well as the rock mass characteristics. The mechanism of the initiation system and formation of cracks along the pre-split line was studied widely by (Chiappetta et al., 1987; Konya, 1990; Clark, 1987). Although the rock fails under tensile stress, the cracks are formed gradually by crack extension and propagation. Stress concentration is the very important part in the control direction of propagation (Jiag, 1996). The explosion load exerted at the weak planes such as joints and bedding planes in sharply attenuates and does not break rock masses. These weak planes may produce the internal damage of rock masses and reduce their load-bearing capacity and stability. In surface blasting operation, the effect of blasting area has been difficult and yet not solved (Zang and Chang, 1999). Thus, it is important to study the micro cracking mechanism for blasting in rock masses and simulation. This result will contribute to selection of blasting parameters. The mechanism of rock breakage depends mainly on rock mass properties, physico-mechanical aspects of rock and environment related to mining operations etc.

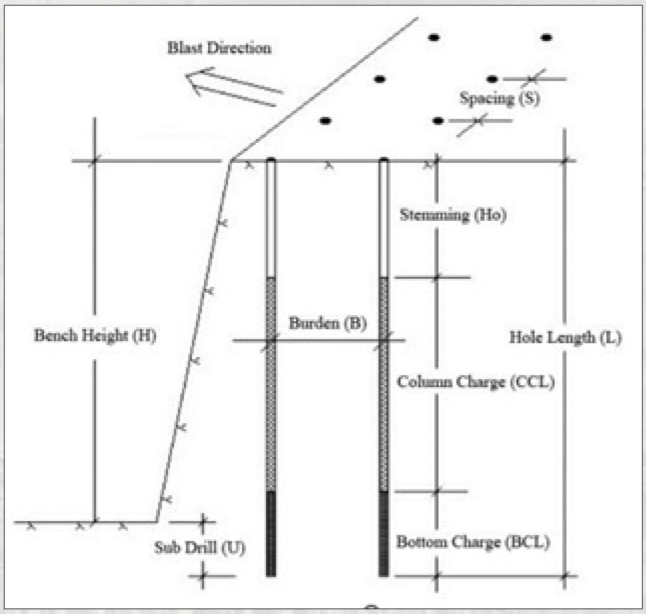
However, the way rock is broken by explosive loading is very complex and is not yet fully understood (Fourney, 1993). The sequence of the activities that take place during blasting is as given in Figure:

Where,
ao : Borehole radius
σr : Radial stress component
a: Equilibrium borehole pressure
σθ : Tangential stress comp



2.2 Bench Blasting

The main purpose of bench blasting is to facilitate the fracturing and moving of the intact rock mass so that it can be loaded, hauled and further processed in an easy and efficient way. In bench blasting, there are two types of parameters which influenced the fragmentation of rock. The first is non-controllable parameters and second is controllable parameters. Non-controllable parameters are geological properties, rock mass characteristics, specifications as well as the distance to the nearest structures. Controllable parameters are blast design parameters, firing sequence, explosive parameters, and blast design patterns etc.



2.3 Explosives

An explosive is a solid or liquid substance, alone or mixed with other substances, which on the application of suitable stimulus to a small portion of the mass, is converted in a very short interval of time into another more stable substances predominantly gaseous, with the development of large heat and pressure. There are fundamentally two different kinds of explosive materials, single explosive, and composite explosive mixtures. Single explosives are chemical substances that contain all the compounds needed for an explosion. A composite explosive can be a mixture of two single explosive substances, a mixture of a fuel and an oxidizer, or an intermediate mixture containing one or more single explosive substances together with fuel and oxidizer ingredients.

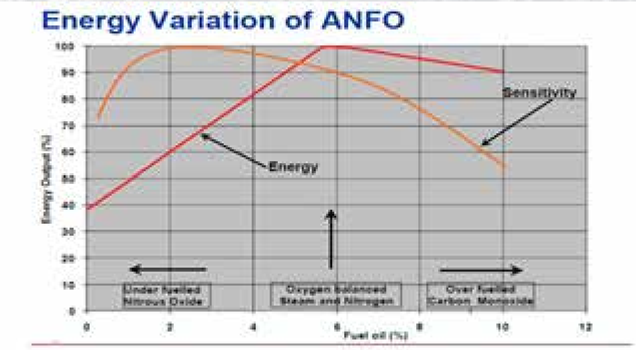
2.4 ANFO

The word ANFO is an abbreviation of Ammonium Nitrate and Fuel oil. The Ammonium Nitrate is the form of a porous prill and the fuel oil is diesel fuel or distillate. Other carbonaceous fuels have also been used from time to time instead of fuel oil. This include pulverised coal and sump oil fuel which has the advantage of being cheap, readily available, easy to mix and is readily absorbed by the AN prill. The chemical reaction of Ammonium Nitrate (AN) and Fuel oil may be represented as following:

$$3NH_4NO_3+CH_2 \rightarrow 3N_2 +7H_2O+CO_2+3.78 \text{ MJ/kg}$$

Based on the above reaction, it is clear that the most widely used ANFO product is oxygen balanced, free flowing mixture of about 94.5% AN prills and 5.5% diesel oil. Properties of ANFO:

Properties of ANFO	
Density (g/cm^3)	0.82
Energy (Kcal/Kg)	883 (High Heave Energy Potential)
Typical VOD (m/s)	2500 – 4500
RWS %	100
RBS %	100



2.5 Blast Performance Measurement

2.5.1 Fragmentation Assessment

The well fragmented rock is one that which needs no further treatment after blast and the desired size can be different if the blasted rock is to be transported to the dump area then if it has to be sent to the crusher.

The oldest theory of Rittinger (1867)(Nielsen 1983) states that energy consumed in size reduction is proportional to the reduction in particle size. Hence,

$$W = K_R \,(1/D_1 - 1/D_2)$$

W = Energy input of size reduction; D_1=Initial particle size; D_2=Final Particle size, K_R=Rittinger's constant

3. Site Selection

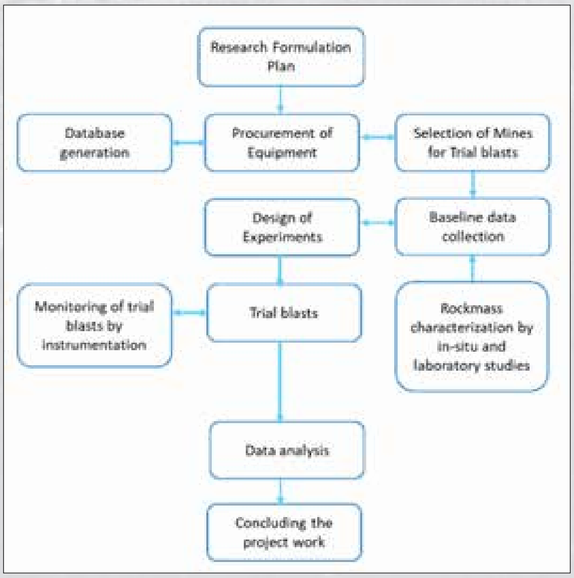
For execution of the trial blasts, field visits to Durgapur OCP, WCL were carried out in the months of October 2019 to January 2020. Data has been generated during blasting practices by SME as well as ANFO. Comparative study has been done regarding drilling, blasting and mucking-operation and performance for equipment in the shovel benches at Durgapur OCP. The DOC Mine is bounded by Latitude of 19º 59' 41'' to 20º 01' 14'' and Longitude of 79º 19' 16'' to 79º 19' 58''as per Topo sheet no 55 p/8- 56m/5 Survey of India.

A.) Geology

Detailed exploration in Durgapur-Motaghat Block reveals the existence of Composite Seam with 2 split sections. The roof of the potential Top Section/Combined seam occurs in the depth range of 18.74m (MWPD09) to 175.36m (MWDD05) as per the boreholes drilled in the block.

In Durgapur-Motaghat Block, the stratigraphic thickness of Top Section varies from 4.82 m (MWDD06) to 8.52 m (D15) and thickness of Bottom Section varies from 7.00 m (CMWDU07) to 11.47 m (D34) whereas the same for Combined Seam varies from 14.26 m (MWPD15) to 19.99 m (D45). Thickness of Top + Bottom Section (excluding intervening parting) varies from 13.24 m (CMWDU07) to 17.51 m (D112). The roof of Top Section in D34 is deteriorated to carbonaceous shale resulting in reduced seam thickness. The parting between Top Section and Bottom Section varies from 1.17 m (D08) to 3.55 m (D36). General parting range is between 1.50 m to 2.50 m.

B.) Methodology



Durgapur OC Image

C.) Equipment & Instruments

DataTrap II™ Data (VOD Recorder)

Instantel Micromate

Handi Trap-II

VOD Meter & Delay-Timer

High Speed Camera

Other Tools:
Motion and Fragmentation Analysis Software, Handheld GPS device, Handy cam, Delay Timer & VOD meter ,Digital camcorders and Digital High Speed Camera.

4. Baseline Study

Baseline study was done with following objectives:

- To study performance of mucking operation due to blasting from SME and ANFO.
- To estimate the overall powder factor and average cost of drilling and blasting per round of blast SME and ANFO.
- To determine the average cost of one cubic metre OB due to blasting from SME and ANFO.
- To determine the PPV due to blasting from SME and ANFO.
- To determine the burden relief rate due to blasting from SME and ANFO

4.1 Laboratory Test

- The physical/chemical properties of ANFO have been determined in the laboratory.
- Characteristics of prilled Ammonium Nitrate, in terms of Density, Fuel Oil Absorption/ Retention, Hardness, and Prill size distribution tested at the Smartchem Technologies Limited Plant lab in presence of CMPDIL officials.
- Chemical testing of PPAN has been done by Smartchem Technologies Limited through third party (having certified NABL).

Technical Specification of PPAN used is given below:

Form	Round & uniform prills.
Feature	Coated & Free flowing.
Characteristics	Thermally stabilized.
Purity	Min. 99.0% purity.
Oil absorption/ Retention	Min. 5.7% Fuel Oil by wt. for Prill
pH (1:10 dilution)	Min. 4.8
Prill Size distribution	+ 2.36 ; 8% max.
	-2.36 + 1.00 mm ; 90% min.
	-1.00 mm ; 2% max.
Bulk Density	750 to 850 Kg/m^3.
Moisture	Max. 0.15% by wt.
Crushing strength	Min. 20 Kg/cm^2.
Wear resistance	Min. 90% by weight.
Shelf Life	Around 2 months with proper storage & transportation.

4.2 Confined and Un-confined VOD Measurement

Confined and Unconfined VOD monitoring of the SME and ANFO explosives were done with DataTrap-II/Handitrap-II/VOD meter. The Data Trap- II is a portable, 8 channels, high speed, high resolution, data recorder. It is used to record continuous VOD of explosives. It has an ability to record high resolution VODs of explosives and simultaneously record transient events such as blast vibrations, explosion pressures, air blast etc. at high speeds and high resolutions.

The Data Trap-II Advanced Analytical Software allows to analyse VOD traces and convert DC voltage signals recorded by the Data Trap-II into the desired engineering units for analysis and presentation. The software is used to program the recording parameters of the instrument and to retrieve, display, analyse, print & export VOD and data from other types of gauges.

The main features of the Data Trap-II for data recording are:-

- Eight channels capable of recording at up to 10 MHz (10 million data points/sec).
- The instrument is provided with a standard 128 MB digital memory to store the recorded data
- The instrument has a capability to store 32 events in its permanent memory before having to download the recorded data to a computer

4.3 Density of Explosives

The density of an explosive may be expressed in terms of specific gravity. Specific gravity is the ratio of the density of the explosive to the density of water under standard conditions.

The density of ANFO used during trial blasting had been varied 0.8-0.9 gm/cc whereas the SME density had been varied 1.1-1.2 gm/cc.

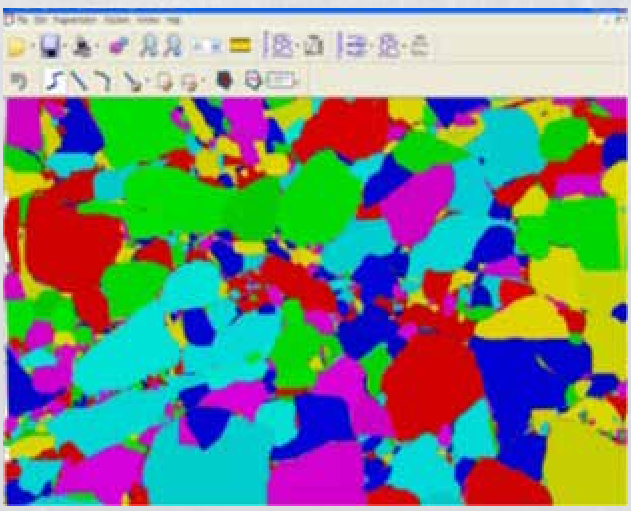
4.4 Fragmentation Assessment

The blast fragmentation is mostly influenced by factors viz. rock mass properties, specific drilling, specific charge, drilling pattern, firing pattern, hole deviation and size of the round.

It can be used along with insitu block size (Maerz and Germain, 1996) to evaluate the efficiency of the explosives, and the accuracy of blasting simulations. It can be used to optimize all blasting parameters to reduce costs.

4.5 Digital Image Analysis Technique

Digital Image processing technique uses sophisticated software and hardware to quantify the geometric aspects of images in two dimensions such as area, number, perimeter, shape, size and orientation. The method includes



Fragmentation Analysis

imaging muck pile, scaling the image, filtering the image, segmentation of image, binary image manipulations, measurement, and stereo metric interpretation

4.6 Blast Induced Ground Vibration Monitoring

The motion of the ground particles (vibration) occurs in three dimensions, which are vertical, radial and transverse. When there is vibration each particle has a velocity and the maximum velocity is referred to as the peak particle velocity in each direction. This motion is usually captured by use of a seismograph and the maximum velocities of all three directions are given. The practice by most is to use the reading of the peak particle velocity as the standard for measuring the intensity of the ground vibration. In most cases the PPV is closely linked to the potential to damage structures.

For every blast, the seismograph will measure the peak particle velocity of all three axis of vibration. For each of the peak particle velocity recorded there is a corresponding peak amplitude and frequency. In order to compare the effect of ANFO and SME in creation of induced ground vibration measurement of PPV was carried out with M/s Instantel made seismograph at different distances from the ANFO and SME charged blasting sites. Precautions were taken so that the geophones are properly coupled with the ground.

4.7 Estimation of Powder Factor

Powder factor of OB is entirely based on the present geo-mining conditions. Powder factor was determined in each blast conducted by ANFO and SME. Length and width of the blasting patches were measured. Depth of each hole was also monitored before charging of explosives. After obtaining average depth from the measurement, volume was calculated as:

Powder Factor (PF) of OB bench:

Volume of OB Block geometry of the patch to be blasted (VOB) (m^3) = L x B x H
Where,
L = Avg. Length of OB patch (m)
B = Avg. Width of OB patch (m)
H= Avg. Depth of drill hole in OB bench (m)
Total explosive consumed in OB Bench (kg)= TOB

PF of OB (in-situ) (m^3/kg) = VOB ÷ TOB

4.8 Techno-Economic Efficacy

Technical comparison between ANFO and SME was carried out by measurement of the following parameters:

a. Velocity of detonation (VOD) of explosive in confined condition.
b. Velocity of detonation (VOD) of explosive in unconfined condition.
c. Distribution of explosives charge in the blast-hole.
d. Powder Factor analysis with both ANFO and SME Explosives
e. Analysis of PPV for ANFO and SME Explosives.
f. Fragmentation and motion analysis with ANFO and SME Explosives.

5. Data Analysis

In each trial of SME and ANFO, the blasting parameters such as diameter of blast holes, depth of holes, burden, spacing, no. of holes were almost kept same. 26 Trial blasts were conducted for both SME and ANFO each.

In all trial blasts diameter of hole was kept 150 mm. Trial Blast with ANFO and SME was conducted on same benches with same Geo-mining condition.

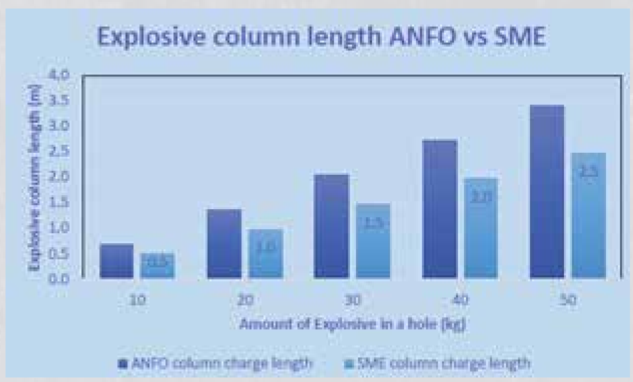


Fig 5.1 Column Charge length with SME and ANFO in hole

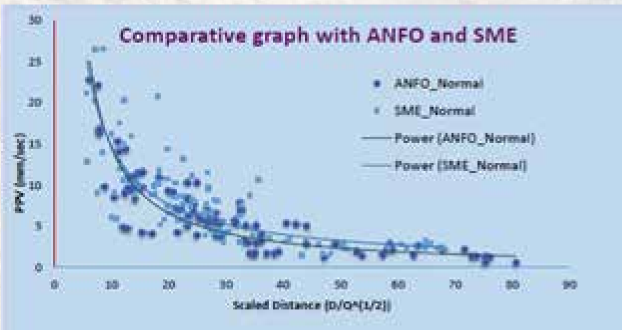


Fig 5.2 PPV Vs SD for SME and ANFO Blasts

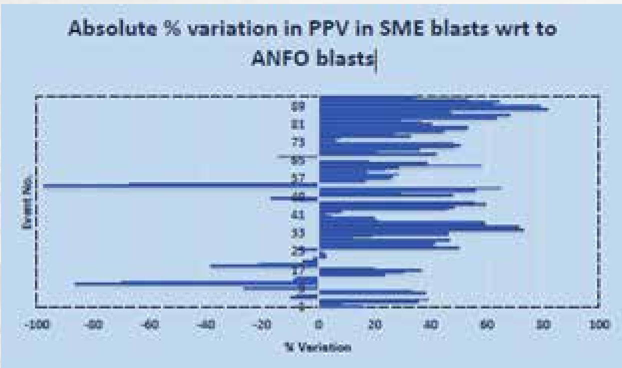


Fig 5.3 Absolute % Variation in PPV of SME wrt ANFO

In most of the cases, fragmentation achieved in ANFO blasting was better as compared to SME blast and desired fragmentation was achieved using ANFO with an average 42.21% higher powder factor than SME.

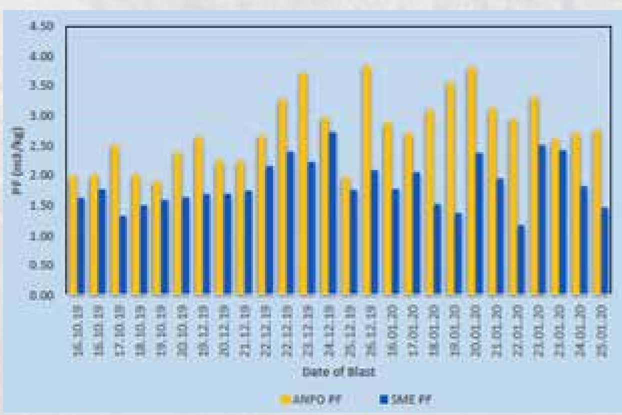


Fig 5.4 Powder factor of SME and ANFO Blasts

To further understand the efficiency of explosive, a curve between volume of OB blast vs total amount of explosive was plotted which showed a 44.37% higher average powder factor (m^3/kg) with ANFO w.r.t SME.(Fig 5.5)

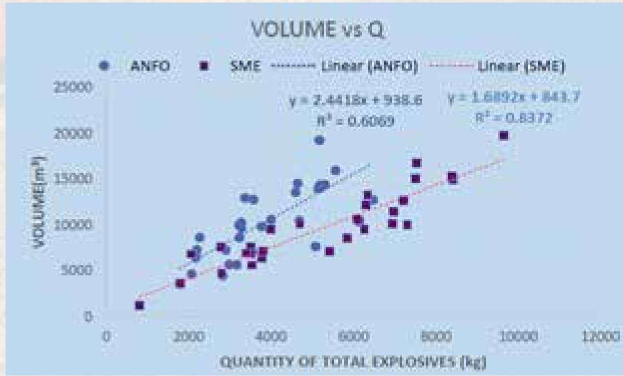


Fig 5.5 Volume of OB Blasts vs Explosive used

5.1 Cost Analysis

Two case scenarios were considered:

Case A: To assess the price of ANFO, we have considered the landed price of PPAN at WCL along with the diesel cost to arrive at the final product cost of ANFO. As per the theoretical calculation of PPAN content of 94.2% and 5.8% diesel in ANFO by weight, the price of ANFO in this Case A at WCL is Rs. 32,329/MT, whereas for SME weighted average of volume and price for all subsidiaries of CIL during tender period of Rate Contract (RC) 2017-19 considered i.e. Rs. 29,426/MT

Case B: The price of ANFO has been determinedon the basis of actual consumption of PPAN and diesel i.e., with 100 MT of PPAN and 6000 Lts of diesel, 104.65 MT of ANFO was measured at WCL. Based on this Case B, the ANFO price at WCL is Rs. 31,725/MT., whereas for SME weighted avg of volume and price for all subsidiaries of CIL during tender period of RC 2019-21 considered i.e., Rs. 25,508/MT.

6. Result

- With ANFO density as 0.83 gm/cc and SME density 1.15 gm/cc, a significant increase of 38.6% in the column charge length with ANFO in comparison to SME can be achieved, resulting better distribution of explosive charge in the hole.
- Values of confined VOD (at 150 mm drill diameter) of ANFO explosives reduced from

Financial Year	Total Annual coal Production Target/ Achieved of Coal India Limited (Million tonnes) (Opencast mines only)	Total Annual OB removal Target/ Achieved of Coal India Limited (Million m^3)	Average Stripping Ratio (Column 3/Column 2)	Volume Dry OB patches (Million m^3) with % dry OB				Cost saving (Million Rs) with % dry OB							
								Case-I (i.e. Rs. 3.86 Rs/ m^3)				Case-II (i.e. Rs. 1.78 Rs/ m^3)			
				10	20	30	40	10	20	30	40	10	20	30	40
2017-18	536.8	1178.12	2.19	117.8	235.6	353.4	471.2	454.8	909.5	1364.3	1819.0	209.7	419.4	629.1	838.8
2018-19	576.4	1161.99	2.02	116.2	232.4	348.6	464.8	448.5	897.1	1345.6	1794.1	206.8	413.7	620.5	827.3
2019-20	572.11	1155.54	2.02	115.6	231.1	346.7	462.2	446.0	892.1	1338.1	1784.2	205.7	411.4	617.1	822.7
2020-21	678.76	1371.10	2.02	137.1	274.2	411.3	548.4	529.2	1058.5	1587.7	2117.0	244.1	488.1	732.2	976.2
2021-22	754.11	1523.30	2.02	152.3	304.7	457.0	609.3	588.0	1176.0	1764.0	2352.0	271.1	542.3	813.4	1084.6
2022-23	836.49	1689.71	2.02	169.0	337.9	506.9	675.9	652.2	1304.5	1956.7	2608.9	300.8	601.5	902.3	1203.1
2023-24	958.01	1935.18	2.02	193.5	387.0	580.6	774.1	747.0	1494.0	2240.9	2987.9	344.5	688.9	1033.4	1377.8

6.51% to 27.52% in comparison to SME explosives.

- Unconfined VOD of ANFO and SME increases with hole dia.
- The overall powder factor achieved during 23 successful blasts was 1.90 and 2.71 with SME and ANFO respectively.
- PPV values increases in SME explosives.
- Overall SME used was 156,487 Kg and ANFO used was 105,187 Kg.
- Average ANFO required was 5.44 kg/m while average SME required was 7.94 kg/m.
- Fragmentation with ANFO is better than SME with higher powder factor.
- The time taken for charging of ANFO in drill holes is comparatively higher than that of SME charging time. Some modification in ANFO BMD vehicle is required to minimize the charging time of ANFO.
- Due to low density of ANFO, it can be only used in dry hole condition.

7. Conclusion

The conclusion of the study is as below:

i. Density:

The average density of ANFO and SME was 0.83 gm/cc and 1.15 gm/cc respectively. An increase of 38.6% in the column charge length with same quantity of ANFO in comparison to SME can be achieved, resulting in better distribution of explosive charge in the hole.

ii. Confined VOD:

The values of confined VOD (at 150 mm drill diameter) of ANFO explosives reduced from 6.51% to 27.52% in comparison to SME explosives.

iii. Peak Particle Velocity:

Up to 81.78 % increase in PPV for the blasts conducted with SME was observed in comparison to ANFO.

iv. Powder Factor:

There was 42.63 % increase in powder factor achieved using ANFO as compared to SME.

v. Fragmentation:

The fragmentation using ANFO was better as compared to SME.

vi. Cost Savings:

There was a projected savings of Rs 1.78/m^3 as per rate contract (RC) of CIL for year 2019-21 and Rs. 3.86/m^3 as per RC of CIL for year 2017-19.

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Amenability of Dry Processing of High Ash Indian Coal by Air fluidized Deck Separator

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Abstract

In India, the reserve of non-coking coal is 89.8% and contains high ash due to its inherent lithological association, intercalated shale of varied thickness and out-of-seam dilution through open cast mining. Processing of the coal is needed for end use. About 20% of noncoking coal is processed for ash reduction due to high cost involved in the wet process. In the present study, two high ash Indian non-coking coal samples from two diversified coalfields namely, Talcher (HM) and Ib valley (LM) have been taken for dry processing using an air fluidized vibrating deck separator. The ash yield of Coal-HM is 40.91% and that of Coal-LM is 44.25%. The gross caloric value of Coal-HM and Coal-LM samples are 3620 kcal/kg and 3363 kcal/kg respectively. Coal characterization with respect to washability study was carried out to assess the cleaning performance of two coal samples. The washing characteristics indicate that Coal-HM was easy-to-wash and Coal-LM was difficult to wash. Dry processing studies were carried out considering the important process variables namely the airflow rate, longitudinal and transverse angle of the deck. The effects of the variables on product yield, recovery of combustible, ash reduction were determined. The cleaning performance was described by the organic efficiency and probable error (Ep). The Ep of dry processing was found to be 0.17 for easy-to-wash-coal (Coal-HM) and 0.21 for difficult-to-wash coal (Coal- LM). The organic efficiency of Coal-HM was found to be 91% and 80% for Coal-LM. It was found that the response of two coal samples is dependent on their washability characteristics, and accordingly, the operating parameters need to be adjusted for achieving the desired product.

Keywords: Dry processing; ash rejection; organic efficiency; combustible recovery, near gravity material; separation efficiency

1. Introduction

The resource of coal in India is about 344.021 billion tonnes (as on 01-04-2020) which is much higher compared to oil and gas. Out of total reserve, prime-coking coal is 5.313 billion tonnes, medium-coking and blendable/semi-coking is 29.692 billion tonnes and non-coking coal, including high sulphur (tertiary) is 309.017 billion tonnes (Mineral Year Book, 2020).

Coal is the predominant source of energy in India. About 53% of energy is produced from coal. There has been increasing demand of non-coking coal for the power sector leading to the mining of higher tonnage of coal. However, Indian coal deposits are generally of high ash due to drift origin and varying the ash level from 36-50%. They feature in poor washability, which causes significant challenges to the end users. Most of the coals supplied for power plants are raw coals

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containing more than 40% ash, thereby causing low thermal efficiencies, high operating and maintenance costs, erosion problems, difficulty in pulverization and generation of the excessive amount of fly ash with a large amount of unburnt carbon.

In India, conventional practice of coal washing is by the wet method. Processing of the coking coals are emphasized to reduce the ash level to 17-20% as per requirement for coke making. However, the processing of the non-coking is very limited. It is about 20% of the total coal used. Wet processing is found to be very effective in reducing the ash content of the coal to a lower level. The processed coal retains surface moisture (6-15%) depending upon the feed size and reduces the calorific value of the coal. Wet processing methods have some disadvantages as it generates effluent, requires large amount of process water and dewatering system. The dry processing of coal has several advantages over wet beneficiation as the process products are free from surface moisture. In this method, no process water and dewatering systems are required and prevents the generation of effluents. This process is very compact. Therefore, less floor area is required to set up a dry processing plant. It is also reported that dry processing is cost-effective. Nowadays, water is a scarce commodity. Dry processing can be practiced at the arid region and mine sites to remove the shally materials and thus could reduce the transportation cost.

Most of the coal-producing countries like China, South Africa, USA, etc are practicing dry processing of coal. In early 1916, dry processing of coal fines was introduced in United States (Lockhart 1984, Haibin et al., 2011). The air density separators were widely used between 1930 and 1960. Lots of research work have been carried out to evaluate the performance of the dry coal cleaning units. It has been reported that dry beneficiation of coarse coals are found to be effective in reducing the ash content in clean coal by different techniques (Honaker et. al, 2008; Yang et al. 2013, Gupta et. al, 2012). In air fluidization-based technique, mixture of air and fine coal powder produces the autogeneous medium that behaves like a separating medium. The degree of segregation of fine lignite sample in a vibrated gas-fluidized bed was reported by Zhao et al. (2015). Theoretical considerations shows that effective separation in air table can be achieved when the time of free fall could be minimized (Osborne 1988; Haider and Levenspiel 1989; Zhao et al. 2011). The dry separation of fine particles in the air is difficult due to low differences in settling velocity. However, modern techniques assist to increase the efficiency of separation by introducing other parameters, like transverse oscillation, slanting the deck in longitudinal and transverse directions which increases the flow of the particles according to the desired grade.

The aim of the present study was to produce a suitable product for application in a thermal power plant by dry processing of non-coking coal using air fluidized vibrating deck separator. In this investigation, high ash non-coking coals have been studied for understanding the separation behaviour and their response in ash reduction to a level of 34%.

2. Materials and Methods

Two high ash non-coking coal samples from Hingula mines of Talcher coalfield (HM) and Lakhanpur mines of Ib valley (LM) of Mahanadi coalfield were undertaken for the present investigation. Detailed characterization with respect to proximate analysis, ultimate analysis, size and size-wise ash analysis, calorific value, and washability study are discussed below. Dry processing of crushed to 50 mm coal samples were carried out varying the process parameters like frequency of deck vibration, airflow rate, longitudinal and transverse angle of the deck. The responses like ash of the products, recovery of combustibles and ash rejection are determined using the following equations for measuring the separation performance of two coals having diverse characteristics.

$$\text{Combustible recovery, \% } (R_{comb}) = C*(100\text{-concentrate ash})/(100\text{-feed ash}) \quad (1)$$

$$\text{Ash recovery in product, \%}(R_{A/CC}) = C*(\text{concentrate ash/feed ash}) \quad (2)$$

$$\text{Ash rejection, \% } (A_{rej}) = (100\text{- } C)*(\text{tailing ash/feed ash}) \quad (3)$$

Where, C and T represent the yield of concentrate and tailing respectively.

2.1 Cleaning Characteristics

The washing characteristics of coal samples of HM and LM are studied by washability study. This study reflects the maximum product yield which could be achievable at any targeted ash level. As the Indian boilers are designed to take coal having 34% ash or below, a targeted ash level of 34% is considered for the process products. The studies were conducted at a varied density of the medium from 1.4 to 2.2 g/cm^3 for both coal samples. The curves generated from the washability results indicate the washing characteristics of the samples. This study facilitates in the prediction of theoretical results for the gravity-based coal processing techniques.

2.2 Dry Processing

Dry processing of the coal samples were carried out using Air fluidized vibrating deck separator. It consists of a perforated deck which is hanging from four steel strings. The slope of the separating deck can be altered in longitudinally and transversely. The autogenous medium produces due to the auto mixing of the fines of the feed materials and air blown from the bottom of the deck. Materials on the separating deck are dilated by fluidization. Stratification takes place under the influence of fluidized medium in which the heavier particles gravitate through the bed and come in contact with the deck while lighter particles move up due to the differential settling velocity of the particles. Under the influence of deck vibrational force provided by the deck, heavier particles get dragged towards the feed end of the deck (back plate) due to the vibration-induced inertia force (Fig.1). The heavy particles are forced by the deck vibration and the continuous influx of the new feed material to follow a helical motion (Fig. 2). Heavier particles move towards the narrowing end of the separating table where the final refuse is collected. The lighter particles are collected along the length of the deck. In air fluidized vibrating deck separation, airflow rate, oscillation assisted by the deck vibration, deck inclination (transverse and longitudinal angle), feed rate and splitter position play significant role and effectively control the yield and ash content

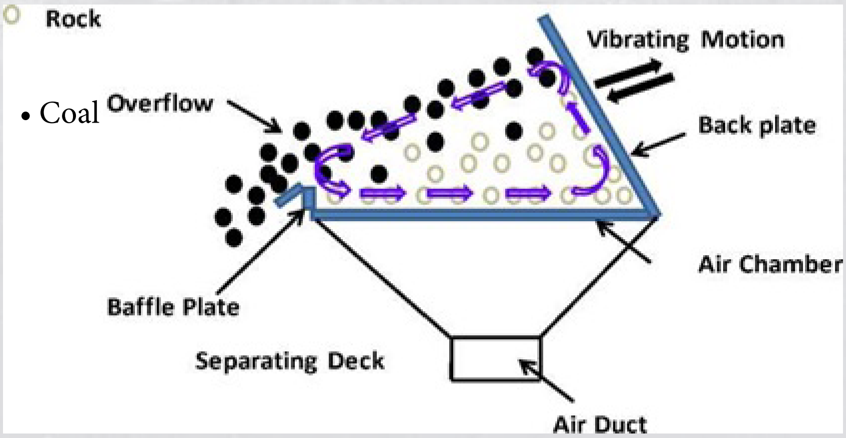


Fig.1: Separation on a deck of air fluidized vibrating deck separator.

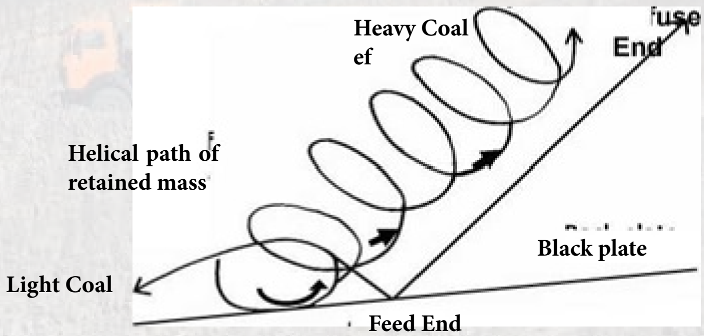


Fig. 2: Separation principle of dry separation of air fluidized vibrating deck separator.

of the clean coal. The bag filter and air cyclone are the dust collectors. Air cyclone also helps to recycle the air that could be used for the separation process.

3. Results and Discussion

3.1 Characterization of sample

The coal samples characterized with respect to proximate and ultimate analysis and results are indicated in Table 1. The Gross calorific value (GCV) of Coal-HM and Coal-LM are found to be 3555 and 3263 Kcal/Kg respectively. The Coal-HM contains 3.3% less and more fixed carbon than Coal-LM.

3.2 Size distribution of coal sample

The dry size-analysis carried out for the crushed to 50 mm coal samples of HM and LM are indicated in Table 2 and Fig. 3. It has been found

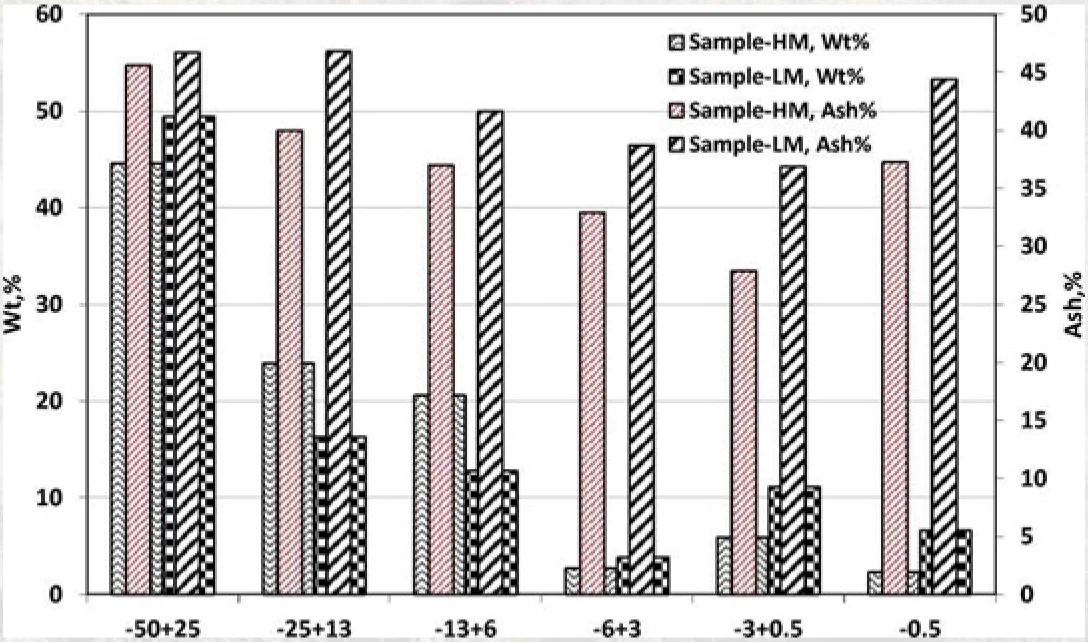
Table 1: Characterization of as-received coal samples

Coal Samples	Proximate analysis (wt %)			
	M	A	VM	FC
HM	3.57	40.91	16.30	39.22
LM	1.65	44.25	30.66	23.44
Ultimate analysis (wt %)				
Coal Samples	C	H	N	S
HM	45.15	3.29	1.09	0.51
LM	39.32	2.98	0.99	0.52

M: moisture; A: ash yield; VM: volatile matter; FC: fixed carbon;C: carbon; H: hydrogen; O= Oxygen, N: nitrogen; S: sulphur

Table 2: Particle size distribution and size-wise ash analysis of -50 mm sample

Size (mm)	Wt%	Ash%	Wt%	Ash%
	Coal	HM	Coal	LM
-50+25	44.6	45.59	49.4	46.7
-25+13	23.9	39.98	16.3	46.8
-13+6	20.6	36.99	12.8	41.6
-6+3	2.7	32.90	3.8	38.7
-3+0.5	5.9	27.88	11.1	36.9
-0.5	2.3	37.26	6.6	44.4



Particle Size in mm

Fig. 3: Distribution of particles in crushed to 50 mm coal samples of HM and LM.

that ash content of the -6 mm fraction of Coal- HM is below 34 %. Thus, the fraction does not require any ash reduction. Therefore, it could be used directly as a product. All the fractions of Coal LM contain higher ash than Coal-HM.

3.3 Washability characteristics

The washability study of two coal samples was carried out for different size fractions. The composite results derived from the fractions of both the coals, and the products of float and sink test carried out at the medium-density of 1.4 to 2.2 gm/cm^3 are presented in Fig.4.

The washability curves (Figs. 4a and 4b) of two coal samples show different trend. The Coal-HM is found to be comparatively easy to reduce the ash content and the Coal-LM is of difficult- to-wash coal. The yield recovered at an interval of 0.1

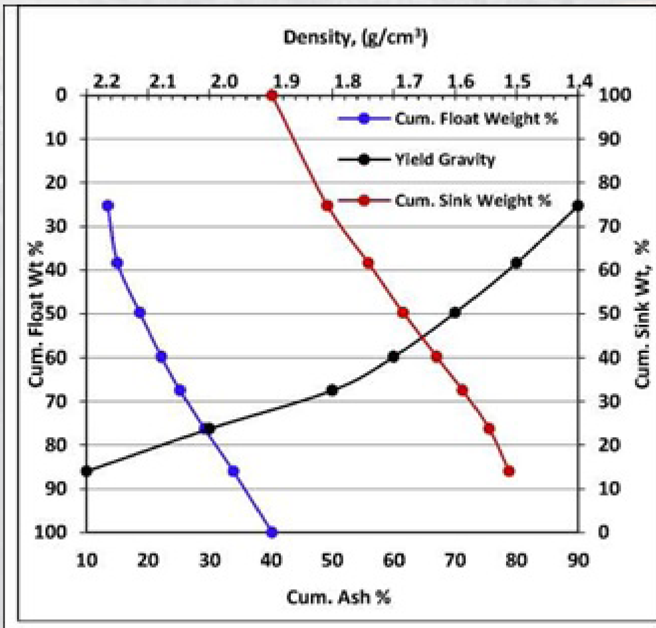


Fig. 4(a): Washability curve of Coal-HM.

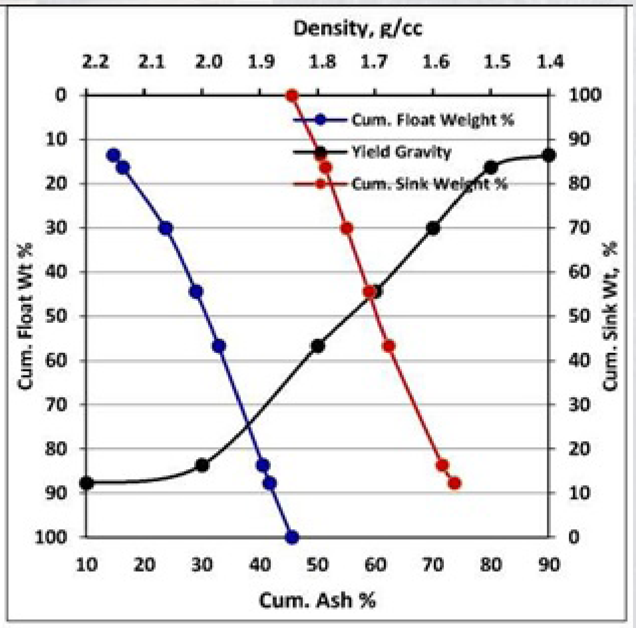


Fig. 4(b): Washability curve of Coal-LM.

specific gravity is not significant for Coal-LM (Fig. 4b) which reflects the difficulty in the processing with respect to ash reduction. The yield recovered from the washability curves at 34% ash level for two coal samples are given in Table 3. The recovered yield at 34% ash level for Coal-HM is 82% which is 22% more than Coal-LM while the separation cut-density is 2.05 g/cm³ and NGM is 5. However, for Coal-LM, separation cut-density is 1.85 g/cm³. The NGM of Coal-LM is as high as 27.4 (Fig. 5) which reflects that separation is not sharp and considerable middling product could be produced during separation.

Table 3: Washability results of coal samples at 34% ash level

Coal samples;	Product yield %;	Recovery of Combustibles %;	Cut Density g/cm³;	NGM
HM	82.0	97.7	2.05	5.0
LM	60.0	73.5	1.85	27.4

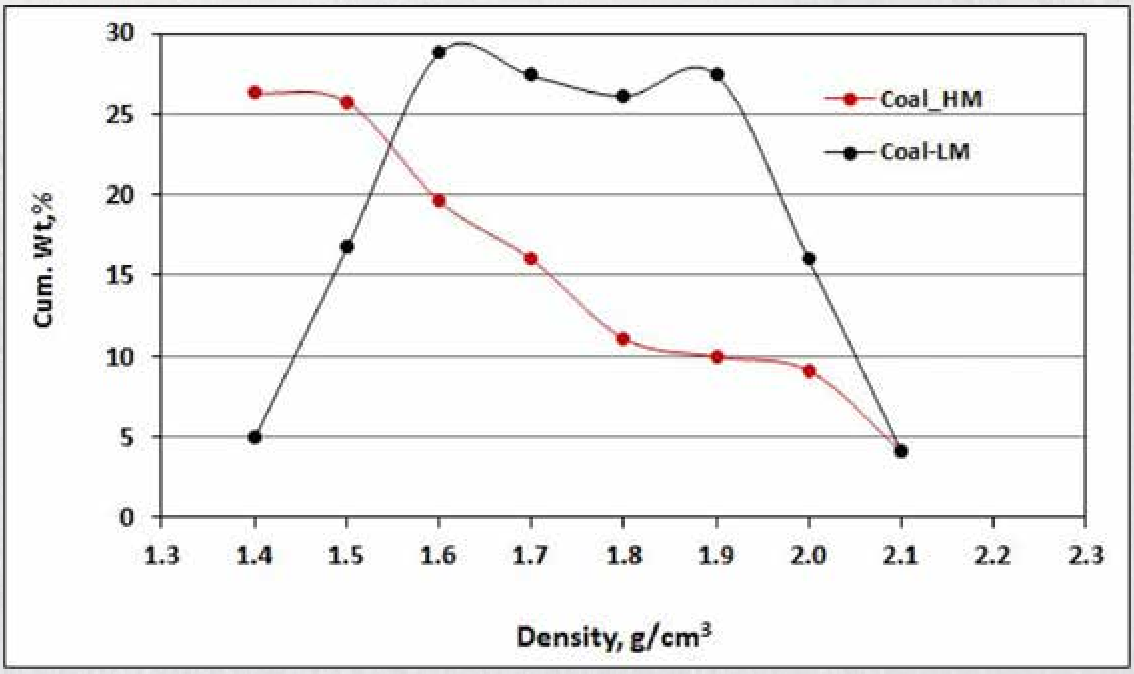


Fig. 5: Near gravity material of Coal samples HM and LM.

3.4 Dry Separation Studies

From the size analysis of crushed to 50 mm Coal-HM it was found that -6 mm contains only 31% ash and the -50+6 mm contains around 42% ash. The focus of the study was to recover the product with 34% ash. Therefore, the -6 mm fraction was separated out before subjecting to dry processing as it could be used as a direct product. The Coal sample-LM has been studied at -50+3 mm size as the -3 mm fraction contains 39.6% ash and could be mixed with the final product. The dry beneficiation was performed under the varying conditions presented below.

3.4.1 Effect of Separating Deck angle

The deck angle of the separating table has significant effect on the yield and grade of the products. When the transverse angle (TA) is increased, the materials move towards the discharge end of the deck. The mechanism of dry separation of Air Table has been described by Sahu et al. (2017). With the decreased of the transverse angle, higher density particles move towards the higher end of the separation deck (back plate) and the lighter density particles report in the discharge end.

The effects of transverse angle on two coal samples indicated in Fig. 6 show two distinct sets of curves. The easy-to-wash Coal-HM has a marginal effect while increasing the TA from 7° to 8°. Further increase in TA to 10°, increases the combustible recovery to 90% with the increase of product ash. It has been found for the Coal-LM that a product with 34-35 % could be achieved in the range of 7° to 8° transverse angle. Further increase in TA to 9°, significantly increases the recovery of combustible matters with the product ash of 38%. It infers that high TA is favourable for dry de-shaling purposes for maximizing the combustibles and producing a reject with high ash. Low TA is found to be favourable for difficult-to-wash coal due to the availability of longer residence time of the particles on the separating deck. Therefore, transverse angle plays a significant role in achieving a desired grade of product.

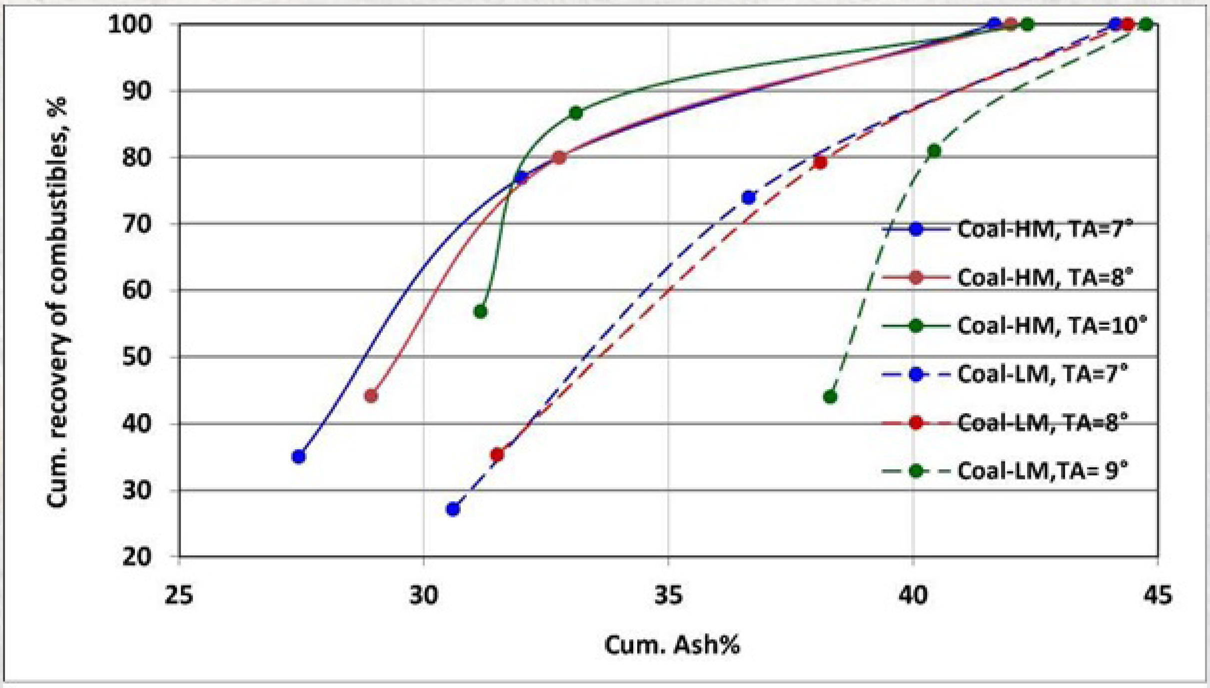


Fig. 6: Effect of transverse angle on product yield and ash.

3.4.2 Effect of Longitudinal Angle

The longitudinal angle (LA) affects the yield

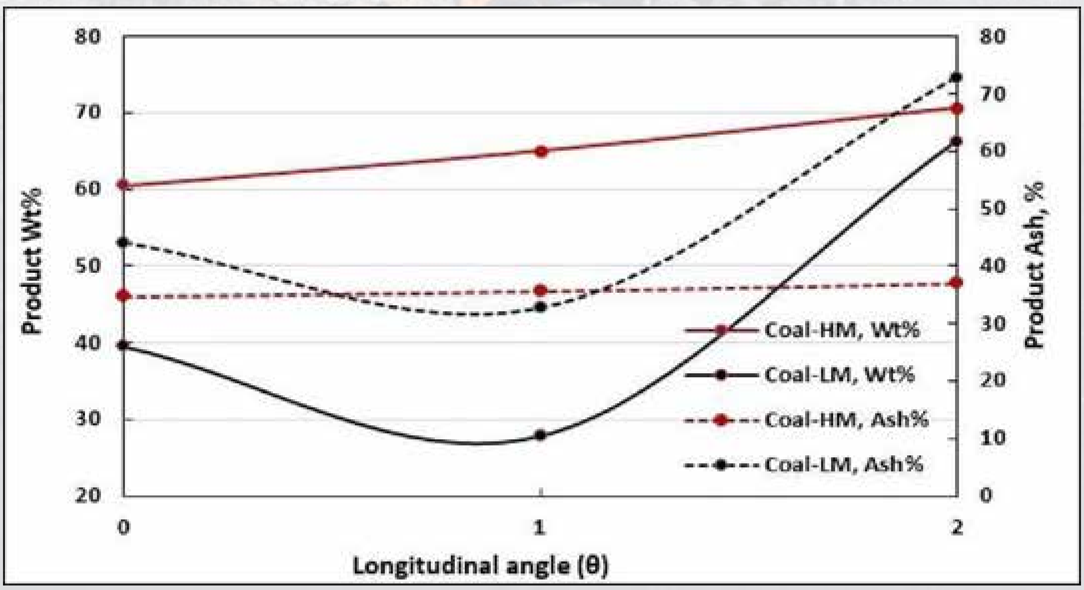


Fig. 7: Effect of longitudinal angle on product yield and ash.

and ash content of the reject stream. When the slope of the longitudinal side increases with the feed point, it allows the particles to move towards the reject stream and decreases the combustible recovery and ash content of the reject. The results are given in Fig. 7. The effect on the Coal-LM is more than on the Coal-HM. This difference is also found in the theoretical cleaning characteristics described by the washability curves (Fig. 4) and high NGM value of Coal-LM (Fig. 5). In both the coal samples, ash of the product increases with the increase of the inclination of the longitudinal angle. For Coal-HM, at a higher LA of 2°, product ash increases as some of the high-density particles report to the product section due to the longitudinal slope of the deck towards the feed end. The maximum recovery (73%) with product ash of 34% could be obtained at +1° longitudinal angle and the recovery of combustible decreases at 0° LA. In the case of Coal-LM, only low longitudinal angle (0°) is effective for achieving a product with 34% ash.

3.4.3 Effect of Airflow

The airflow is one of the important parameters in all air fluidization separation processes. The airflow rate should be enough to dilate the bed material for their stratification. A higher airflow rate causes the mixing of heavy and light materials during the separation. Conversely, when the air-flow is less, due to the smaller bubble sizes, space becomes insufficient for the particle setting in the disturbed region below the rising bubbles (Yang et al., 2013).

The feed rate, transverse and longitudinal angle of the deck were kept constant while varying the air flow rate. The airflow rate was varied from 0.55 to 1.3 m^3/sec and results are shown in Fig. 8. The effect was found to be more on the Coal-HM due to the better liberation which assisted differential settling velocities among the particles having different densities. The low airflow rate was favourable for Coal-LM to generate a product with ash of 34-35 %. At a higher airflow rate, the interlocked particles tend to report to the product stream and increase the ash content of the product. It was found that at low air flow rate the fluidization was not sufficient and low-density particles remained entrapped with the heavy particles. As a result the yield of clean coal decreases and yield of the reject stream increases. With the increase of the airflow rate the bed materials get sufficiently

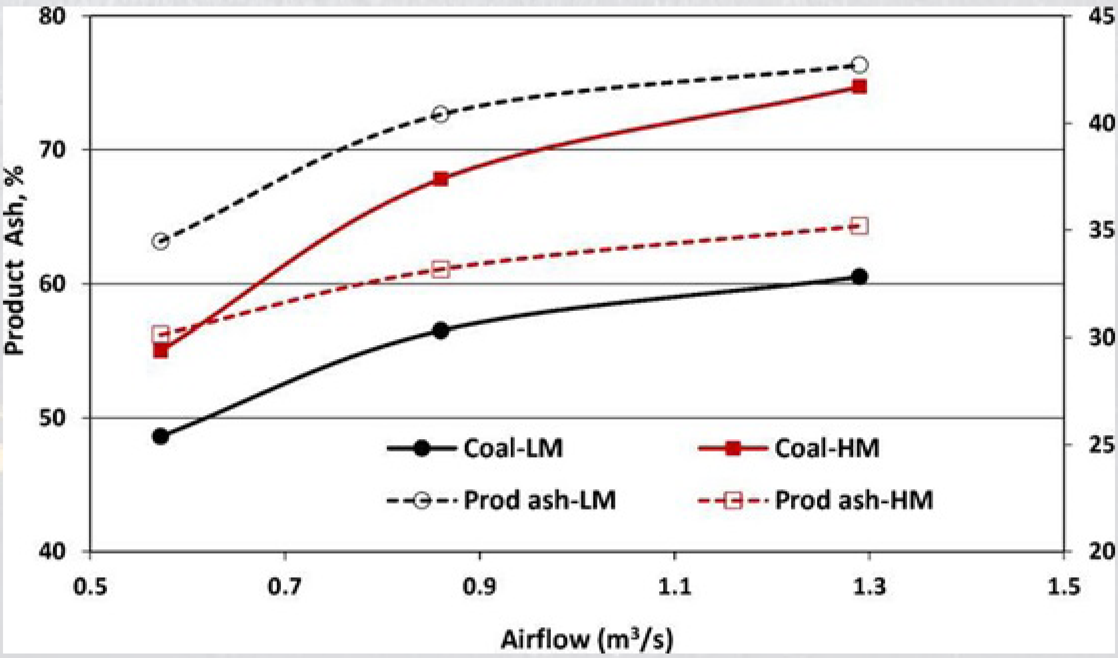


Fig. 8: Effect of airflow on product yield and ash of Coals HM and LM.

fluidized and facilitate the separation process. The lighter particles remained on the upper layer report in the concentrate section. The middling sections and the heavy particles bearing high ash report to the reject section. It shows that the process conditions drastically change with the washability characteristics of the coal samples. High airflow is effective for de-shaling of high ash coal to remove the ash-bearing carbonaceous material with minimum loss of carbon values.

The results obtained through dry processing of two coal samples are presented in Table 4. The Coal-LM being difficult-to-wash coal produces less yield than Coal-HM at 34% ash. However, Coal-LM produces more yield (around 52%) at the ash level of 36%. Thus, effective dry separation of Indian coal is feasible when the operating variables are critically studied.

Table 4: Results of dry processing

Coal Sample	Wt % of product	Ash % of product	Recovery Comb. %	Organic Efficiency
Coal-HM	73.9	34.08	82.8	91.0
Coal-LM	44.0	34.77	51.46	79.5
Coal-LM	52.0	36.00	59.4	86.7

3.5 Separation Efficiency

3.5.1 Probable Error (Ep)

The separation efficiency of dry processing is evaluated by a partition curve. It defines the ratio of concentration that has been removed from the feed stream to the initial concentration in the feed stream. The efficiency of the process can be represented by the slope of a partition curve. It describes the separating efficiency of the separator and also is used for the estimation of performance and comparison between separators. The separation efficiency for dry processing of two coal samples using Air fluidized vibrating deck separator is presented in Fig.9.

Ep was determined from the partition curve using the equation (4). The actual separation density (1.75-1.77 g/cm^3) was found to be lower than the theoretical values as derived from the

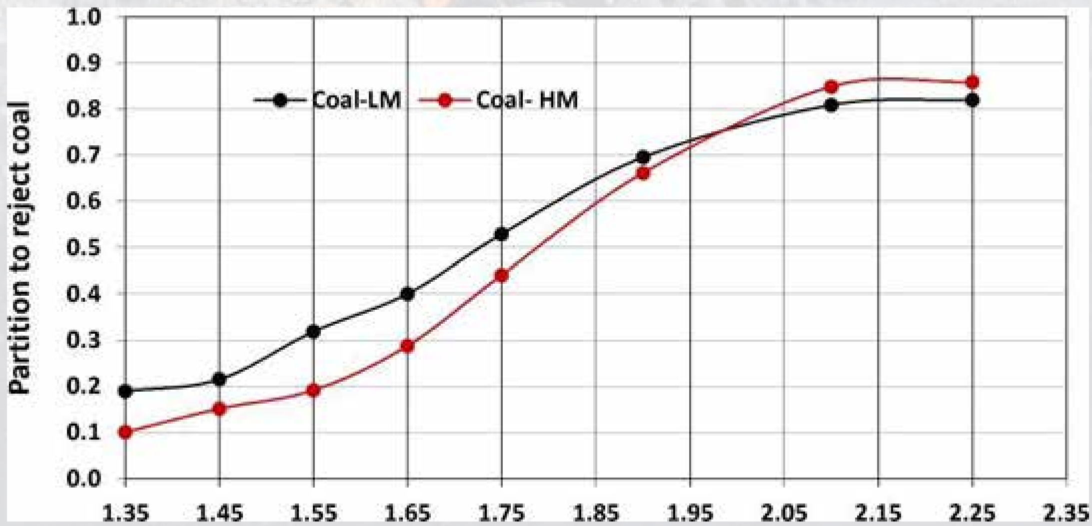


Fig. 9: Partition curve for dry separation of two high ash Coals-HM and LM.

washability study. The Ep value is also dependent on the NGM. The Ep for Coal-HM was 0.17 as it has lower NGM in the higher density, whereas Ep for Coal-LM was 0.21 due to the high NGM in the density range of 1.55 to 1.95 g/cm^3 as reported in Fig. 4.

4. Conclusion

The dry processing of Indian high ash non-coking coals of different geological regions was studied and encouraging results were found in reducing the ash content of the coal at higher ash levels (34-35%) of the products. The selection of the operating conditions plays a significant role in achieving the best separation. The findings of the study are summarized below:

- The studies indicate that inclination of the separating deck is one of the critical parameter. The transverse angle has significant effect on clean coal yield & ash. The low transverse angle is favorable for interlocked coal (inferior quality) to achieve the desired product with 34-35% ash content. Dry de-shaling of high ash coal is favorable only at high transverse angle. The longitudinal angle of the deck affects the reject ash.
- Separation efficiency of the dry separation process measured by Ep for easy-to-wash Coal (HM) is 0.17 which is quite good at higher density separation. Ep value will be high for difficult-to-wash coal samples.

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Restoration of Orchid flora of Makum Coalfield areas of Digboi Forest Division

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Abstract:

Orchids are among the most fascinating group of flowering plants showing incredible diversity in form, amazing ornamentation, brilliant colour combination and extended blooming period, that have attracted the admiration of scientist, horticulturist and industrialist. The foot hills of the Himalayas have been the traditional home of many exquisite varieties of orchids. The present study was an attempt to evaluate the orchid diversity of North Eastern Coalfield areas under Digboi Forest Division of Assam, identify their host ranges and mass multiplication for their conservation through reintroduction.

North Eastern Coalfield areas and nearby forest with its perfect climate are the harbor of nearly 48 genera with 111 orchid species mostly of epiphytic habit. Terrestrial orchids show very localized occurrence and represented 19 species and amongst them P. tankervilleae, the most spectacular orchid is now in critically endangered status, found extremely sparse and observed mainly in cultivated condition. Dendrobium occupied second largest position among the epiphyte orchid. Ten Rare, Endangered and Threatened (RET) orchids were selected for in-vitro seed propagation and mass multiplication. **Murashige and Skoog Medium** *(MS) media was found best proliferation medium and combined effect of NAA (Naphthalene acetic acid) and BAP (***6-Benzyl Amino Purine***) was more effective for multiple shoot formation. Activated charcoal plays an important role in growth and development of orchid species. Fifteen hundred seedlings were multiplied and planted in re-vegetated mined out sites, nearby forest site and Rain Forest Research Institute (RFRI), Jorhat botanical garden with exhaustive care. Conservation and maintenance of orchid species were done at RFRI botanical garden and Tikak Colliery, Margherita was a part of ex-situ conservation plan. An awareness programme was held in Project Office, Tikak colliery campus for creating awareness in favor of multiplication and conservation of orchid resources. The officials of North Eastern Coalfields actively participated and showed keen interest on conservation and maintenance of orchids.*

Introduction

Orchidaceae is the second largest family of flowering plants and distributed in a wide ecological range of habitats with maximum concentration in high humid tropical and subtropical belts. In India orchids are distributed in the Himalayan region with maximum abundance in North East India, in Western Ghats, Deccan plateau and Andaman & Nicobar Islands. They are valued for their unbelievable range of floricultural excellence, gorgeous foliage, fragrant and long lasting flower that have attracted the commercial growers all over the world and interest has paid to take advantage of this group. Destruction of habitats, large scale conversion of forest, over exploitation, open cast mining, construction of new roads and buildings, agriculture expansion, jhum cultivation

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and other developmental activities, this group is now facing the danger of depletion. Fruit setting in majority of the magnificent orchid species is also very less. Therefore, the family Orchidaceae come up to the position of rarity and considered under the APPENDIX- I & II of the CITES. Increasing vulnerability of these species it is an urgent need to restore the ecology of their habitat for effective conservation and has demanded technology for ex situ conservation. The process of open-cast coal mining involves removal of top overlying soil layer with vegetation cover leads denuded and total elimination of forest cover. Majority of the orchids are found as epiphytes and destruction of tree species created permanent elimination of the epiphytes. Presently many spectacular and economically important orchid species of Assam are facing danger of extinction owing to destruction of habitat due to mining. Till date no any conservation strategy has been taken except few enumerations work done by Gogoi et al (2011, 2012) in nearby district of the proposed areas.

Objectives

Taxonomic exploration of orchids of North Eastern Coalfields, their mass multiplication and reintroduction in wild for germplasm conservation.

- Taxonomical exploration of orchids and identification of the host plants in Makum coal fields of Assam.
- Mass multiplication of Rare, Endangered and Threatened (RET) orchids through in-vitro propagation.
- Re-introduction of propagated orchids into the re-vegetated mine dumps and adjacent sites.
- Ex situ conservation of orchid species at RFRI Campus, Jorhat and NEC Campus, Margherita.
- Capacity building for multiplication and conservation of orchid resources ensuring environment and ecology.

Results

Extensive field study was conducted to taxonomic investigation of orchid flora from 15 reserve/proposed reserve forests of North Eastern Coal fields and neighbouring areas, and assessment of habitat ecology for reorganization of their occurrence. Presently 111 numbers of orchid species were recorded, among them 92 species were epiphytic in nature and merely 19 species was found in terrestrial habit. Terrestrial orchids showed much localized occurrence and Maximum number of species was found in Upper Dihing RF, which the part of rain forest Dihing Patkai National Park. Amongst the terrestrial orchids, P. tankervilleae was now in critically endangered status, found extremely sparse; Hetaeria affinis was belonged to endangered category as well as Geodorum densiflorum and Paphiopedilum hirsutissimum, were in vulnerable status. Considering the Dendrobium species, D. nobile and D.sulcatum were placed in critically endangered category; D. aduncum, D. cumulatum, D. lituiflorum and D. terminale were endangered, where as D. densiflorum, D. transparens and D. jenkinsii were in threatened category. Study on host range of epiphytic orchids revealed 27 number of species identified and Lagerstroemia speciosa sheltered highest number of orchids followed by Dipterocarpus retusus, Tectona grandis and Bischofia javanica. In view of the documented species 24.45% of the total species were Rare, 3.64 % Vulnerable, 3.64 % Near threatened, 6.36 % Endangered and 2.73 % Critically endangered making the area a significant habitat of orchids. Forest destruction, drastic depletion of forest areas and illegal mining activity has detrimentally affected the population of the orchids.

Mass multiplication through tissue culture is the most popular multiplication method and essential components of plant genetic resource management, conservation and restoration of rare and endangered plant species (Fay, 1992). In vitro seed propagation technique may be an efficient and alternative tools used for mass propagation. During the present investigation of in vitro seed propagation, the effects of various basal medium, plant growth regulators and natural additives on organogenesis in all the species have been thoroughly considered. Principle requirements for seed germination of different species were the composition of micro and macro elements in the culture medium. In the present study MS media exhibited the best proliferation followed by Mitra medium. 85-95% of seed germination was seen in the present study for all the species except Phalaenopsis mannii. Combined effect of NAA and BAP was more effective for multiple shoot formation than the single effect of NAA, IBA and BAP. Activated charcoal plays an important role in growth and development of some orchid species. Natural additives like Banana extract, Coconut water, potato extract and yeast extract were used for the regeneration of different Dendrobium species. Seed derived propagation is very prompt and easy approach for multiplication of these species. It could be successfully applied for mass multiplication of these orchids intended for large scale propagation, future conservation, reintroduction in their natural ecological niche and commercial aspects.

The multiplied seedlings were planted in re-vegetated mined out sites and forest site with exhaustive care. Conservation is a practice taking up preservation, maintenance, sustainable utilization, restoration and enhancement of the natural environment. The main aim of conservation is to preserve quality of environment (Sengwar, 2015). Conservation and maintenance of orchid species were done properly at RFRI botanical garden and Tikak Colliery, Margherita is a part of ex situ conservation plan. All these can be rectified to a great extent by creating environmental awareness among the general public. An awareness programme was held in the Tirak colliery site and the group which participated in the awareness programmes includes officials of North Eastern Coalfields. The programme highlighted a number of view shared by different persons about the diversity and conservation of orchids with its specific habitat. A wide variety of strategies such as the preservation of specific habitats, collection and preservation of plant genetic resources has been applied for conservation of plant diversity. Creating awareness by involving the public helps raise awareness of plant conservation issues and a sense of community responsibility for caring for the environment. The officials of North Eastern Coalfields showed keen interest on conservation, maintenance of orchids and precaution from various diseases.

Outcome /Recommendation

The present study on the orchid flora is of utmost importance for knowing the species strength of the area and restoration of the unique biological resources. Orchids are considered as good bio indicator of forest virginity and health of an ecosystem (a well and pollution free environment), because they have a low tolerance for changes in their environment. Owing to destruction of specific habitats due to various reasons the orchid group is under threat. Open cast mining severely changes the landscape and eliminates existing vegetation which permanently eradicates the epiphytic orchids. Many spectacular orchid species of Assam are vanished gradually due to mining activities. The present study focus on detecting the location of occurrence of orchids and to explore their host ranges which will help in analyzing the microenvironment and developing condition for ex situ conservation. Reorganization and conservation of supporting trees is of outmost importance to protect these valuable resources. Conservation of orchids through in vitro seed propagation is the best methods for preserving the rare species. It helps multiplication of orchids which facilitated reintroduction in neighbouring natural forest as the success of restoration of the area can judge by the presence of orchids. In vitro seed propagation and ex situ conservation of some rare orchids of the studied forests has been initiated as future challenges of the study.

Exit Plane

The foot hills of the Himalayas have been the traditional home of many exquisite varieties of orchids. The present study was an attempt to evaluate the orchid diversity of North Eastern Coalfield areas of Assam, identify their host ranges and protection of supporting trees, mass multiplication for their conservation through reintroduction. In vitro seed propagation is the best methods for preserving the rare species. It helps multiplication of orchids which facilitated reintroduction in neighbouring natural forest as the success of restoration of the area can judge by the presence of orchids. Comparable work to be implemented in other areas of North eastern region particularly in Tropical evergreen forests and Tropical deciduous forests types where the orchid thrives well.

Befits to Coal industry

Presently many spectacular and economically important orchid species of Assam are facing danger of extinction owing to destruction of habitat due to mining activity. Orchid were collected from the affected site of North Eastern Coalfield areas, multiplied in laboratory (in vitro seed) and planted in the re-vegetated mined out sites as well as in the adjacent forest sites. RET species which are sensitive to situation specific microclimate, hence, it was reintroduced with intensive care according to their ecological requirements as possible. The reclamation of mined areas will be complete along with introduction of the orchids.

The conservation strategies of orchid flora will not only help in restore the bio resources native to this Indo Burma bio geographic zone but also will help the mining industry to prove its credentials towards protection of environment and ecology.

As the orchids are considered the most precious floristic component and most of the orchids are geographically sensitive and endemic, a repository of such species will certainly attract people. A little effort and endeavour will give great possibilities of ecotourism and thus will open up a scope for entrepreneurship development for a section of people. The successful establishment of the orchids in the areas developed ample scope for ensuring livelihood option to the mine affected people of this region through tourism.

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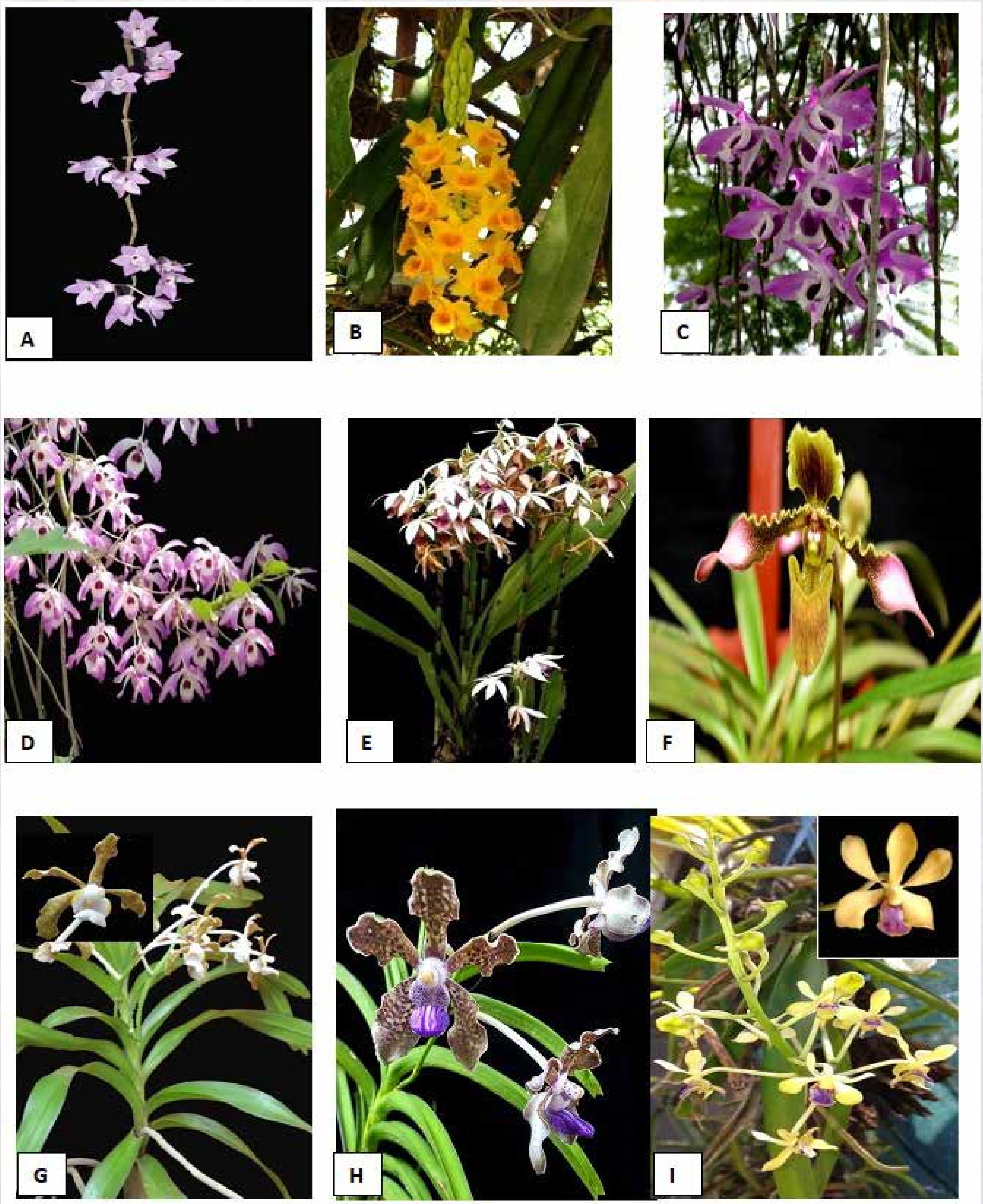

PLATE-I: Some rare orchid of North Eastern Coalfields,Assam, A- Dendrobium aduncum Lindl, B- Dendrobium densiflorum Lindl, C- Dendrobium lituiflorumLindl, D- Dendrobium nobile Lindl, E- Phaius tankervilleae (Banks) Blume, F- Paphiopedilum hirsutissimum (Lindl. ex Hook.) Stein, G- Vanda bicolor Griff, H - Vanda tessellata (Roxb.) Hook. ex G. Don I- Vanda testacea (Lindl.) Rchb.f

PLATE- I

A B C D

1 2 3 4 5

PLATE- II

PLATE-III, ***For Plate-II & III***: In vitro seed propagation of certain magnificent Orchids of Northeast India: 1. Aerides multiflora; 2. Cleisocentron pallens; 3. Cymbidium aloifolium; 4. Dendrobium aduncum; 5. D. fimbriatum; 6. D. lituiflorum; 7.D. Moschatum; 8. Phalaenopsis mannii; 9. Phaius tankerville and 10. Rhynchostylis retusa.

A: Protocorm formation; B: Well developed root & shoot; C: Best potting media D: Mass muliplication