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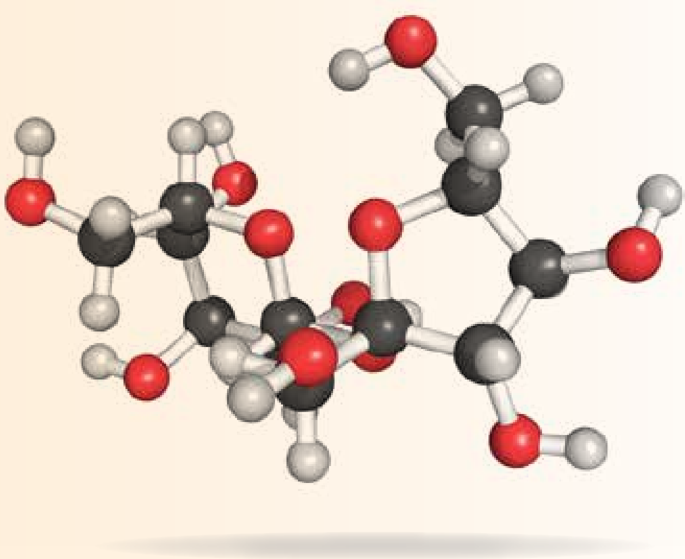
A Mini Ratna Company

ISSN 0970-7204

खनन विज्ञान
minetech

खण्ड 39, अंक 4
अक्टूबर–दिसम्बर 2018

Volume 39, No. 4
October-December 2018



खनन विज्ञान minetech

सीएमपीडीआई प्रकाशन

वार्षिक शुल्क: ₹ 800 (Handling and postage charges ₹ 50 per copy extra)

A CMPDI PUBLICATION
Inland ₹ 800 (Annually) (Handling & postage charges ₹ 50 per copy extra)
Overseas US $ 200 (including airmail)

For free internal circulation within CIL Subsidiaries (under support from Coal India Limited)

खनन, गवेषण एवं सम्बन्धित विषयों का मुख्य भारतीय त्रैमासिक

कोड नं. 015 : 8/एमटी

खण्ड : **उनचालीस**

अंक : **चार**

अक्टूबर-दिसम्बर, 2018

India's premier quarterly journal of mining, exploration and allied subjects

Code No. 015 : 8/MT

Volume : **THIRTY NINE**

Number : **FOUR**

October-December, 2018

मुख्य संरक्षक : शेखर सरन
संरक्षक : बी. एन. शुक्ला
ए. के. चक्रवर्त्ती
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सेन्ट्रल माइन प्लानिंग एंड डिजाइन इन्स्टीच्यूट लिमिटेड
गोंदवाना प्लेस, काँके रोड,
राँची - 834 031

Published by

CENTRAL MINE PLANNING & DESIGN INSTITUTE LIMITED, GONDWANA PLACE, KANKE, ROAD, RANCHI - 834 031

मुद्रक

सुमुद्रण
दूसरी गली, हिन्दपीढ़ी, राँची - 834001
फोन नं॰ : 0651-2204437

Printed at

Sumudran
2nd Street, Hindpiri, Ranchi - 834001
Ph No. : 0651-2204437

printed in December 2018

ISSN 0970-7204

खनन विज्ञान
minetech

खण्ड 39, अंक 4
अक्टूबर-दिसम्बर, 2018

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विषय सूची
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व्यक्त विचार लेखकों के हैं
और ये आवश्यक नहीं कि उनके मन्तव्य उनके संगठन अथवा सीएमपीडीआई के अनुरूप हों।

The views expressed are of the authors
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CHALLENGES IN UNDERGROUND COAL MINING

Anil Kumar Rana [1], A.K. Sharma [2] , Shambhu Sharan [3]

ABSTRACT

Under the scenario of progressively increasing coal demand of the country, the continuously declining trend of production from underground mines has been a matter of serious concern for the coal industry. The contribution of underground mines of Coal India Limited (CIL), one of the largest coal producing companies in the world, has touched a new low of around 5.7% to the total coal production during the year 2016-17. The reason for this may be attributed to higher attention towards opencast mining in the race of chasing the fast inflating demand. More than 50% of its underground mines are producing even less than 1 lakh tonnes per annum and output per manshift has remained more or less stagnant over the years. Further, the average cost of mining has been very high in comparison to the sale price of the coal resulting in huge losses in underground operations. Stringent prevailing environmental laws and laws for land acquisition, rehabilitation and resettlement has added further concerns for making the underground mining an economically viable proposition. The challenges in underground mining has been discussed in this paper with a few suggestive measures to deal with them.

Introduction

The energy demand is progressively increasing in the country. Coal being the primary source of fossil fuel for energy generation, chasing the ever increasing coal demand has always been the greatest challenge for the Indian coal industry and the other institutions and organisations associated with it. It is a hard fact to be admitted that over the past two decades while pursuing the endeavour of increasing the total coal production, the attention of the entire coal industry was focussed towards increasing production from opencast mines for several obvious reasons. The coal industry can be said to have been successful in its endeavour of meeting the domestic coal demand, but on the way of its path of progress the performance of underground coal mines in terms of production as well as their contribution to the total coal production has suffered badly.

Persistently declining coal production from underground coal mines and the trend of their contribution to the total coal production, which is presently a mere 5.7% only, are issues of serious concern for the Indian coal industry. While in large coal producing countries like China, USA and Australia the contribution of underground mines have been at 95%, 34% and 26% respectively, the same in India is really an issue of grave concern. Breaking this trend by enhancing production and productivity of underground mines is the biggest challenge before the Indian coal industry. Over the past few years, there is a growing consensus over the need for increasing production from underground coal mines substantially to meet the challenges of increasing demand in the coming future and improving the scenario of contribution by underground coal mines. This would be the greatest challenge for the Indian coal industry in the times to come.

Coal production from underground mines of CIL, the largest coal company of India, has progressively gone down to around 31.5 Mt during the year 2016-17. Fig.-1 below indicates the trend of production from underground mines

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as against the total coal output of CIL and that of their contribution to the total coal production since inception. The rapid fall in contribution of underground mines as evident from **Figure-1** is primarily due to phenomenal growth in production from opencast mines conjugated with progressive decline in production from underground mines.

In addition to this, what is more alarming is the continuously soaring cost of production of underground mines. On reviewing the available data for the past few years, it is evident that the cost of production increased from Rs. 2885.24 per tonne in the year 2009-10 to Rs. 5611.13 per tonne in the year 2014-15 – almost two-fold increase. This has resulted in a tremendous loss to the company as a whole and as per the available sale value for the year 2014-15, the total estimated loss from underground mining has crossed Rs. 9000 crores. This very high cost of mining has been one of the most important reasons for continuously declining trend of production from underground mines. Arresting this rapidly declining trend of production is one of the biggest challenges among others such as technical, economic, environmental and social challenges, which have been discussed briefly below. The prevailing scenario warrants for strategic planning both at corporate and unit level and taking steps towards achieving goal of enhancing coal production from underground mines.

Challenges

Technical challenges

Underground mining is presently limited most commonly within a depth range of 200 to 400m, barring a few mines such as Chinakuri in ECL, Moonidih in BCCL, etc. But with depletion of reserve within shallow cover, underground mining will have to move to deeper levels. With increasing depth, following issues will need to be taken care of during planning as well as operation of underground workings:

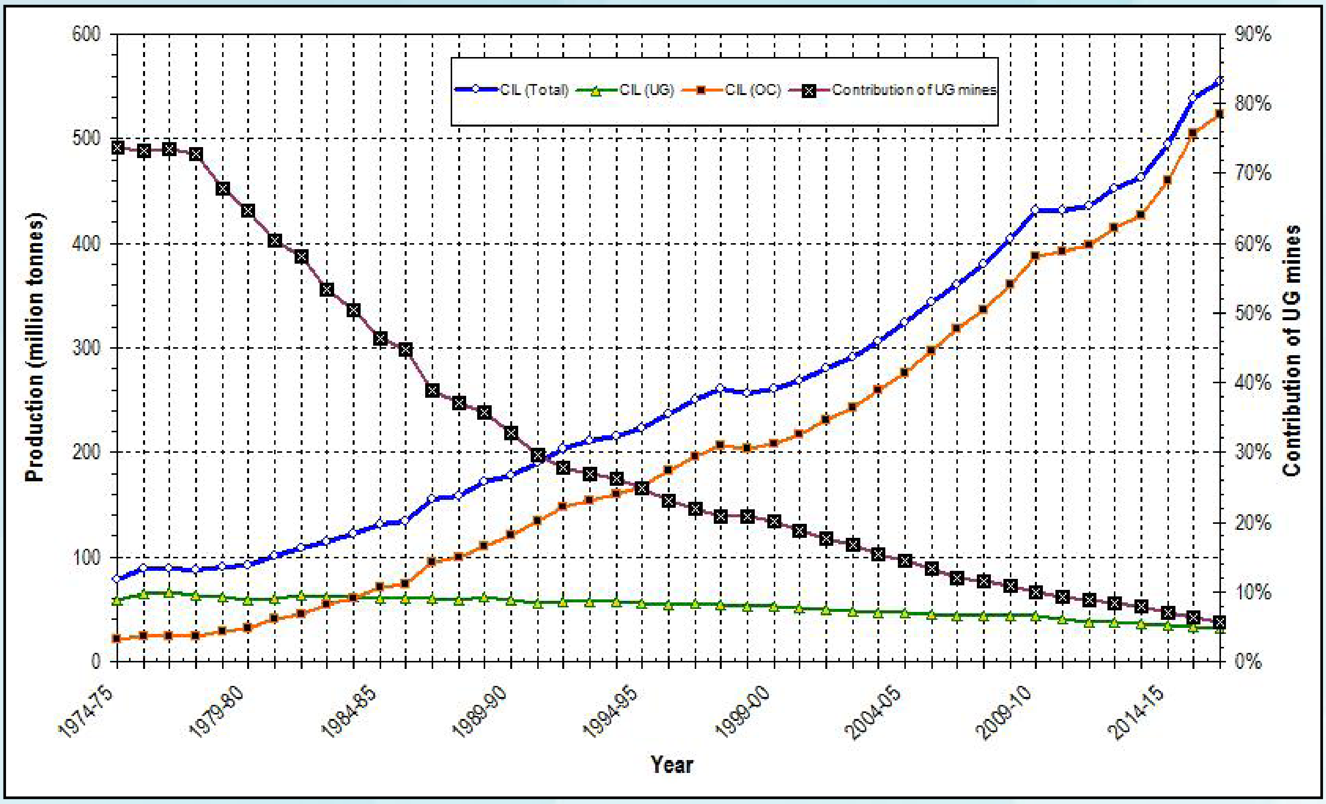

Figure 5 : Year-wise production from OC and UG mines, total production and contribution from UG mines

- Deeper new underground projects will have comparatively higher gestation period and would require comparatively higher initial capital outlay, which will adversely affect the economic viability of such underground projects;
- With increasing depth, workings will encounter increasing stresses, both vertical as well as horizontal, leading to
  - o increased strata control problems;
  - o problems of bumps;
  - o higher cost of supporting roof and sides;
  - o requirement of larger pillar sizes;
  - o adverse impact on productivity;
  - o comparatively lower recovery, etc.;
- With increasing depth, path of transportation of coal, men and material will also increase thereby increasing the cost of transportation;
- With increasing depth, complexity of ventilation arrangements to control mine environment will increase leading to higher cost of ventilating the workings (due to additional requirement of air conditioning, higher capacity main mechanical ventilators, other control devices, etc.) and adverse effect on productivity of working systems;
- Bord and pillar method of working, which is widely prevalent today, may not be applicable for deeper mines and other methods of mining would have to be resorted to, which might be capital intensive and may require larger investments on scientific studies and research (Longwall mining technology is being used successfully for mines as deep as around 1000m in China);
- High depth of working would mean increased problem of water management requiring larger high head pumps, larger capacity water lodgements/ sumps, increased numbers of intermediate sumps, complex network of pipe ranges, etc. thereby increasing the cost of pumping,
- Deeper workings would mean increased complexity of power supply and communication networks, etc.

Also, working under old caved/ stowed goaf areas, working simultaneously in multiple seams/ sections, working thick, thin and inclined seams, etc. would add dimension to the challenges before the coal industry particularly in Raniganj and Jharia coalfields. All these would have dual adverse impacts viz., reduced rate of production and comparatively higher cost of mining. This would be a challenge for the coal industry to deal with.

Additionally, proving virgin seams lying below caved/ stowed goaves and developed seams by detailed exploration with directional drilling, drilling from underground, and 3-dimensional seismic survey (which is used in China to decipher even 2-3m throw faults) would not only incur extra cost but would be challenging too.

Challenges of higher rate of mining

In order to increase production from underground mines, increasing the rate of mining would appear to be a simple solution but will be a challenging task. Modern mass production technology (namely, longwall technology and continuous miner technology), as the name indicates, has the potential to mine at a considerably higher rate. These are the technology that can bail the coal industry out of the grave situation of inordinately low contribution of underground coal mines. These technologies are in operation in a few underground mines of India, but their contribution to total underground production is ostensibly low. Now it would be a challenging task for the Indian coal industry to adopt and make them successful. Although, 12 continuous miner sets and two longwall sets are presently in operation in CIL, it has to go a long way from here. Presently, contracts for their application in a few more mines are currently being pursued by CIL.

The following are some of the notable aspects of these technologies which pose challenges before the Indian coal industry.

- ► Since these technologies are capable of mining at a comparatively faster rate, large reserve base with suitable geo-mining conditions is required to justify the economic life of capital intensive equipments. Being natural resource nothing much can be done in this regard except for identifying suitable mining blocks and/ or suitable virgin seams of existing mines or group of mines.

- Further, application of this technology requires specific set of geo-mining conditions and hence, the same cannot be applied
- These technologies need huge capital investment and the process right from tendering to finalisation of contract in the government-owned coal companies is a long cumbersome process often leading to development of disinterest among capable bidders.
- Since these technologies are not indigenous, contracts are generally negotiated with the global manufactures/ suppliers/ mining contractors. Learning from mistakes/ shortcomings in the earlier contracts made is the need of the time to move towards maturity.
- Since these technologies are fairly new even now for the Indian environment, training and re-training of the operation and maintenance crews are of vital importance to avoid costly maintenance and operation contracts.

Most of these issues can be dealt with if we are able to manufacture indigenously the required equipments for these technologies parallel in quality to that manufactured abroad. This will not only result in reduction in the cost of the equipment, but will also solve the problems of maintenance and spares which most of the mines face with imported equipment. Manufacturing these equipments indigenously would really be a challenging task for the Indian coal industry and interested entrepreneurs of our country. This holds the key to the success of the endeavour of higher rate of output with modern mass production technology and consequently to enhance production from underground mines.

Challenges to mitigate hazards

In the near future, expected increase in complexity of geo-mining conditions due to increasing depth of working and increasing degree of mechanisation in underground mines would also add new hazards which were not commonly experienced before viz., crushing and pinning hazards due to use of large number of mobile machinery plying in the active working areas, increased dust hazards, hazards associated with ground control, bumps, hazards from heat and humidity (requiring air-conditioning with dehumidification), etc. The coal industry will have to face challenges in controlling and managing risks due to these expected hazards associated with underground mining in the near future to enhance health and safety in mines.

Economic challenges

Dealing with the aforesaid technical challenges would certainly mean larger investments in underground mines which would lead to increasing the cost of mining unit tonne of coal. Keeping the underground mining operations economically beneficial would depend basically on the cost of mining and the revenue generated from the sales of coal produced. The mining companies would, therefore, require to minimise the cost of mining while maximising the revenue from the coal produced. While sales proceeding is quality dependent, operating cost of mines is dependent on various factors ranging from surface constraints to geo-mining conditions, method of working to degree of mechanisation, departmental or contractual working, etc.

Further, as DGMS insists the mines to have surface rights of land prior to commencement of depillaring in underground mines, land acquisition particularly after promulgation of the LARR Act, 2015 has become tremendously expensive, which further burdens the project making the economic viability of these mines a distant possibility. Mining coal economically from underground mines and maintaining competitiveness in market would really be a challenging task for the mine operators both under public and private sectors in the times to come. This will also be important from the point of view of financing part of required investments for underground projects through debt capital as the debt providers must be convinced of economic returns from the projects.

Social challenges

Due to high population density, the social issues assume typically high importance in India for any industry. The mining industry, particularly, in India needs to address a lot of social issues which are critical to the success of the mining projects. Some of these issues are land acquisition, rehabilitation and resettlement of project affected persons, carrying out corporate social responsibilities, creating employment opportunities for the local people and providing social welfare services, generating other sources of income to local people and improving their quality of life, etc. The concern for social well-being on part of the mining companies does not cease at the end of the project life, but continues even after the project closure. Handling these issues is becoming more and more difficult day-by-day. Above all, frequent interference by the political leaders in dealing with these issues makes the situation even worse. All these issues not only have financial implications on the project, but also quite often are causes for project delays. These issues are expected to grow further in dimension with time, dealing with which would be challenging for the mining companies.

Environmental challenges

With the growing awareness of the people and world being conscious of the environmental protection, mining coal while protecting environment and ecology has become one of the greatest challenges today for the mining industries worldwide. In order to control global warming, international pressure is increasing to reduce GHG emissions. Hence, the Ministry of Environment & Forest (MOEF) discourages damage to forest cover and affecting the wildlife in any way. It is apprehended that in the times to come, protection of environment and ecology would become even more complex an issue taking into consideration that future coal blocks are mostly in forest areas. Rules and regulations with respect to environment and ecology are becoming more and more stringent with time. Mining projects having forest cover over the coal reserves need to obtain forest clearance with certain conditions that do affect the mine economics and project schedule. Due to underground mining, though, the impact on environment and forest is comparatively less than opencast mining, the underground projects also do need forest clearance if they fall under forest cover. Thus, this issue presents a challenge for underground mining too.

Way Forward

Underground mining in the present scenario, as discussed above, is in a grim situation. The condition of the mine surface during the past few years due to the prevailing laws for land acquisition, rehabilitation and resettlement, environment and ecology, etc. is playing crucial role in deciding the financial viability of underground projects, which is fast becoming a distant possibility.

In view of the above, it is now required to direct attention towards underground mining so as to arrest the declining trend of production and its declining contribution to the total production. Strategic steps and concerted efforts are required to check the increasing trend of cost of production. Some of these steps including some hard decisions may have to be taken are mentioned below.

- For increasing production from underground mines, those underground projects for which project reports have already been approved in principle should be put on fast track and a monitoring mechanism at the apex level should be established to ensure that projects are not delayed.
- In mines deploying SDL/LHD, additional SDL/ LHD may be considered if, even a marginal increase in production can be achieved. The key factor for consideration should be linked with the cost of production (production in a panel per shift) rather than machine productivity on roll basis for SDLs/LHDs.

- Large number of mines, where coal production is extremely low, need to be examined for each of its systems and sub-systems for identifying bottle-necks, adopting mitigative measures, and finding scope of improvement.
- Induction of mass production technology in underground mines having suitable geo-mining conditions needs to be seriously considered for improving performance of underground mines, since this technology has the potential to improve the grim situation of underground coal mining in the country.

  As the required geo-mining parameters for the application of LHDs and continuous miners are the same, an effort should be made to replace LHDs with continuous miner (a mass production technology) in all the mines deploying intermediate technology, in a time-bound manner.
- Where semi-mechanised or mechanised workings are in operation, availability and utilization of equipment should be closely watched and suitable corrective measures should be adopted if these fall below a particular level.
- In order to obviate land acquisition or for protecting the surface from extraction of coal, partial extraction or extraction with stowing may be considered. Wherever mining with hydraulic sand stowing is in practice or has been proposed, using crushed overburden may considered from the point of view of scarcity of river sand, higher cost of their transportation, no subsidy for stowing, and environmental protection.
- All the points given above were on the basis that there is no subsidy for production of coal from underground mines. It is also suggested that some fixed levy should be imposed on opencast production per tonne which should be equally distributed over the production of underground mines across the subsidiary. A legally vetted mechanism would, however, be required so that the subsidy can be transferred inter-subsidiary also without any additional liability of tax to either of the companies.
- Amalgamation and reorganization with a strict focus on either increasing profit or reducing loss should be made on time-bound basis.
- Stringent measures for reducing cost of production needs to be considered and in mines where substantial cost reduction does not appear to be feasible for any reason, whatsoever it may be, the management might have to seriously consider taking hard decisions of closing them down.
- Master plan for underground mining needs to be prepared for each coalfield for planning new projects, reorganizing existing projects, identifying mines for foreclosure, exploring possibilities for redeploying manpower due to closing down of mines, planning for rehabilitation and resettlement for potentially project affected families, planning for required infrastructure, etc.
- At present there is no laid down procedure for implementation of new technology and new machinery, which is hampering introduction of new technology in underground mines. A simple procedure should be laid down for the introduction of new technology and new equipment in underground mines and there can be three distinct classifications under which the procedure can be made.
  - In case where introduction of new technology results in an IRR of 12% or more on incremental basis, such technology or introduction of new equipment should be introduced on experimental basis with simplified procedure;
  - In case the introduction of new technology resulting in break-even,

then a simple procedure should be there to test the technology on experimental basis;

- Where it is not possible to accurately estimate the rate of return by introduction of new technology or rate of return is not favourable, R&D route may be taken which is available as of now also.

- Procedure to procure materials, services and spares should be simplified.

Also, developing green technologies like underground coal gasification, tapping coalbed methane (CBM), coal mine methane (CMM), abandoned mine methane (AMM) and ventilating air methane (VAM) from gassy coal seams would play a significant role in exploitation of fossil-based energy. All these would add new dimension to the underground mining in the times to come.

Summary and conclusions

As discussed above there are several challenges that underground mining in the Indian coal industry has been facing and will continue to face in the times to come. These challenges would be multi-faceted ranging from technical to economic and social to environmental. The coal industry will have to face these challenges strategically and boldly for the growth of production from underground mines and its contribution to the total coal production in the country. Though opportunities are less than challenges, the industry will have to tap each of these opportunities efficiently and use it effectively. All those concerned will have to make concerted efforts to ride over the waves of challenges ahead through mechanisation, modernisation and re-engineering of underground mining operations and achieve success in the endeavour of this industry.

IMPACT OF COAL CHARACTERISTICS ON COAL GASIFICATION

Navin Kumar Singh [1], Varun Kumar Panghal [2], Anunay Jain [2], Trilok Nath [2]

ABSTRACT

Coal is an important source that can play critical role in boosting any countries economy. India is among one of the few countries that has vast coal reserves. Utilizing this resource in the best possible manner can only be achieved by exploring alternative use of coal applying Clean Coal Technologies. Its importance increases manifolds considering India's commitment to Paris Climate Treaty to reduce the carbon emissions intensity by 30%-35% below the 2005 level by 2030. The country's dependence on coal as primary source of energy will continue in the future as India plans to produce 1.5 Billion Tonne of coal by 2020 and increase it to 2.5 billion by 2032. In view of such increase in coal production and consumption, India's commitment to Paris Climate Change Agreement and Make in India Programme of Government of India for import substitution adoption of clean coal technologies for production of chemicals (through gasification route) and to improve efficiency in power generation should be a part of our energy security plan.

Coal gasification is a proven Clean Coal Technology which not only captures the CO2 emissions but also helps in chemical production along with carbon sequestration. Coal gasification is the process to utilize coal for production of chemicals, fertilizers, petrochemicals and many other applications particularly methanol which is a building block for many chemicals and can also be blended with gasoline pool to replace naptha and also attracts the business in our country. The process is regulated by several operating parameters. In order to select an optimum technology for surface coal gasification, it is important to study the various coal characteristics which affect the gasification process. Therefore, laboratory applications become vital in understanding these coal characteristics. A number of investigations have been carried out in this direction. The effect of several operating parameters such as, pressure, temperature, porosity, coal rank reaction time and catalyst on gasification has been discussed in this article.

Introduction

India is one of the country having vast coal reserves and utilizing the source in the best possible manner can prove to be highly significant by producing Ammonia, Fertilizers, Chemicals and Petrochemicals in addition to conventional use as an energy source either for electricity or heat at present. India has very limited gas and oil reserves. Currently coal is primarily used for power generation. Considering the current crude & gas price scenario these options especially Coal Gasification have been found to be challenging in terms of investment required. However, with respect to nation's energy security these are the tried and tested options which cannot be overlooked. The syngas from Coal gasification is still competitive given the low price of coal with respect to petcoke. Past couple of years, even the government has been promoting Coal gasification as the alternate feedstock for the fertilizer industry, methanol etc for developing

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self-reliance, apart from the domestic gas. Globally syngas is also being used to make valuable chemicals at competitive price.

Coal gasification is considered an important strategy towards Clean Coal Technology with a goal of reducing its environmental footprints/low carbon energy development. The product of the coal gasification process is a syn-gas, which is a mixture of carbon monoxide, hydrogen, methane, carbon dioxide gases, unsaturated carbon etc. with associated Gross Calorific Value (energy content). The composition of the gas mixture and its calorific values depend on the type of coal fuel, gasifying media and operating parameters of the gasifiers. It can be utilized just like natural gas in an eco-friendly manner. Gasifiers are designed according to coal characteristics.

Coal characteristics are the most important factors that influence the gasification process selection and design. Generally, low-rank coals are the preferable feedstocks for the commercially available gasification processes, in comparison to the caking bituminous coals. The main properties of low-rank coals, which impact the choice of gasifier or process application, are the reactivity, the moisture and oxygen content, the volatiles content, the caking properties, the ash characteristics and the sulfur content.

Major Coal Characteristics affecting Gasification

1) Reactivity

Reactivity is defined as relative degree of ease with which coal undergoes gasification reaction. The major property which governs the ease of conversion is the rank of coal, which in turn reflects its volatile matter content, oxygen content, level of maturity, extent of aromatic ring condensation, and porosity. Low ranked coal has high volatile matter content and more porous structure. As the rank increases the carbon lattice becomes better aligned and the porosity reduces and the carbon structure becomes less reactive developing the flat basal structures. The low rank coal is more reactive than that of high rank coal.

The cause of the higher reactivity in low rank coals is the higher porosity, the larger number of active sites, and higher content & dispersion of catalytic metals such as calcium, potassium, and sodium. The organic matrix in low rank coals have carboxylic acid and other heteroatomic (Oxygen, Sulphur, and Nitrogen) functional groups that have exchanged hydrogen ions with these cations producing ideal catalytic sites which lowers the activation energy for gasification reactions.

Reactivity Measurement

Thermogravimetric analysis is used to measure the reactivity of materials and can be operated under isothermal and non-isothermal conditions. This technique is particularly employed in coal research to determine the rate of mass loss in an oxidizing/ inert atmosphere under dynamic heating conditions.

Figure 1 : HP-TGA

2) Moisture and Oxygen

The moisture present in the coal acts as a diluting agent. Higher moisture contents reduce the thermal efficiency of gasifier and leads to low gas heating values. Igniting the fuel with higher moisture content becomes increasingly difficult, which results in poor gas quality & poor yield.

High moisture content of the feed lowers internal gasifier temperatures through evaporation and the endothermic reaction of steam and char. Therefore, a limit must be set on the moisture

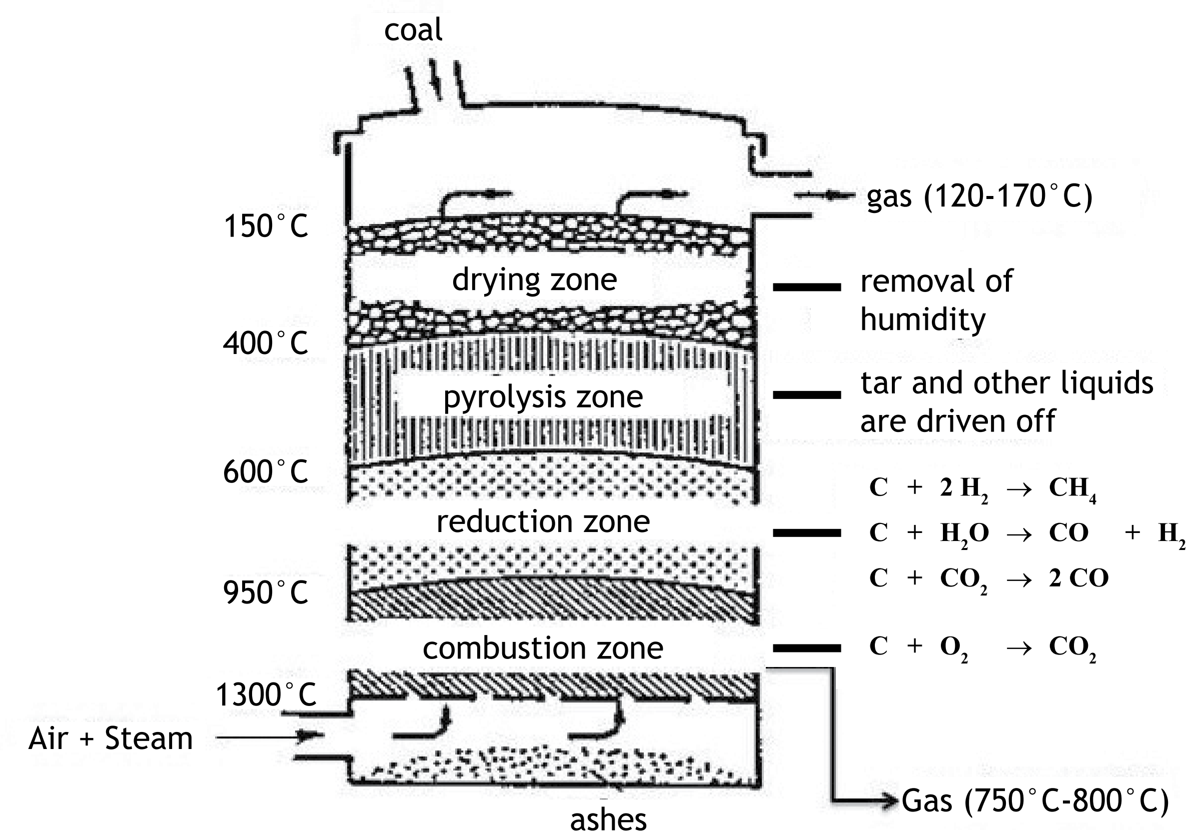

Figure 2 : Different stages of mass loss of coal in Double Stage Gasifier

content of coal supplied to the gasifier, which can be done by coal drying operations. For fixed bed gasifier and medium ranked coal with average ash content, this limit is about 35 percent. Entrained flow and Fluidized bed gasifiers have a lower tolerance for moisture, varying generally from 5~10 % for a similar coal feedstock. As moisture or ash content of coal is increased, the oxygen supplied for coal gasification will have to be increased.

The higher oxygen content in low rank coals results in lower heating value when compared with higher rank coals. To minimize the effectively higher oxidation state of the low rank coals a higher coal feed rate is required to obtain similar product gas quality. Due to high coal feed rate, larger amount of solids, liquids and gases are generated and therefore larger process equipment is required.

Additionally, as the oxygen and moisture contents increase, the integrity of the coal structure becomes weaker. The high oxygen content of low-rank coals affects the gasification process, in a similar way to the moisture content. Since low-rank coals are partially oxidized, the energy content of the product gas is lower.

If the moisture level of the feed is high, the heat produced in the lower region of the reaction will be insufficient to vaporize it. As a result, the bed temperature will drop and the flow of molten slag may be stopped, shutting down the unit.

3) Volatile Content

Reactivity of coal char during gasification is dependent on volatile matter content in coal and rank of coal. Reactivity of char is directly proportional to the volatile content of coal. With the increase in volatile matter content the reactivity of char increases. The change in volatile content of coal with respect to pressure change is well established. Total volatile content decreases with increasing pressure during pyrolysis. This

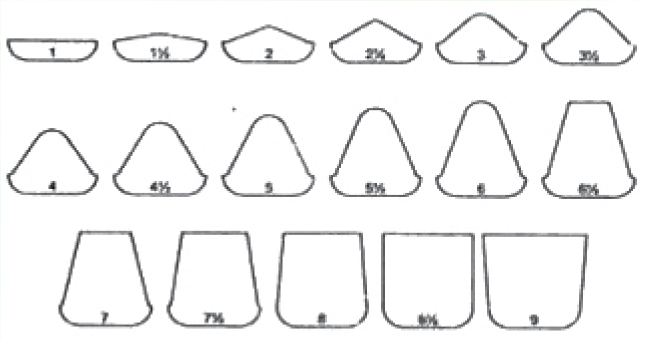

Figure 3 : Standard profile of coke for Crucible Swelling Number

trend is observed due to deposition of secondary char on the particles and suppression of volatile yield at higher temperature.

The composition of the volatiles produced from low-rank coals during gasification is different than that of higher rank coals. Separation, treatment and utilization of these volatile substances will be different in plants utilizing low-rank coal than in plants using high-rank coal.

A large amount of tars, oils, phenols and other compounds are produced in fixed-bed gasifiers. Fluidized and Entrained-bed gasifiers which operate above 800°C, the produced tars, oils, phenols and other compounds are cracked to carbon and hydrogen thus eliminating the requirement for complex treatment facilities.

4) Caking Properties

Most of the bituminous coals tend to swell and agglomerate when heated between 350°C and 550°C. Masses of coke that form during gasification cause disruptions to the uniform flow of gas through the gasifier and also results in lower thermal efficiencies. These coals can be gasified without problem in entrained-bed systems where particle interactions are minimized.

However, they are not suitable for use in fixed or fluidized-bed systems without some pretreatment, which will reduce their caking tendency. The caking properties of coals could be destroyed by fluidizing the coal with a gas such as nitrogen, nitrogen plus carbon dioxide, or steam, containing at least 0.2 percent oxygen at 400°C or 425°C.

On the other hand, low-rank coals do not have caking properties and can be processed without pretreatment in all types of gasifiers.

5) Mineral Matter

Gasifier performance is affected by mineral matter. For most slagging gasifiers minerals melt to form and provide an insulating surface on the wall of the gasifier. Due to this, the rate of heat transfer decreases during the gasification reaction. Mineral matter also has an effect on the requirements of the slag tap and the slag handling system. Mineral matter also affects slagging efficiency, is the percentage of mineral solids recovered as slag out of the bottom of the gasifier relative to the total mineral solids generated by the process.

Iron sulfide, or pyrite, has a high density and relatively low melting point and is often found in the clinkers produced by temperature excursions in fluidized bed gasifiers. Fluxing agents, such as sodium and calcium, particularly when combined with the ubiquitous clays and pyrite reduce the ash melting temperatures and are often identified as the cause for the initiation of process clinkers.

As a result, coal mineral composition is monitored as closely as the heating value in an attempt to avoid operational problems. These minerals are generally evaluated by analyzing the oxide residue or ash produced upon burning the coal.

Ash Fusion Temperature

The ash fusion temperature is the temperature at which the mineral matter in the coal starts to melt. It is important for industrial dry-bottom gasifiers to operate below this temperature, because when the gasification temperature rises above this temperature, the ash will melt and agglomerate, which will in-turn cause unstable gasifier operation. When the minerals melt, it covers the external surface area of the particle. This in turn results in a decrease in char reactivity due to the decrease in the available surface area for the gasification reaction to take place, because

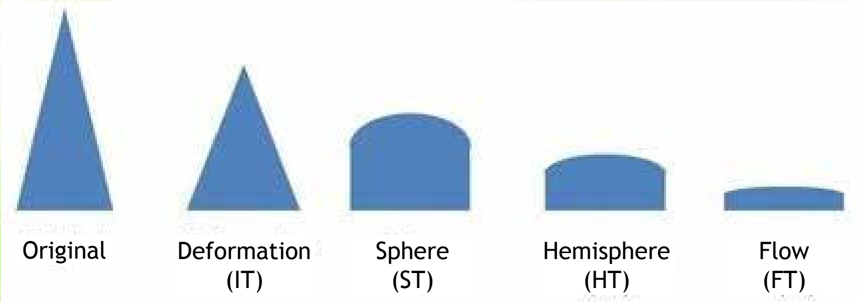

Figure 4 : Shapes of the AFT Measurements

the reactant gases cannot diffuse to the active carbon sites on the char particle. An increase in the SiO_2/Al_2O_3 ratio as well as the Fe_2O_3 concentration in the coal ash indicates a lower ash fusion temperature.

Fouling Precursors : Fouling in Gasifiers can result from constituents such as chlorine, sodium, potassium, and calcium. Most fouling indexes are based on experience with pulverized coal boilers. This information is often used to select conventionally high fouling coals to obtain fouling data on gasification units.

Corrosive Components : The primary coal properties affecting corrosion are sulfur and chlorine levels. Upon gasification these elements form acidic gases, hydrogen sulfide, and hydrogen chloride, which are responsible for corrosion of metals and other materials. The formation of these corrosive species is dependent on their content in the feed coal.

Ash Melting Point/Slag Viscosity : For gasification technologies utilizing a slagging gasifier, slag flow behavior is an important parameter. To determine slag viscosity, the viscosity of coal ash is measured in a reducing atmosphere .Slag behavior is affected by the properties of both gaseous and solid phases, gasifier wall structure, fluid dynamics, and operating conditions.

Under reducing environments (gasification), the viscosity at a given temperature is generally lower than under oxidizing atmospheres (conventional combustion).

At elevated temperature, slag acts as a Newtonian fluid, and its viscosity usually decreases logarithmically as temperature increases. At lower temperature, crystallization or the separation of immiscible liquids may cause a dramatic increase in viscosity, and, as a result, the slag behaves as a non-linear viscoplastic fluid.

Slag viscosity, along with temperature of critical viscosity (Tcv), is used to characterize slag flow behaviors and is the most important parameter in selecting the operating temperature of the gasifier. Because slag viscosity strongly depends on temperature and chemical composition, it could be optimized by raising/ reducing the gasifier operating temperature or adding a flux or blend coals with low fusibility.

The chemical composition of coal ash is an important factor in slagging gasifiers because it affects ash fusibility, slag viscosity, and refractory life. Silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), ferric oxide (Fe_2O_3), titanium

Figure 5 : Viscometer

oxide (TiO_2), phosphorus pentoxide (P_2O_5), calcium oxide (CaO), magnesium oxide (MgO), sodium oxide (Na_2O), potassium oxide (K_2O), and sulfur trioxide (SO_3) are the major components of coal ash. All these components, specifically the calcium and iron contents are believed to be indicators for ash fusion properties. CaO in particular is an important factor in the viscous properties of slag. As the CaO content increases, the viscosity of slag increases. Trace components, such as mercury, chlorine, fluorine, etc. contribute greatly to the environmental issues associated with coal usage. Certain chemical components of coal ash (i.e., CaO, SiO_2, Fe_2O_3) can attack the refractory and cause cracks.

Using an Arrhenius type equation, related viscosities of slags for the entire temperature range to their compositions expressed in terms of the percent by weight of SiO_2, Al_2O_3, MgO, CaO, and iron oxides, where viscosity equation:

$\eta = A \exp(E/RT)$

changed to

$\log(\eta)$ (in poise) $= [(10^7 \times m)/(t-150)^2] + c$

(where, m and c are given in terms of compositions (metals oxides) as defined below and t is the temperature in degrees C).

$m = 0.0083\ SiO_2 + 0.00601\ Al_2O_3 - 0.109$

$c = 0.0415\ SiO_2 + 0.0192\ Al_2O_3 + 0.0276\ Fe_2O_3 + 0.0160\ CaO$

$(SiO_2 + Al_2O_3 + Fe_2O_3 + CaO + MgO = 100 (wt\%))$

$\log(\eta) = [4.468 \times (S/100)^2 + 1.265\ (10^4/T) - 7.44$

Where, S is the silica ratio and T is the temperature given in K.

6) Porosity of Char

Pyrolysis results in removal of volatile matters and yields a solid residue called char. It is important to study the internal structure of solid residue after heat treatment because it affects the char reactivity. There are number of randomly oriented and different shapes pores with radii ranging from one length of nanometers to tens of nanometer. To explain the formation of pores during gasification, there are three mechanisms

1. The width of existing pores,
2. The formation of new pores by selective gasification of certain structural components and
3. The opening of formerly unreachable pores.

Pore structure of the coal has significant role in coal combustion and gasification. International Union of Pure & Applied Chemistry classified the pores into three categories:

- Micropores (diameter <2 nm),
- Mesopores (diameter 2– 50 nm) and
- Macropores (diameter >50 nm)

Effect of temperature on pores formation is well established. It is learnt that as the temperature increases up to a certain level (i.e.,600 0C) porosity increases and concentration of feeder coal decreases but results in lower reactivity, with

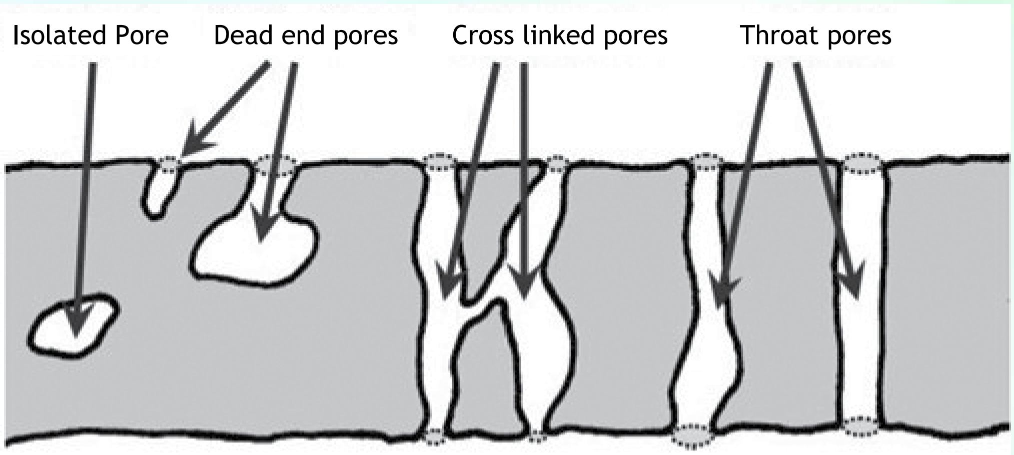

Figure 6 : Various pores distribution

further increase in temperature. The reactivity of coal after certain temperature can be decreased because of heat treatment which promotes closing of pores. Closing of pores caused due to presence of large molecules, compressing disorganized carbon, cross linking and collapsing of pores at higher temperature due to plasticity of char.

Porosity of the coal is usually calculated from the particle density (Dp) and true (Ht) density:

Porosity (%) = [(Ht - Dp) / Ht] × 100

7) Petrographic analysis of coal and its impact

The properties associated with the petrographic constituents in coal have a great influence on coal behaviour during heating and gasification. The Coal consists of maceral (organic) and mineral (inorganic) constituents on microscopic level. The maceral groups refer to the various plant material from which the coal was derived.

These petrographic properties include:

- Vitrinite reflectance.
- Maceral composition of the coal.
- Microlithotype composition of the coal.

The reflectance of a coal sample gives an indication of the degree to which the coal is matured, which varies from brown coal to anthracite. The reflectance value increases with an increase in rank, and thus, also with an increase in the carbon content of the coal. The vitrinite maceral group was chosen as the reference for coal reflectance measurements, as the vitrinite reflectance increases with an increasing degree of coalification.

The chemical make-up related to the various maceral constituents in the coal also influences the gasification behaviour of the coal. Inertinites are derived from strongly altered or degraded plant material that is thought to have been produced during the formation of peat; the inertinite maceral group has the highest carbon content, as well as the lowest volatile yield; therefore it has the highest carbon/hydrogen ratio compared to the other maceral groups. Inertinite is associated with the formation of dense, hard to ignite chars during pyrolysis, and is capable of forming any type of char depending on the rank of the inertinite coal. It is known that low-rank inertinite-rich coals exhibit swelling behavior during pyrolysis which results in a slightly more porous char with increased reactivity.

Vitrinite is shiny, glass-like material that is considered to be composed of cellular plant material such as roots, bark, plant stems and tree trunks. Vitrinite-rich coals contain a higher amount of volatile matter compared to the inertinite maceral group, but less than the liptinite group. The vitrinite maceral group is rich in oxygen. Vitrinite-rich bituminous coals soften during pyrolysis and expand to form cellular structures, which increase the internal surface area resulting in a porous char. It can be said that vitrinites undergo both a physical (porous structure) and a chemical (devolatilisation) change during pyrolysis.

Liptinite macerals are considered to be produced from decayed leaf matter, spores, pollen and algal matter. Resins and plant waxes can also be part of liptinite macerals. Liptinite macerals tend to retain their original plant form, i.e., they resemble plant fossils. These are hydrogen rich and have the highest calorific values of all coal macerals. Liptinite-rich coals have the highest volatile content and thus also the highest hydrogen content. This maceral group has been shown to have the lowest reflectance value as well as the lowest aromacity. These liptinite-rich coals have the highest tar and gas yields during pyrolysis, due to the large amount of volatiles contained in the coal.

It follows that the coal properties associated with microlithotypes, which are the combination of maceral groups also influence the gasification behaviour of the coal. When vitrinite occurs in combination with another maceral group, the resulting coal has a higher reflectance compared to the pure vitrinite maceral; these coals also have a higher density compared to pure vitrinite. These microlithotypes are influenced by the pyrolysis temperature and have a low porosity compared to the pure vitrinite, which also results in lower reactivity due to the limited surface area available

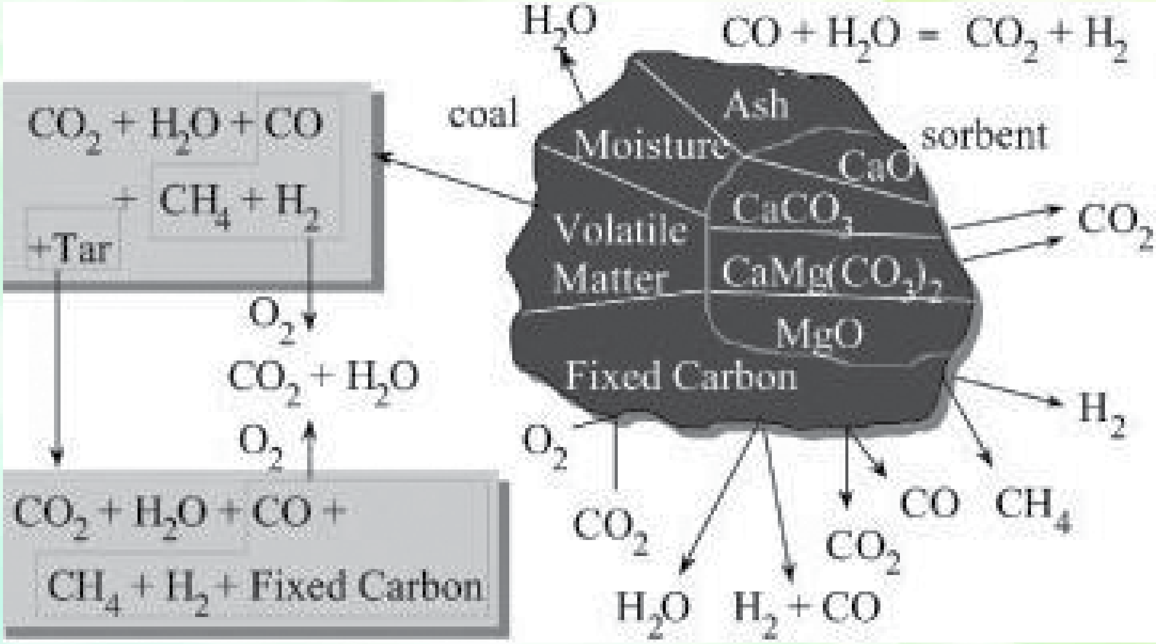

Figure 7 : Gasification Chemistry

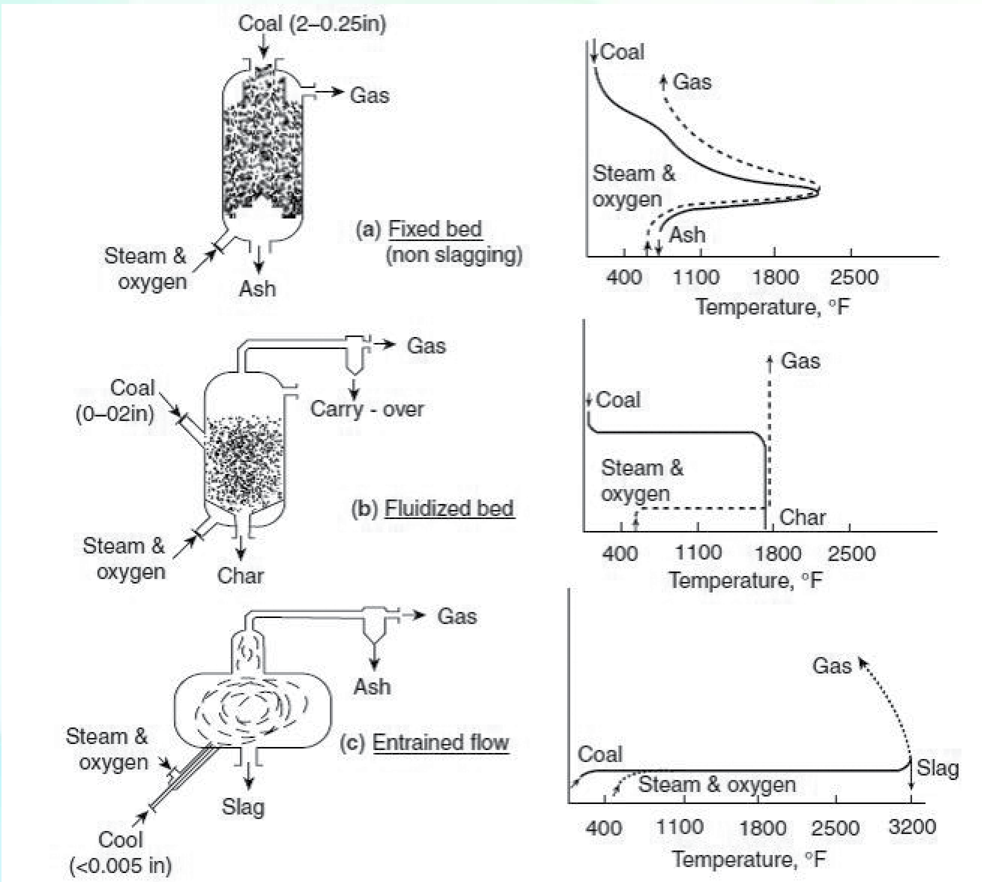

Figure 8 : Different types of Gasifiers along with operating curves

for the reaction to take place.

8) Gasification Chemistry: (Refer **Figure-7**)

9) Types of gasifiers

Depending upon the medium of gasification, gasifiers can be classified into two categories

(1) Air Blown: Air is used as a gasification medium in this type of gasifiers.

(2) Oxygen-Blown: Pure oxygen is used as a gasification medium.

When air is used as gasification medium, the N_2 is simultaneously brought into the process which results in the product gas dilution. As a result product gas will have a lower calorific value compared to that of oxygen blown which is free from diluents like N_2.

Depending upon the contact between gas and fuel, gasifiers can be further divided into following three types (Refer-**Table-1**):

(1) Moving or Fixed Bed Gasifier.

(2) Fluidized bed Gasifier.

(3) Entrained Bed Gasifier.

Table-1 : Types of gasifiers and comparision

CATEGORY	FIXED/MOVING BED		FLUIDISED BED		ENTRAINED BED
Ash Conditions	Dry Ash	Slagging	Dry ash	Agglomerating	Slagging
Typical processes	Lurgi	BGL	Winkler	KRW, U Gas, HTW, CFB, SES	Shell, GE, CB&I (E Gas), Neoll, KT
Suitable Feedstocks	Wide coal	Bituminous coals, Petcoke	Lignite, coal, biomass and bituminous coals (Non-caking coals)		Lignite, bituminous coal (all types), petcoke
Feed Characteristics					
Size	6-50 mm	6-50mm	6-10mm	6-10mm	< 100 um
Fines Acceptability	Limited	better than dry ash	Good	Better	Unlimited
Preferred coal rank	Any	High	Low	any	Any
Temperature	~ 700-1100°C		~900-1200°C		~1500°C
Operating characteristics					
Combustion temp.	1300°C (Slurry feed)	1500-1800°C (Dry feed)	~900-1200°C		~1500°C
Outlet gas temp (Temperature Range)	Low	High (425-650°C)	Moderate (900-1050°C)		High (1250-1600°C)
Pressure range (Atm)	1-10		10-30		30-80
Oxidant demand	High	Low	Moderate		High
Steam demand	High	Low	Moderate		Low
Throughput	Low throughput per gasifier		Medium throughput & low conversion per pass		High throughput & high per pass conversion
Residence time	High (1-3 hr.)		Medium (20-150 min)		Short (0.4-2 sec)

Conclusion

Looking at the National Energy Security and import of Oil & Gas, Chemicals, Fertilizer, Petrochemicals and vast reserve of coal in our country, this is a need of the time to use coal as alternative feedstock for chemical, petrochemical, fertilizer etc. Benefits of using coal as an alternative feedstock to chemicals, petrochemicals and fertilizers would be beneficial for Macro Economy, Employment Generation, Make in India Program of Govt. of India, saving in foreign exchange and help in PM's ambitious target of reducing 10% import dependence of oil & gas by 2022 from 2014-15 levels, revenue generation-taxes, duties, royalty etc., low emission of gaseous pollution, low carbon footprint, favoring energy security of India etc. Recognizing the potential of coal as game changer in the Indian Energy Sector, Surface Coal Gasification would be a suitable Clean Coal Technology for future.

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ECO-FRIENDLY AND MASS PRODUCTION TECHNOLOGY WITH SURFACE MINER IN OPEN CAST COAL MINING IN INDIA

*Prof. M. P. Dikshit **

ABSTRACT

Contribution from open Cast (o/c) coal Mining is significantly increasing after nationlisation of Indian coal mining Industry and it comes to around 93.75 % of the national coal production in the last fiscal. In Coal India Limited (CIL) it is 94.62 % in the financial year 2017-'18.

The disadvantage from the O/C technology in large scale Mining is the environmental & Land use issues.

At this juncture we are to adopt eco-friendly coal mining in our mega o/c coal mines for its better acceptability of the society.

In surface miner operation besides eco-friendly mining option there are many positive sides for its most economic operation, less activity, sized output being need for power utilities who are the major consumer of thermal coal.

Where the O/C mine property is with sufficient reserve and mine geometry permits, surface miner operation is perhaps the best option for economic and eco-friendly mining solution.

1. Introduction

Our coal Mining Industry has shown quantum jump in production in last 3 decades and also witnessed a phenomenal growth in open cast coal production.

There is a continuous downward trend in underground (u/g) coal production after nationalisation of the coal Industry. However open cast (o/c) coal production increased consistently and contributes around 93.75% in the country and in Coal India Limited it is 94.62% in the last fiscal (2017-'18).

In Coal India Limited, the o/c coal production of 15.4 Mt at the time of nationalisation stands now 536.82 Mte in the year 2017-18. In the period of last 10 years the o/c coal production shows a growth of 243 Mte. In Coal India Ltd and it is to further increase as per the projected 1 (One) Bte coal production by the financial year 2019-20.

The mega o/c coal mine even 41 Mte / annum capacity has come to a reality in India now and more such mega o/c mines are being planned with suitable mechanization using high capacity Heavy Earth Moving Machinery (HEMM), crushing of coal, automatic silo loading, Merry go round etc.

Now a days major open cast operation with conventional drilling & blasting, crushing, coal loading conveying leads to adverse impact towards environment, land degradation & water pollution etc.

Hence mega o/c mine operation calls for improvement in the coal wining system, handling etc. so that the growth is eco-friendly, acceptable to the community and sustainable as techno-economically the best.

Adoption of surface Miner technology in

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Table 1			
Description	**Middle drum**	**Front Cutting boom**	**Front cutting wheel**
Cutting width (mm)	250-4200	5250	7100
Cutting depth/height (mm)	0-800	1000/5500	0-2900
Weight (Te)	40-190	135	540
Installed power (KW)	450-1200	750	3350

opencast coal mining practices is a strong positive step towards mega o/c mine management efficiently from both the important considerations like techno-economic and environment friendly.

2. Surface Miner-its Application in Mining Industry

In Indian Mining Industry, surface miner made its beginning in year 1996 and that in coal mining operations in 1999. Presently some 150 surface miners are operating in countries coal mining industry.

Some surface miner as being operated in our open cast coal mines on the basis of their market availability as are detailed below.

a. Front cutting drum type

b. Front cutting wheel type

c. Middle drum configuration type.

Brief technical parameters of the above types of surface mines are shown in **Table-1**.

In the above 3 type of surface miners, middle drum type finds wider applications specially for the Geo-mining environment prevailing in Indian opencast coal mining. There are also surface miners from L&T, Puzollana which are working satisfactorily. Now a days other models with variations are also developed for faster operation and higher output achievement. The average machine productivity varies from 7000 to 15000 TPD of coal.

Production of coal from surface miner is increasing for its numerous advantages and specifically to meet the growing demand of sized coal in our power utilities and other ancillary industries.

3. Formulation of Mega Opencast Coal Mines in India

In Coal India Ltd, Coal production for the financial year 2017-'18 was567.36 Mte where o/c shared 536.82 Mte. The growth in opencast coal production and productivity show a steady rise subsequently as mentioned in the **Table-2**.

Productivity in o/c coal mines is almost doubled for technology improvement and thus operation of high capacity opencast coal mines in Indian Coal mining scenario. Coal production is to reach 1 Bte by 2019-20 with appropriate technology adoption and capacity improvement in mines. Underground mine has got many restrictions and hardly there are counted mines which produces over 1 Mte/annum and there is only one u/g mine in the country which crosses 2 Mte/annum i.e. Jhanjra u/g mine (ECL).

But there are so many o/c mines which operates over 10 Mte capacities/annum.

Even number of mega o/c coal projects in the country are able to produce 20 Mte/annum now. It is a need of the hour for formulation and implementation of high capacity Mega o/c coal mines now and in the days to come in meeting the further challenges for increase in coal production economically with safety and eco-friendly in India.

It's a fact that the decline in coal production from existing old and some completed projects are not fully made up by on going projects only. Now it requires planning and implementation of new projects not only to make up the loss of output from existing mines but also to achieve the subsequent projected growth in coal production. In the existing situation thus message is clear and loud for opening many new high capacity mega opencast mines to achieve the targeted coal output to meet the national demand. Also the

Table-2 : National Coal Production & CIL's production/productivity from 2005-06 to 2017-18									
Year	National coal Production (Mte)			CIL's Coal Production & Productivity					
	U/G	O/C	Total	Production (Mte)			Productivity		
				U/G	O/C	Total	U/G	O/C	Overall
2005-06	60.965 (14.98%)	346.074 (85.02%)	407.4	45.82 (13.34%)	297.57 (66.66%)	343.39	0.71	7.51	2.95
2006-07	57.698 (13.39%)	373.199 (86.61%)	430.897	43.33 (12.00%)	317.61 (88%)	360.94	0.71	8	3.54
2007-08	58.88 (12.90%)	397.517 (87.10%)	456.397	43.54 (11.47%)	335.95 (88.53%)	379.49	0.73	8.6	2.79
2008-09	58.972 (11.96%)	433.785 (88.04%)	492.757	43.96 (10.88%)	359.77 (89.12%)	403.73	0.76	8.95	4.09
2009-10	58.52 (10.99%)	473.522 (89.01%)	532.042	43.25 (10.02%)	388.01 (89.98%)	431.26	0.78	9.51	4.47
2010-11	54.86 (10.29%)	477.832 (89.71%)	532.692	40.02 (09.27%)	391.3 (90.73%)	431.32	0.77	10.06	4.73
2011-12	51.96 (09.62%)	487.99 (90.38%)	539.95	38.39 (08.80%)	397.45 (91.20%)	435.84	0.75	10.40	4.89
2012-13	52.206 (09.36%)	505.501 (90.64%)	557.707	37.78 (08.35%)	414.41 (91.65%)	452.19	0.77	11.48	5.32
2013-14	49.65 (08.77%)	516.12 (91.23%)	565.77	36.11 (08.46%)	426.3 (91.54%)	426.41	0.76	12.18	5.62
2014-15	50.20 (08.20%)	516.8 (91.80%)	612.00	35.04 (07.08%)	459.19 (92.92%)	494.23	0.79	13.13	6.20
2015-16	48.5 (07.59%)	583.68 (92.41%)	638.18	33.79 (06.27%)	504.75 (93.73%)	538.75	0.79	14.83	6.88
2016-17	44.35 (6.69%)	618.44 (93.31%)	662.79	31.47 (05.67%)	522.66 (94.33%)	554.14	0.78	15.14	7.47
*2017-18	42.30 (6.25%)	634.18 (93.75%)	676.48	30.54 (5.38%)	536.82 (94.62%)	567.36	0.86	14.66	7.84

**Provisional Figs*

u/g coal production to be enhanced consistently but it cannot be in the same voluminous tune as possible from o/c mines. At least u/g production to be restricted from further negative growth rather with some positive growth which now contributes hardly around 5% of the national coal production.

4. Status & Strategy for Future Open Cast Coal Mining

The growth of o/c Coal Production has been cumulatively in increasing tune by using high capacity HEMM in o/b and surface miners in coal production particularly in the mega o/c Projects in India. Presently opencast coal mining contributes around 634.18 Mte (93.75%) of total national coal production and that in coal India it comes to 94.62 % (536.82 Mte) in the financial year 2017 - '18 with a productivity (OMS) of 14.66 in o/c coal mining in CIL.

In CIL, out of the total o/c coal production of 536.82Mte, surface miner contributes around 60% at this stage. Most of the machines are on outsourcing basis. However some surface miners are procured by the coal companies like MCL (20Nos), NCL (4nos.) and presently operating outsourced surface miners engaged in coal production are around 85 nos. in CIL Mines. There are attempts for more deployment of surface miners so as to increase the sized coal output and for favorable mine economics. Some of the leading coal producing subsidiaries of CIL like MCL has already organized over 90% o/c coal production from surface miner operation. Similar attempts are there in other coal companies to increase the share of o/c coal output by deploying surface miners in large scale and for further procurement of surface miners also.

Most of the opencast/surface coal mines are meeting the constraints of land acquisition thereby working areas. The introduction of surface miner has caused less environmental effect and relatively lesser pollution than that of conventional o/c coal wining by drilling and blasting and road transportation of coal by tippers. Many times, land constraints ultimately lead to controlled blasting due to objections from the neighboring populations who in many cases do not even vacate their accommodation after getting compensation / employment.

Now there is a need for sized coal supply to all most all consumers and eco-friendly mining solution specially in our o/c coal Mining. The above both advantages are possible to be well attended by using surface miner in o/c coal wining process. Also the cost of coal production is well maintained to the lowest level than any other method of coal mining when the same is from surface miner. Moreover there is premium from consumer for – 100 mm sized coal as available from surface miner and coal wining without much vibration and fire hazards in benches out of shattering effect during blasting and crack formation in solid coal benches there after source of fire.

On overall consideration, surface miner operation in o/c coal Mining is sure to increase its share for less expensive, safe and eco-friendly mining operation soon.

5. Coal Wining by Eco-Friendly Mining Solution

The equipment cuts the coal with the drums and always the coal cutting tools in the m/c are with sufficient cooling facility to serve both the purpose of m/c cooling and dust suppression. Unless sufficient water spraying is maintained there is interlock and the m/c will automatically stop operation.

By such water power interlock, the dust suppression and the purpose of m/c cooling is maintained. No blasting, no fume, no shattering/crack formation in coal benches and both sized coal with selective mining are possible. The adoption of surface miner in o/c coal mining is gaining popularity for its environmental support and eco-friendly mining solution too. The mitigating measures against environmental degradation out of drilling, blasting, crusting, handling of blasted coal becomes less expensive and easily manageable.

6. Options -Technology in Opencast Coal Mining

The options in equipment selection in o/c coal mining are either by drilling and blasting both for coal & o/b or by using surface miner in coal wining and drilling & blasting in o/b removal.

However other options like bucket wheel excavators, hydraulic mining by high pressure water jet are also tried but did not gain popularity for the obvious grounds in each equipment selection.

In most of the mega opencast coal mines, surface miner has been the option in coal wining for the purpose of sized product and for less infrastructure requirement, less capital out lay. In surface miner operation, no need for further crushing after coal wining and huge arrangement / investment for the crusher installation / maintenance/manpower and operation is dispensed off.

Besides it, the ultimate pit configuration can give better facility for higher recovery as the bench with drilling, blasting has got stability problem and thus maintained with flatter slope angle in coal seams where thick coal seams are worked by o/c mining.

In most of the large o/c coal mines inherent problem of fire in coal benches are also greatly controlled by avoiding conventional drilling and blasting for coal wining.

Till now, the o/b removal in general is by conventional drilling & blasting as no such energy effective economic o/b removal is possible even today using surface miner. In coal, the size of coal gives premium and a best option for operation and highly encouraging for the consumers satisfaction also particularly power sector where maximum problems in crushers are met for crusting boulder coal.

In order to operate high capacity o/c coal mine now the best economic, ecofriendly coal wining with sized product is surface miner operation where o/b removal is by conventional drilling and blasting and its evacuation by high capacity HEMM.

The coal evacuation can be with suitable belt network till wagon loading at the rail head. SILO, CHP & Merry go round network is also adopted depending on their suitability at particular locale and mine capacity

Surface miner suitable for cutting coal or soft rock will not be preferable to cut over burden rocks in general on technical and performance considerations. It requires specially designed cutter head suiting for rock cutting in over burden.

There is no need for cutting o/b into small prices, hence the o/b removal by surface miner at the present situation is ruled out.

7. Economics of Surface Miner Operations

Operating cost of surface miners have been examined in some of the mines where major coal output is from surface miner operation. The cost of cutting in situ coal by surface miner varies from Rs. 23 to Rs. 26 /Te .

There is cost elimination from Drilling, Blasting, Crushing/ conveying at site etc. The cost of all above activities have not been quantified but the cost of explosives itself comes to about Rs. 21 /Te of Coal. The use of explosives, its safe handling, involving additional risk and in case non-availability of sufficient input of explosive materials management crisis is also created.

There is gain in sales realization for size parameter where – 100 mm size as product from surface miner is fetching now @ Rs. 87 /Te of coal output from consumers.

8. Suitability of Surface Miners – Advantages in Open Cast Coal Mining

The suitability of surface miner an economic mining equipment offers numerous advantages. Some of these are as under.

i. Substantial reduction of requirement in equipment/machinery, manpower as entire coal wining/sizing/handling at site is from one m/c.

ii. Improved safety status and reduced exposure of working men power to the adverse environment with dust, vibration, shattering, heat and noise.

iii. Elimination of drilling & blasting thereby cost effective, safe and environment friendly mining solution.

iv. Selective mining is possible thus due care for maintaining quality of output / product. Extraneous bands which cannot be conveniently separable by conventional mining is separated without such additional cost in it.

v. Easy and effective supervision, control in operations for concentration of work in mega o/c coal mines with Eco-friendly environment.

vi. The mined coal are mostly in uniform size, avoid crushing, further handling in the process and lesser adverse impact on environment and less hazardous as well as cost effective.

vii. The face and the coal floor both are left with smooth cut surface behind, thus smooth movement of trucks with reduced wear of its tires thereby consequent reduction in transportation cost.

viii. Seams prone to spontaneous heating is possible to be worked with reduced risk of heating than conventional mining. The compact and plain surface of m/c cut coal face without cracks eliminates fire hazards & oxidation of coal.

9. Variation in product size

The size of the product/coal mined by surface miner can be further down sized from – 100 mm by changing the cutting drums. It can be restricted to even – 50 mm size for same seam which will help to fetch even additional revenue. Productivity of surface miner by such exercise may get bid reduced but overall economics will be helpful. Such size reduction to – 50 mm from -100 mm is to be decided on the basis of strength parameters of coal, type of machine used, Geo-mining environment and to be on the site specific assessment.

10. Conclusions

The contribution of o/c coal in national coal production is likely to further increase in subsequent years. It is essential to dispatch 100% crushed coal preferably – 100 mm even – 50 mm where possible to fulfill the Govt. directives. It can be attended for o/c coal output conveniently by surface miner operation in large scale. Coal from major o/c is consumed mostly by power utilities. Surface miner is best suited in such situations and also in other o/c mines where mine geometry permits for its viable application. Surface miner operation is a solution for relatively safe and eco-friendly operation. Techno-economics is well attended too by adopting such mining system in coal production from our o/c coal projects. Surface miner operation in o/c mining of coal is an option for consumer's satisfaction in power utilities and also for others. On economic consideration, the premium of Rs. 87 / Te of output itself for – 100 mm product from surface miner operation takes care for cost of production of coal i.e. explosive cost, Coal handling till wagon loading etc. (except o/b removal cost). It is sure to find much wider application in Indian o/c coal mining very shortly for its numerous advantages.

11. Acknowledgment

The Author is thankful to his colleagues at IIT Kharagpur, officers of Coal India and its subsidiaries for their cooperation during preparation of this paper. Author is indebted to all concerned associated directly or indirectly in the implementation of the project plan to action for adoption of surface miners in o/c coal mines in the country.

INFLUENCE OF ORGANIC AND INORGANIC OXYGEN IN COAL

*Dr. Santanu Kumar Banerjee **

ABSTRACT

The organic oxygen content of coal is an important parameter in coal characterization and utilization, which is a part of routine coal analyses. The routinely used 'oxygen by difference' values are inadequate for accurate work. In order to determine the organic oxygen in coal one also has to correct for oxygen in mineral matter and oxygen in the water removed as moisture. Coal demineralization or corrections for inorganic oxygen must be performed in order to obtain the organic oxygen content. The organic oxygen components of coal are important in determining coal structure and reactivity in coal liquefaction and other processes. Findings of analyses of 11 coal samples of different geographic locations have been studied and interpreted. It has been observed that better inverse relationship established with GCV, when oxygen was added with ash as impurity, which shows coefficient of determination r^2 = 0.924. The high content of oxygen reduces the calorific value of coal. Oxygen and ash appear to be of nearly equal/proportionate negative or anticalorific values..

INTRODUCTION

During transformation from Lignite to subbituminization oxygen content decreases due to dehydration and compaction loss of O - bearing groups. The oxygen content of coal ranges from as high as 20-30% by weight for Lignite to a low of around 1.5-2.5% by weight for an anthracite. At this same stage expulsion of - COOH, CO_2 & H_2O also occurred, which reduced the oxygen in Coal. During this stage of coalification, the coal loses oxygen mainly in carbon dioxide and water. Condensation, polymerization, and cross-linking reactions increase and continue to occur throughout the coalification process. Coal contains substantial amounts of chemically bound oxygen in the organic components in addition to the oxygen associated with mineral matter in coal. Various sources of oxygen in coal, such as oxygen in Moisture, water of hydration of mineral matter, oxygen in carbonate & oxygen in silicates and other inorganic compounds, in addition to oxygen in the organic matter. Much Hydrogen is consumed in oxygen removal. Direct determination of oxygen is a complicating factor. Generally, oxygen present in coal is considered to be chemically combined and hence is subtracted from the total theoretical amount of oxygen required for combustion. Oxygen structures in coal give off water, carbon monoxide or carbon dioxide on pyrolysis, and the temperatures at which these are evolved depend on the functional groups. The main oxygen-containing products of the decomposition of oxygen groups of the sample are H_2O, CO_2 and CO.

INCLUSION OF ORGANIC & INORGANIC OXYGEN IN COAL

Inclusion of oxygen in coal presumably arise from a variety of plant sources and also with aerial oxygen & with oxygenated water

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that percolates through detrimental deposits. Heterocyclic oxygen are reported from pyrolysis Tar. Vitrinite is formed from cellulose and woody parts of the plant that create a chemical structure high in oxygen and aromatics. Its oxygen content is higher than the liptinite maceral. The oxygen functional groups are responsible for the retention of water by hydrogen bonding in the lower ranks of coal. Porosities of the lignite or subbituminous coals are high and the water adsorbed in the micropores may be 30–50%, or higher. As the oxygen-containing groups dissipate with coal maturation, water content decreases as part of the volatiles emitted. The oxygen of linkages helps bind moisture in the micropores. As the coal matures, it is compressed with increasing burial depth. Oxygen-containing compounds and other volatiles are lost, water is lost and the multilayered stacks rearrange to make their micropores smaller. Because of more and larger micropores, shallower depths and retention forces of oxygen in functional groups of the molecular structure, the lower-rank coals have large bed-moisture contents.

ORGANIC OXYGEN

From a beginning with over 40 per cent of oxygen, in the cellulose and lignose of the woody matter, which comprises so great a part of the organic substance actually entering into coal formation, to the present nearly devolatilized state of an anthracite, with less than 2.5 per cent of oxygen, deoxygenation has progressed continuously, though at varying rates, in every unweathered coal. The organic oxygen in coal is bound to carbon atom. The organic oxygen content of coal is an important parameter in coal characterization and utilization. The organic oxygen content of coal is generally determined by ASTM Method 3176, the Standard Method for Ultimate Analysis of Coal & Coke. In organic portion of coal, oxygen is present in hydroxyl (-OH) usually in phenol groups, carboxyl groups (CO_2H), methoxyl groups ($-OCH_3$)and carbonyl groups (=C=O).

Oxygen is the only element comprising the organic coal matrix which is not determined directly. Rather, it is determined by difference from the ultimate analysis, using the equation: O% = 100 - (C + H +N + S + Ash)% ; accuracy of this indirect oxygen determination suffers from cumulative errors inherent in the analytical methods used for each of the other elements. In addition, it is dependent on the ash content which is obtained by heating the coal at about 815°($\pm$15) for one hour; but since the ash produced at these temperatures is not directly relatable to the original mineral matter in the coal, another source of error is thereby introduced into the oxygen determination. Although various methods for determining oxygen in coal directly have been employed, including neutron activation analysis (NAA) and oxidative or reductive techniques, analyses by these methods include all or some of the inorganic oxygen. The studies using the SEM-EDX technique mineral portions of the coal were avoided by locating organic maceral components of coal using 5000x magnification with the SEM and by monitoring the levels of Fe, Ca, Al , and Si.

By knowing the petrographic composition of the coal and the average organic oxygen content of each maceral may be examined, a weighted average may be used to obtain an oxygen concentration for the organic matrix as a whole. The organic oxygen components of coal are important in determining coal structure and reactivity in coal liquefaction and other processes.

INORGANIC OXYGEN

The O_2 present in dry coal can be further divided into organic & inorganic O_2, which is closely related to the inorganic (mineral) matter in coal, such as silicates, sulfides, carbonates & oxides. Their non-volatile decomposition and combustion products formed during proximate analysis are termed "coal ash". Inorganic oxygen% = 0.5 (% Mineral Matter), this equation has been reported to give good inorganic oxygen estimations for well known coals with relatively low ash contents. Thus, organic oxygen levels can be obtained by calculating the difference in levels of total and inorganic oxygen. The inorganic materials in coal that contains O_2 are various

Table-1						
Sample No.	**Moisture %**	**Ash %**	**Carbon %**	**Oxygen %**	**(A + O) %**	**GCV**
1	6.9	40.2	36.29	12.42	52.62	3270
2	5.8	44	36.43	9.46	53.46	3580
3	5.2	44.2	37.19	8.16	52.36	3390
4	4.5	43.2	38.03	8.01	51.21	3250
5	5.4	40	40.78	9.11	49.11	3927
6	4	39	43.61	9.01	48.01	4020
7	5.5	54.6	29.4	7.1	61.7	2833
8	3.7	37.9	47.23	5.88	43.78	4450
9	7.1	22.4	55.73	9.38	31.78	5450
10	6.1	36.3	37.6	5	41.3	5026
11	7.4	18.9	55.7	10.9	29.8	5322

forms of moisture, silicates, carbonates, oxides & sulphates.

INFLUENCE OF ORGANIC & INORGANIC OXYGEN IN COAL

The high content of oxygen can reduce the calorific value of coal. It may be observed and established that 1% increase of oxygen content, decreases the calorific value of coal by about 1.7%. Carbon content increases with increasing rank, while the oxygen content decreases. Oxygen in coal is supposed to be combined with hydrogen. An equivalent amount of hydrogen is therefore already burnt i.e. not available for combustion, leading to decrease in calorific value. The occurrence of organically-bound oxygen is second only to carbon in most coals. Increase in oxygen content of coals increases their tendency to retain inherent moisture. The efficiency as fuels, oxygen is an original impurity in coals, which improve according to the extent of its removal. The negative importance of oxygen seems to be little realized outside of the ranks of coal analysts.

DISCUSSION & RESULT

Eleven (11 nos.) coal samples of different geographical locations (**Table-1**) were analysed for proximate and ultimate analyses on equilibrated basis. The findings of Ash content, oxygen content , GCV (Gross calorific value) and Carbon% were studied and interpreted. It has been found that GCV shows inverse relationship with ash content, coefficient of determination r^2 = 0.812 (**Figure-1**), whereas when oxygen is added with ash content, then it indicates coefficient of determination r^2 = 0.924 (**Figure-2**), which established a better inverse relationship. From this analytical results, it may be deliberated that enhanced and decreased oxygen value affected the GCV adversely. Oxygen and ash appear to be of nearly equal/ proportionate negative or anticalorific values.

CONCLUSION & SUGGESTIONS

The heat value of the coal as a whole is practically determined by the balance between these two principal impurities (O, Ash) on the one hand and the total carbon (C) on the other. Clearly, in determining the organically bound O^2 in coals, not only O^2 in water to be removed as moisture from "as received" samples, but also that in mineral matter in the dry coal, should be subtracted from the total coal.

The feasibility can be explored for using a scanning electron microscope (SEM) in conjunction with energy- and wavelength-dispersive X-ray analysis (EDX and WDX respectively) to determine the organic oxygen content of coal directly. Therefore, coal

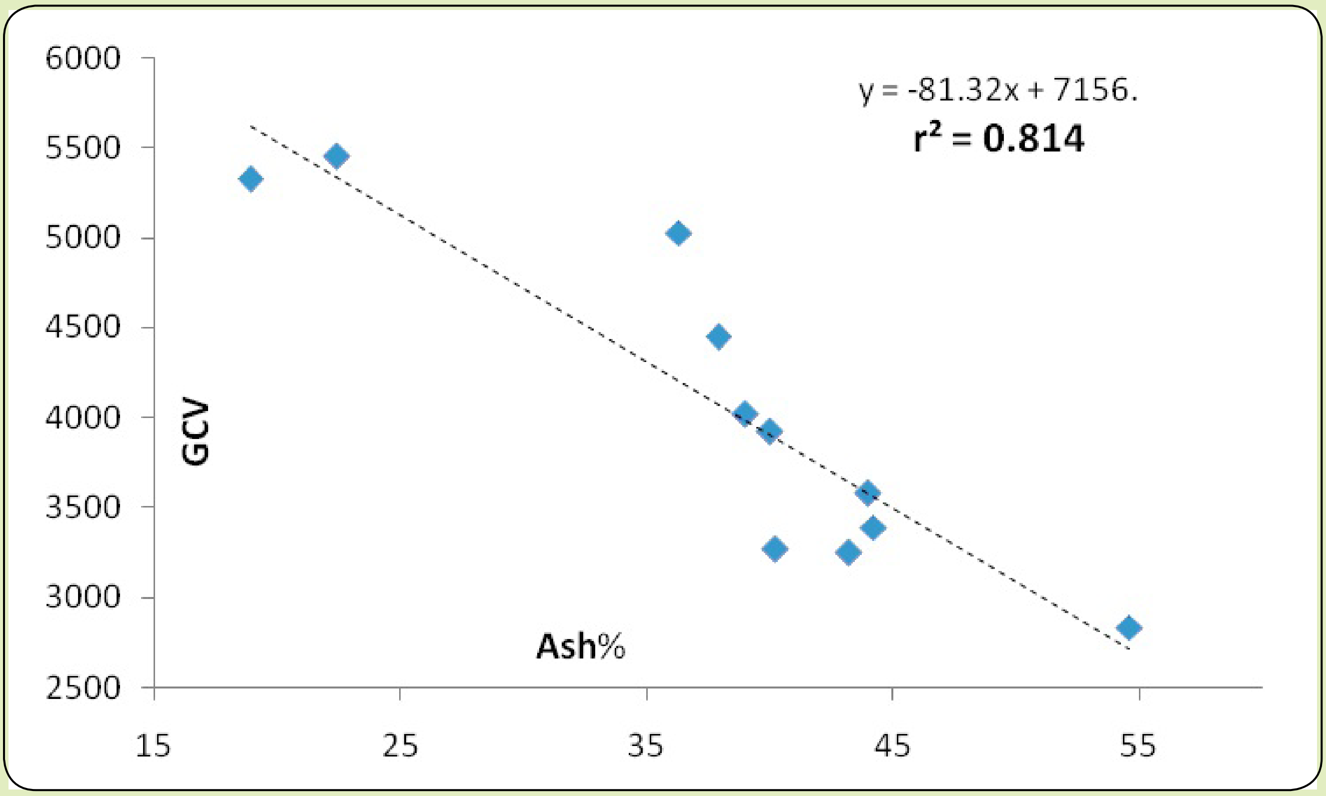

Figure - 1

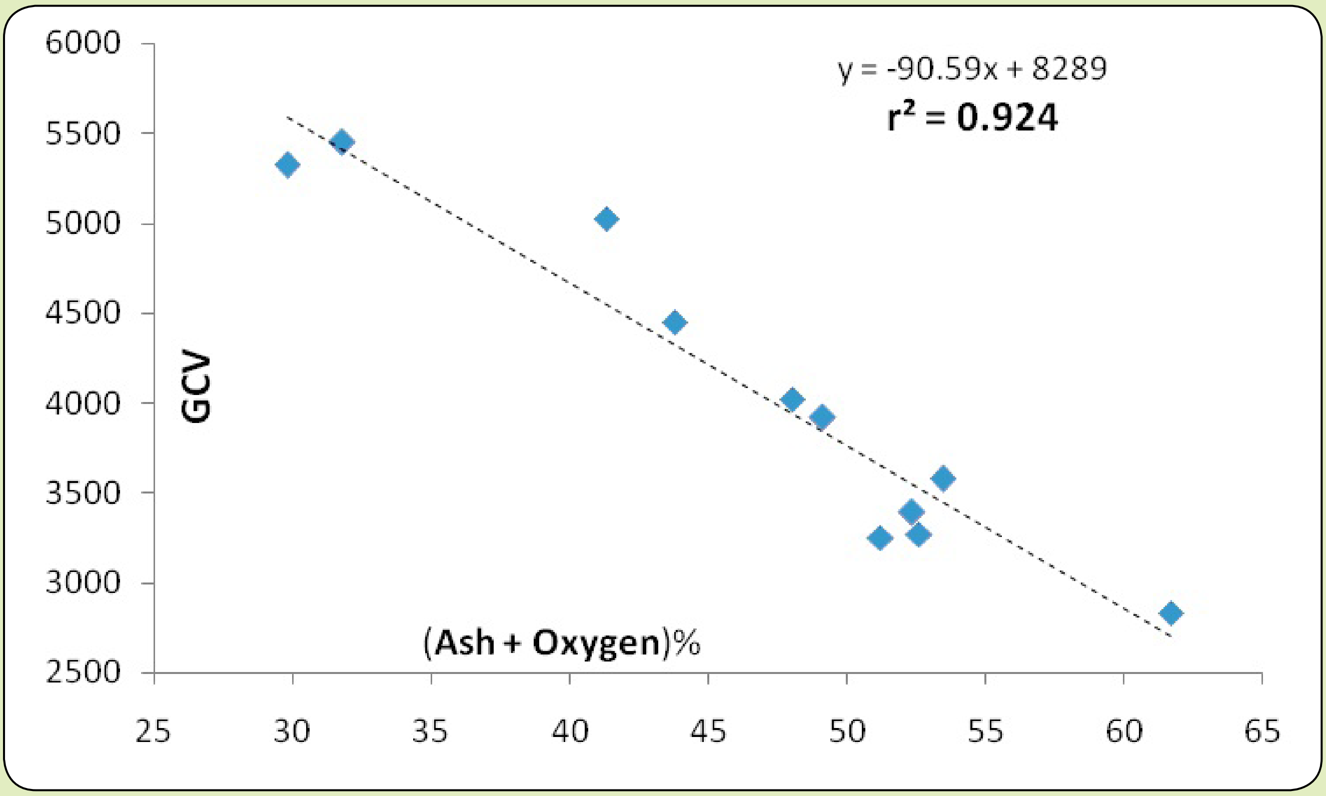

Figure - 2

demineralization or corrections for inorganic oxygen must be performed in order to obtain the organic oxygen content. The routinely used 'oxygen by difference' values are inadequate for accurate work. In order to determine the organic oxygen in coal one also has to correct for oxygen in mineral matter and oxygen in the water should be removed as moisture.

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SOLAR ENERGY – A PANACEA FOR ADDRESSING ENERGY DEFICIENCY

Paresh Saxena [1], Utpal Chakraborty [1], Sarvesh Kumar [2]

Introduction

When India got its independence in 1947, its per capita electricity consumption was only 16.3 kWh. The installed capacity at the time of independence was 1,362 MW. After 70 years of independence, our per capita electricity consumption rose to 1122 units and we were able to achieve an installed capacity 344,000 MW. At one glace, this journey looks really remarkable as our electricity consumption has increased by about 67 times and installed capacity has increased by about 250 times. However, on a microscopic level, the figures won't glad us. India is lagging far behind its peer developing countries like China, Brazil and South Africa with pre-capita consumption of 4,475 kWh, 2,516 kWh & 3,903 kWh respectively. India is also suffering from phenomenon like energy poverty. Energy poverty is a situation wherein households do not have access to affordable electricity and even if they have, the quality and quantity of electrical access remains poor. During the fiscal year 2016-17, the energy availability in India was 1,135.334 billion kWh with a short fall of requirement by 7.595 billion kWh. This short fall of electricity requirement is expected to increase as India's electricity needs are going to double in the next 6-7 years at the present rate of growth of the economy.

The sources of electricity in India with installed capacity (as on 31.03.2018) are:

- Thermal power plants (Coal, Gas and Oil) – 222,907 MW
- Hydro – 45,293 MW
- Nuclear – 6,780 MW
- Renewable sources (Solar, Wind, Bio) – 69,022 MW

On one hand, the growing concerns over increasing carbon-di-oxide emission; which is translating into global warming leading to climate change; affecting the progress of coal-fired power plant, on the other hand, the progress in nuclear and Hydroelectricity projects have been really slow owing to the issues like displacement of people, environment clearances and issues related with the handling of nuclear waste.

In the present situation, solar energy looks really promising in tackling the issues created by other conventional sources of energy. The potential for solar energy capacity in India is enormous. The majority of the country's tropical landmass is located optimally for peak solar radiation. The World Bank has described India as having "among the best conditions in the world to capture and use solar energy". The rise of solar is a benefit not only for a country that still uses coal for nearly 60% of its energy mix, but for the world's climate change agenda more broadly.

Prospect of Solar energy in India

India lies wholly in the northern and eastern hemispheres. The geographical extents, i.e., latitude and longitude of India respectively, are 8°4′ N to 37°6′ N latitude and 68°7′ E to 97°25′ E longitude. Thus, geographically, India is an ideal country for solar energy. We get nearly 300 days of sunshine and we have a seasonal peak in the summer. These are also times when solar energy is at its peak. The average solar irradiance varies from more than 2150 kWh/sq. in Gujrat to

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about 1200 kWh/sq. in Arunanchal Pradesh. The variation of incident energy is shown in the map (Refer **Figure-1**).

The Ministry of New and Renewable Energy has pegged the country's total solar power potential at nearly 750GW (more than twice the present installed capacity) with 142GW of solar resource available in the state of Rajasthan alone.

With about 300 clear and sunny days in a year, the calculated solar energy incidence on India's land area is about 5000 trillion kilowatt-hours (kWh) per year. The solar energy available within the territory of India, in a single year, exceeds the total possible energy output of all of the fossil fuel energy reserves in the country. The average incident solar energy on our country varies from 4kWh/m^2/day to 5.5 kWh/m^2/day, whereas our daily average solar-power-plant generation capacity is about 0.20 kWh per m^2 per day of used land area i.e. about 4-5% of our solar potential. A vast amount of solar energy is still untapped and hence solar energy sector in India has a lot of potential for growth.

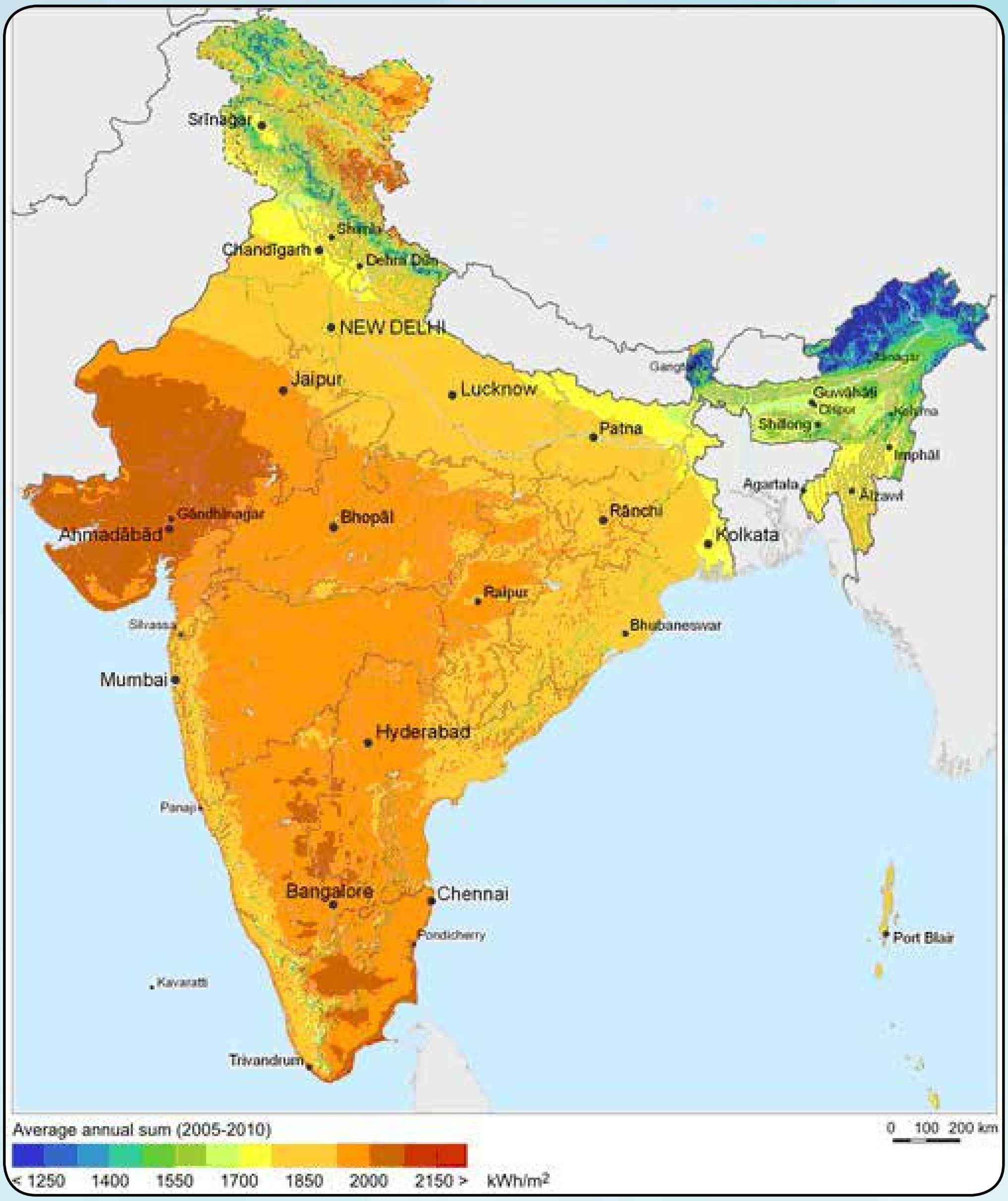

Figure 1

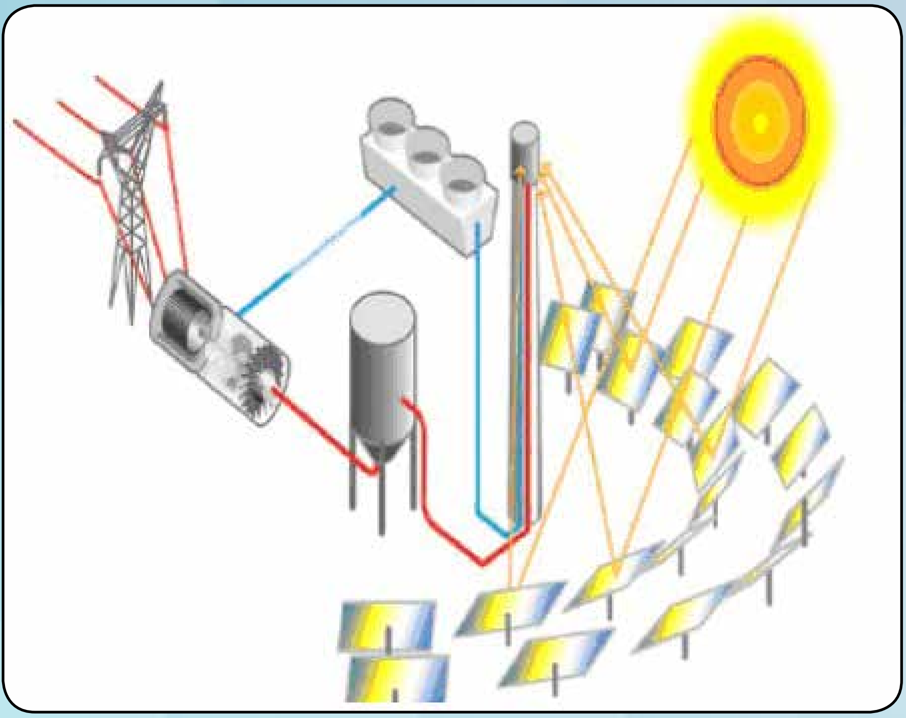

Figure 2

Utilization of Solar energy

There are multiple ways of utilizing solar energy as:

a) Solar Thermal – In this solar energy is used to generate steam which drives the turbine of generator to produce electricity. This is generally done with the help of suitably placed multiple solar mirrors. The installed capacity of commercial solar thermal power plants in India is 227.5 MW with 50 MW in Andhra Pradesh and 177.5 MW in Rajasthan. (Kindly refer **Figure-2**)

b) Photo-voltaic cell or PV cell – In this solar energy is directly converted to direct current with the help of semi-conductor modules. The energy is then either used directly as DC (for a small unit) or converted to AC power (for bigger units). (Kindly refer **Figure-3**)

c) Solar thermal fuels (STF) – The technology and process behind STFs is comparable to a typical battery. The STF can harness sunlight energy, store it as a charge and then release it when prompted. However, they are still not economically viable at this stage.

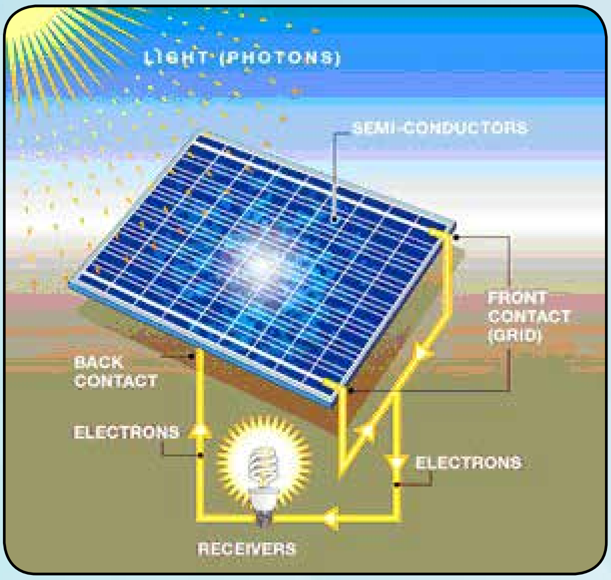

Figure 3

Brief of Solar PV technology

Solar panel works by capturing the sun's energy and turning it into electricity. Our sun is a natural nuclear reactor. It releases tiny packets of energy called photons, which travel from the sun to Earth in about 8.5 minutes. Every hour, enough photons impact our planet to generate enough solar energy to theoretically satisfy global energy needs for an entire year.

When photons released by the Sun hit a solar cell, they knock electrons loose from their atoms. If conductors are attached to the positive and negative sides of a cell, it forms an electrical circuit. When electrons flow through such a circuit, they generate electricity. Multiple cells make up a solar panel, and multiple panels (modules) can be wired together to form a solar array. The more panels, the more energy we can generate.

PV solar panels generate direct current (DC) electricity. This DC electricity may directly be consumed by DC loads like DC fans or may be converted to AC (alternating current) with the help of inverters and then utilized for powering up the AC loads.

There are broadly two modes of working of a solar PV power system i.e. it may either be used as standalone system i.e. off-grid system or it may be grid-tied i.e. connected and synchronized with the grid. Grid here means the system from which we get ac electricity as per our need.

Standalone PV system

A free standing or standalone PV System is made up of a number of individual photovoltaic modules (or panels) usually of 12/24 volts. These PV modules are then combined into a single array to give the desired power output. A simple stand-alone PV system is an automatic solar system that produces electrical power to charge banks of batteries during the day for use at night when the suns energy is unavailable. A stand-alone small scale PV system employs rechargeable batteries to store the electrical energy supplied by a PV panels or array.

Stand-alone PV systems are ideal for remote rural areas and applications where other power sources are either impractical or are unavailable to provide power for lighting, appliances and other uses. In these cases, it is more cost effective to install a single stand-alone PV system than pay

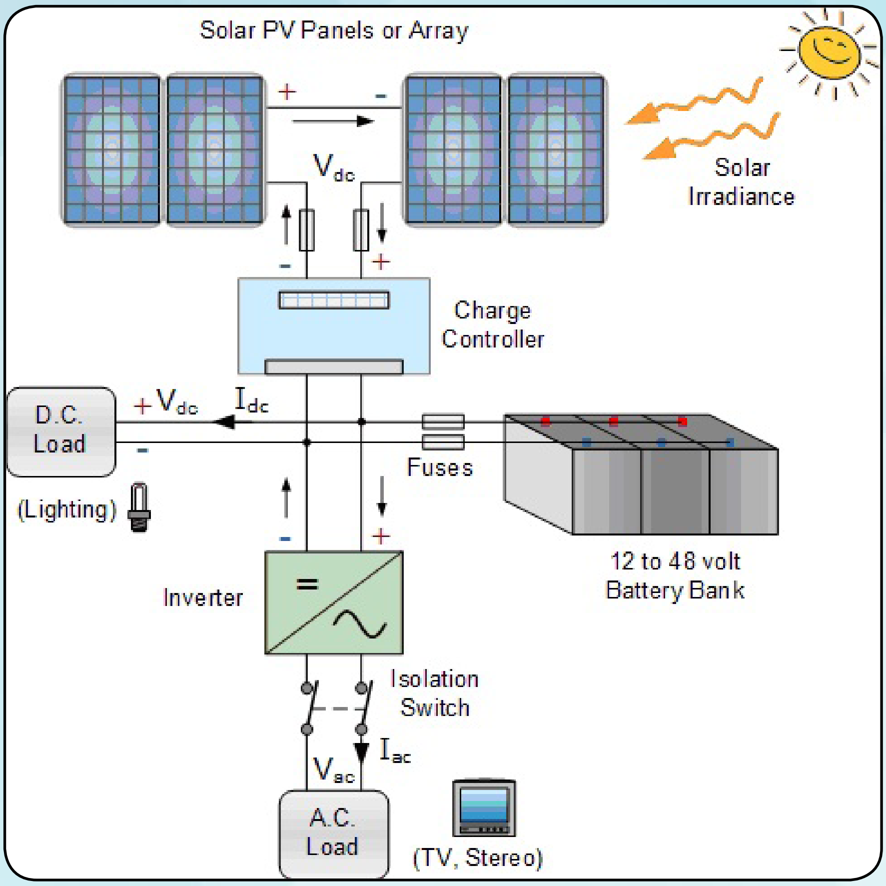

Figure 4

the costs of having the local electricity company extend their power lines and cables directly to the home.

A typical schematic diagram of standalone system is shown in **Figure-4**.

Grid-tied PV System

In a grid connected PV system, also known as a "grid-tied", or "on-grid" solar system, the PV solar panels or array are electrically connected or "tied" to the local mains electricity grid which feeds electrical energy back into the grid.

The main advantage of a grid connected PV system is its simplicity, relatively low operating and maintenance costs as well as reduced electricity bills. The disadvantage however is that a sufficient number of solar panels need to be installed to generate the required amount of excess power.

Since grid tied systems feed their solar energy directly back into the grid, expensive back-up batteries are not necessary and can be omitted from most grid connected designs. Also, as this type of PV system is permanently connected to the grid, solar energy consumption and solar panel sizing calculations are not required, giving a large range of options allowing for a system as small as 1.0 kW on the roof to help reduce our electricity bills, or a much larger floor mounted array that is large enough to virtually eliminate our electricity bills completely.

A typical schematic diagram of standalone system is shown in **Figure-5**.

Designing of a solar PV power plant

Design of a solar PV power plant broadly involves following steps:

a) Identification of site/building

b) Collection of data from site (area, details of near shadow objects, latitude, orientation, tilt of plane etc.)

c) Creating a 3-D model of the site/building including near shadow objects with the help of data collected from step-(b) in the solar analyst software like PVSYST or PVSOL.

d) Determination of sun height at 9:30 AM and

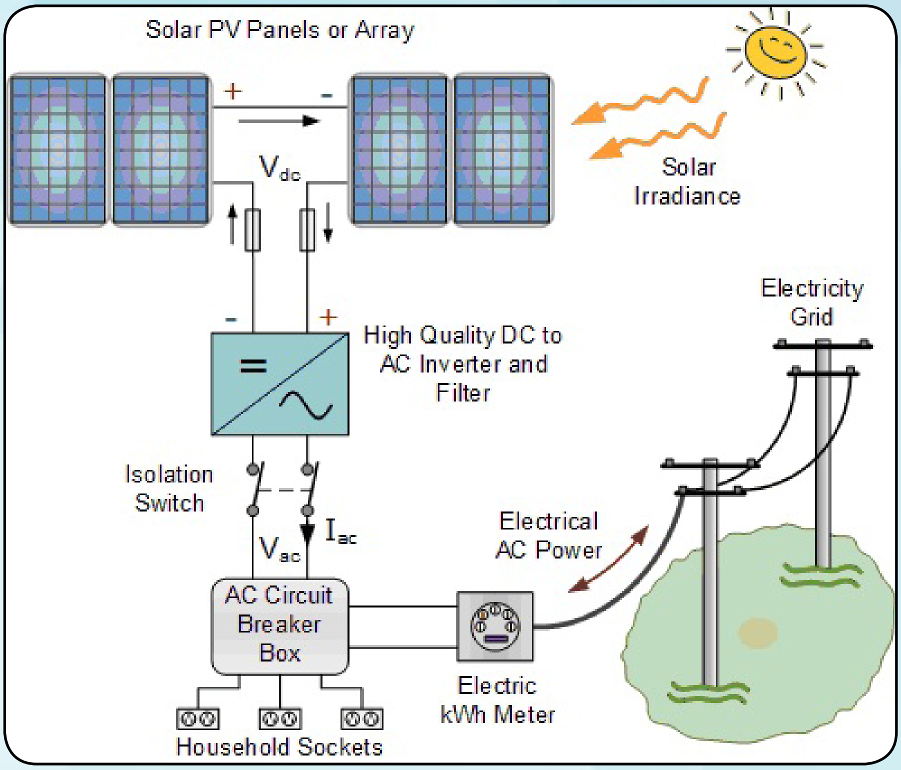

Figure 5

3:30 PM (considering 6 hours of sunshine) corresponding to sun path diagram obtained from the software.

e) Finding optimal spacing between two PV modules and tilt of PV module corresponding to the sun height at 09:30 AM and 3:30 PM.

f) Placing solar PV module with suitable spacing, Azimuth and tilt on the 3-D model of site/building.

g) Capacity estimation along with shade and other losses.

With the help of solar analyst software, it is very convenient to estimate the amount of energy that can be fed to the grid (for grid-connected system). The software also enables us to place the PV modules so as to have minimum shade loss.

Case study for installation of roof-top solar power plant at DAV school, Jagannath Area (MCL)

1) 3-D modelling of DAV school with PV modules indicated in blue (**Refer Figure-6**).
2) ISO shading diagram (Sun path) (**Refer Figure-7**).
3) System loss diagram (**Refer Figure-8**).

Total effective roof area of the school, available for installation of solar plant, comes out to be 1100sq.m. As per the analysis through software, a solar PV plant of capacity 165kWp can be installed on the roof of school. The annual energy output from this plant turns out to be 245 MWh with a saving of 190 te CO_2 emission each year.

Initiatives in the field of Solar Energy by CMPDI

Central Mine Planning and Design Institute (CMPDI), Ranchi, — the think tank of Coal India Ltd has undertaken many initiatives in the field of Solar energy. CMPDI holds the distinction of having largest roof-top solar power plant at its Headquarter office building at Ranchi back in 2014. Since then, it has been constantly striving towards tapping this cleanest source of energy in forms of installing roof-tops solar power plants at its various regional offices, installing solar LED lights for its various field camps. CMPDI is also provided technical support to the subsidiary companies of Coal India limited.

Roof-top solar power plants of CMPDI are:

a) CMPDI (HQ) – Ranchi – 190 kWp
b) CMPDI, RI-I – Asansol – 80 kWp
c) CMPDI, RI-II – Dhanbad – 30 kWp
d) CMPDI, RI-VI – Singrauli – 50 kWp

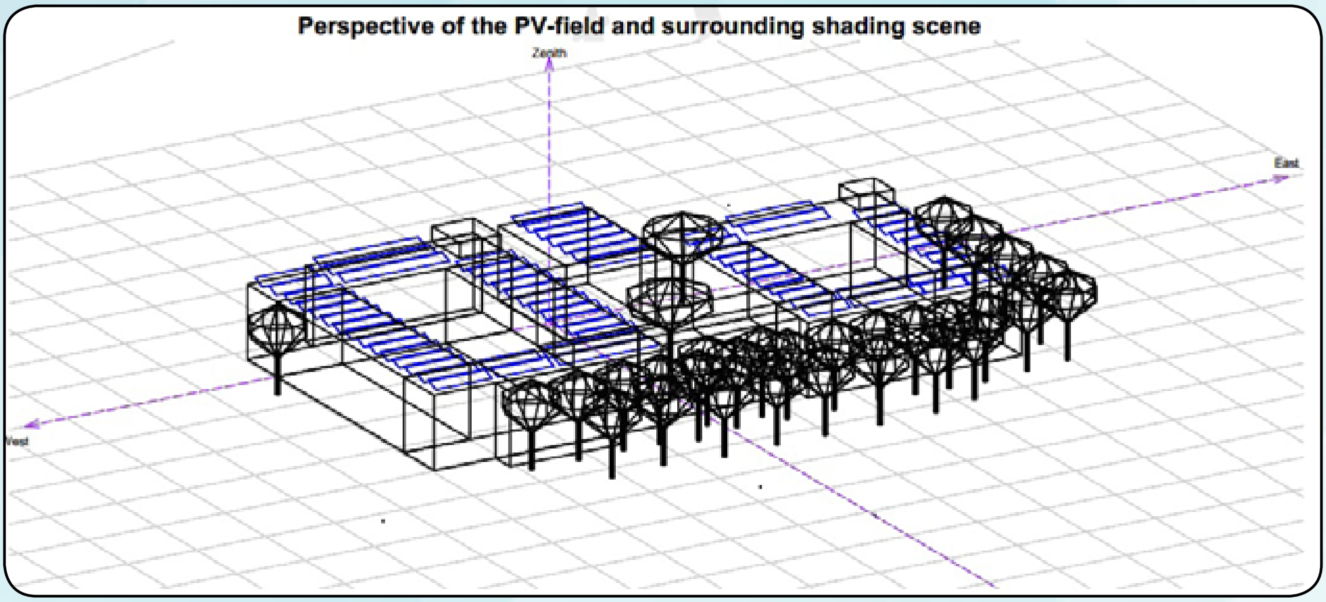

Figure 6

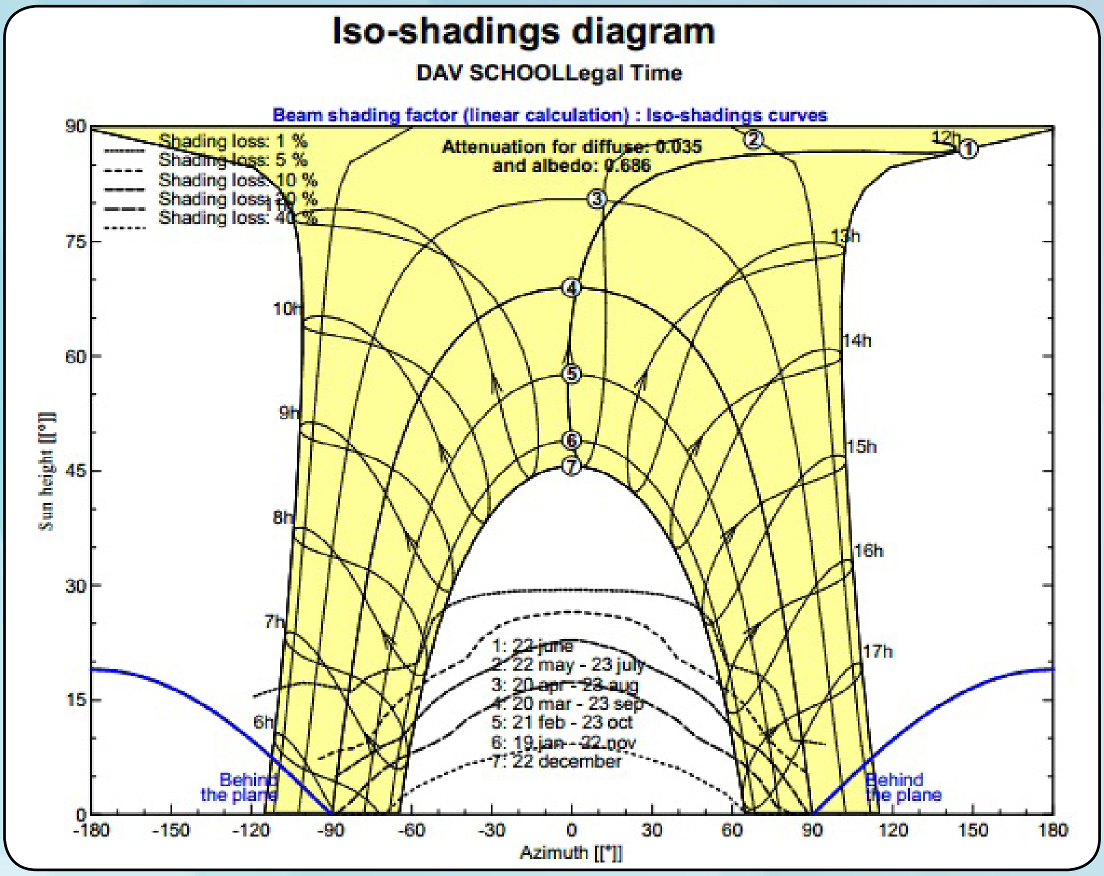

Figure 7

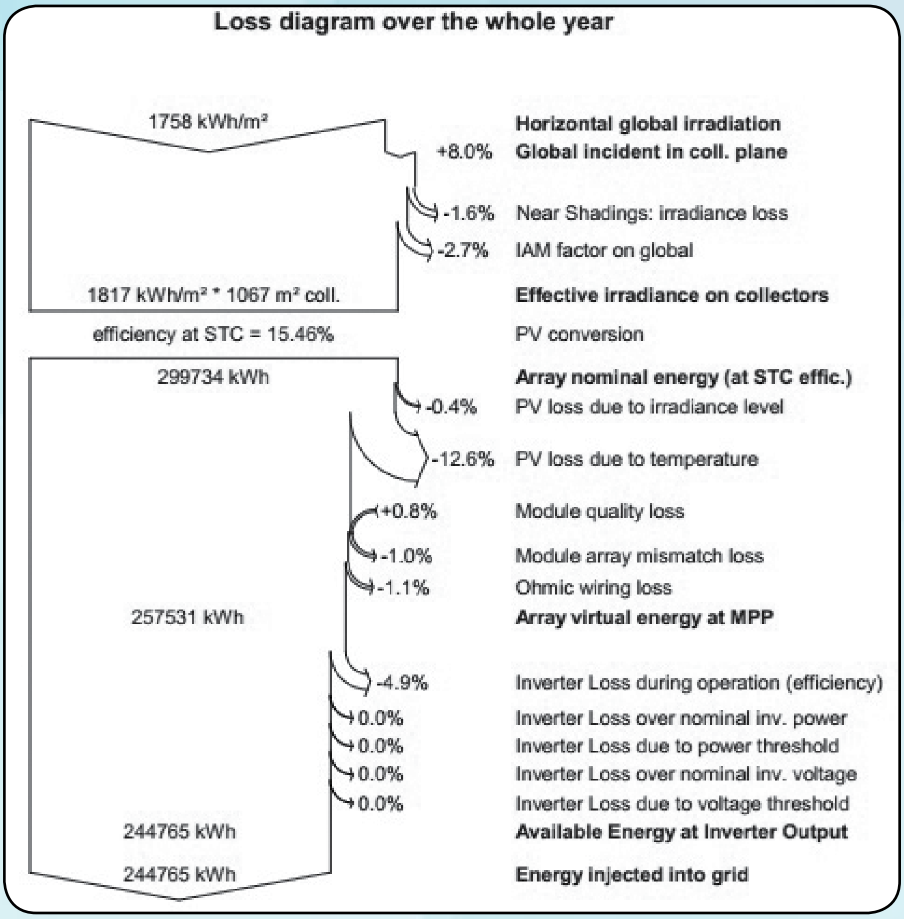

Figure 8

Figure 9 : Roof- top solar power plant over Ravindra Bhawan of CMPDI (HQ) Ranchi.

With combined installed capacity of 350 kWp, these roof top solar power plants generate around 5.25 lakhs kWh of electrical energy annually. This leads to reduction in around 500 te of CO_2 emission per year.

Besides roof-top solar power plants, CMPDI is also venturing into other avenues of solar technology like solar based street lights. It has successfully commissioned around 300 solar based led street lights in its various regional offices and drilling camps. It is also exploring the opportunities for installation of large scale solar power plants on the barren lands/ OB dumps of CIL. In the near future, such projects are likely to become a model project for others to imitate.

Conclusion

Improvement in the manufacturing technology has led to the reduction in cost of solar panels which has resulted in reduction in cost of solar power generation. The reduction in the cost of solar power coupled with strategic policy of the government has resulted in increase in solar power into the energy mix of the country.

India has already achieved a milestone of 20 GW of cumulative solar installation in the month of February 2018. The National Solar Mission had initially set the target of 20 GW installed capacity by 2022. This has been achieved four years ahead of time. The government is further working to achieve the revised target of 100 GW solar installation by 2022 as envisaged in the India's INDC submitted to UNFCCC before the Paris climate agreement. With the present double digit progress in solar industry, India is indeed on the right track of achieving the target of 100 GW solar installations by 2022 and making itself free from energy deficiency.

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STUDIES ON CLEANING POTENTIALITES OF WASHING LOW VOLATILE COKING COALS OF JHARIA COALFIELDS

Dr. Thonangi Gouri Charan [1], U.S.Chattopadhyay [2], Sanjay Choudhuri [3], S.C.Maji [4], Pradeep Kumar Singh [5]

ABSTRACT

The Indian coking coal reserves are less compared to the non-coking coals and the good quality coking coals have been exhausted leaving behind poor quality feed stock for the metallurgical sector. For production of Iron & Steel through blast furnace route, coking coal is an important raw material. The good quality coking coals of the upper seams are fast depleting leaving behind the inferior quality lower seam coals which are low volatile coking in nature and available in Jharia and East Bokaro Coalfields. These coals are characterized by high raw coal ash content and poor washability characteristics. CSIR-CIMFR, had carried out extensive studies on the washability characteristics of these LVC coals and based on the data generated, an attempt has been made to develop a flow sheet for washing these coals at 18% clean coal ash content.

INTRODUCTION

Coking coal is an essential input for production of Iron & Steel through blast furnace route. To save steel industry which is facing acute dependence on imported coking coal, domestic availability of coking coal of desired quality has become imperative. The good quality coking coals of the upper seams are fast depleting leaving behind the inferior quality lower seam coal. The lower seam coals presently being mined are mostly low volatile coking coal (LVC). They constitute about 50% of the total coking coal reserves in India. These coals are characterized by high raw coal ash content and poor washability characteristics.

Of the existing 16 coking coal washeries, only three are less than 20years old, whereas most are 30-50years old. These washeries, except for those owned by Tata Steel, operate at a yield level of 30-40%. Most of the existing preparation plants are being operated basically as 2-product washeries producing steel plant cleans (30-40% yield at 19% ash) and remaining middlings at 35-40% ash with little or no rejects. When lower seam coals are directly treated in these washeries, the sink ash goes beyond 45% ash with no market potentiality. Such cases, though technically very difficult, likely to produce hardly 25-30% of clean at 18% ash and 70-75% will require disposal as waste, which is not cost effective.

The LVC coals are difficult-to-wash as these coals have high percentage of near gravity materials, generally over 50 at the primary separation gravity and in most cases yield considerable proportion of co products like middlings, sinks etc. The liberation characteristics of this type of coal is very poor due to highly inter-grown nature of the coal. Generally, there is no commensurate increase in yield of cleans at equivalent ash level by crushing the coal gradually down to below 13 or 6mm. For effective beneficiation of high ash, difficult-to-wash LVC coals detailed and systematic R & D studies need to be carried out source/colliery-wise to understand the washing characteristics and development of beneficiation circuits.

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Past studies undertaken by various groups/ agencies such as the then CFRI (1990 and 1993), CMPDIL, CFRI & SAIL (1992), Chari committee (1990) and Sachdev committee (1993), CIMFR, RDCIS & CMPDIL (2012) and others, to find ways for reduction of import of coking coals, it was observed that LVMC coals from Jharia Coalfield after beneficiation at 18% clean coal ash content and when blended with 'prime' high volatile 'medium' coking coal may show excellent coking properties.

The paper highlights the work carried out on coal samples of Eastern Sector of Jharia coalfields.

Sample Source

About 10 t each of Low Volatile Coking Coal sample was collected from Eastern Sector of Jharia Coalfields for carrying out the detailed characterization, screen analysis and washability studies.

Sample Preparation

The raw coal was screened at 50 mm and the + 50 mm was crushed in a single roll crusher to below 50 mm, the overall combined fraction of the product below 50 mm was taken for further studies viz., characterization, screen analyses and Float & Sink tests.

Size Analysis

The ROM sample was crushed at 50 mm and size analysis was carried at sizes 25, 13, 6, 3 and 0.5 mm. The size fractions were weighed and analyzed for ash percent. The data is shown in **Table-1**.

Washability studies

The individual size fractions were put for Float & Sink tests in the gravity range 1.40 to1.80 at an interval of 0.1. All the gravity fractions were dried, weighed and analyzed for ash %. The washability data of individual size fractions were tabulated and the combined washability data were also generated for the size 50 – 0.5mm and recorded.

Table-1 : Size Analysis

Size, mm	Wt%	Ash%
+50	2.4	47.1
50 - 25	41.0	46.6
25 - 13	18.5	42.4
13 - 6	14.3	38.1
6 - 3	7.0	34.6
3 - 0.5	8.7	28.0
- 0.5	8.1	23.5
	100.0	40.3

The washability data was used for plotting the washability and Mayers curve for understanding the cleaning potentialities of the test coal and it is depicted in **Figure-1**.

Beneficiation of Coal Fines

It may be seen from the size analysis data depicted in **Table-1** that the percentage of coal fines is 8.1% at ash content of 23.5%. Laboratory flotation tests using Denver cell were carried out for the coal fines sample.

Batch laboratory flotation experiments were carried out taking 250gm of coal fines (below 0.5mm). Before flotation the coal fines sample was made wet keeping known volume of water for more than one hour to form uniform coal slurry. These slurry was then transferred into the Denver D-12 sub aeration type flotation cell. More water was added to maintain the 33% solid concentration. Again these slurry was further wetted for three minutes under dynamic condition at an impeller speed of 1500rpm. The collector as diesel oil was then added at 33% pulp density and conditioned for two minutes. Frother was added and allowed to mix with the pulp for one minute. Now water was added to fill the cell upto the marked height to make the pulp density at 10%. Air inlet valve was opened to allow the air to introduce into the system from the bottom of flotation cell. These air generated air bubbles which carried the coal particles up to the top of the surface as froth. These froth was collected as flotation concentrate for one minute duration whereasthe remaining part was

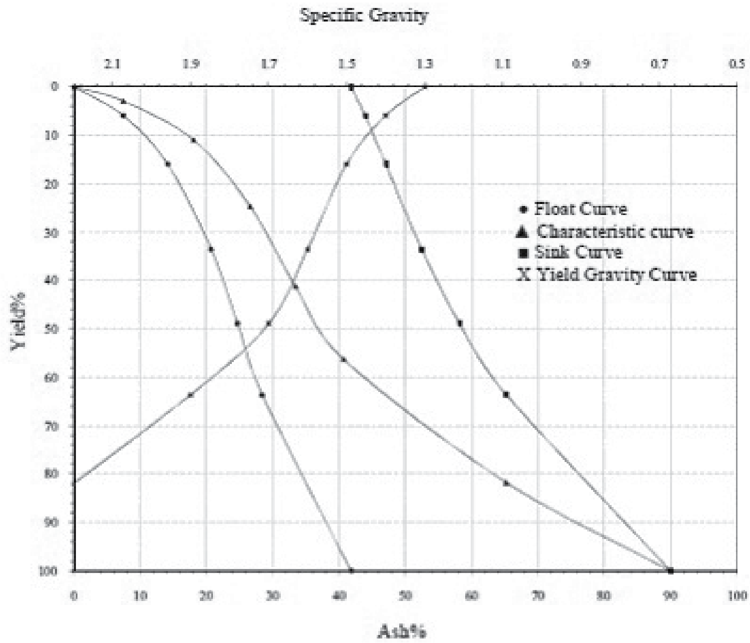

Figure 1 (a) : Washability Curve size tested 50-0.5 mm

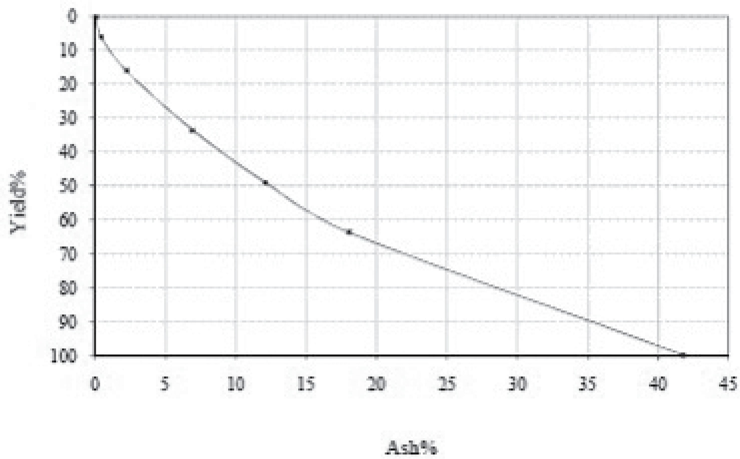

Figure 1 (b) : Mayer's Curve size tested 50-0.5 mm

collected as tailings. The flotation concentrate and tailing were filtered, dried, weighted and analysed. The details of the dosages varied are shown in **Table -2** and the results are shown in **Table-3**.

Table-2 : Details of Reagent dosages for flotation tests

	+1	0	-1
Diesel (C), ml	0.56 C3	0.33 C2	0.1 C1
Nalco frother (N), ml	0.05 N3	0.03 N2	0.01 N1

Table-3 : Flotation Data

Expt No.	Conditions	Cleans		Rejects	
		Wt %	Ash %	Wt %	Ash %
1	C1N1	48.6	17.0	51.4	29.8
2	C1N2	67.8	20.2	32.2	31.1
3	C1N3	85.1	22.1	14.9	33.6
4	C2N1	50.5	17.5	49.5	30.5
5	C2N2	68.5	20.9	31.5	32.1
6	C2N3	86.5	22.1	13.5	35.2
7	C3N1	51.8	18.5	48.2	31.2
8	C3N2	70.2	21.5	29.8	33.1
9	C3N3	88.3	23.1	11.7	35.8

RESULTS AND DISCUSSIONS

Characterization tests of raw coal revealed that for the sample collected from Eastern Jharia, the ash percentage of coal is 40.3% and Moisture percentage (on as received) of the coal is 1.1%. The sample tested is low volatile in nature, the VM% being 15.4. The petrographic studies on the raw coal sample revealed that the vitrinite content is 27%, while the inertinite content is 68.6% and the Ro is 1.2. The carbonization properties of the raw coal indicated that the CSN is 1, while the LTGK is D.

It may be seen from the **Table-1** that there is progressive decrease in ash content with decrease in size, indicating good liberation with size. From the washability and Mayers curve it may be noticed that the theoretical yield% at 18% clean coal ash is about 25.3%, while the corresponding sinks ash is 49.9% and the specific gravity of cut is 1.55. The Near Gravity Material (NGM) at this cut gravity is 32.

It may be noticed that the percentage of sinks is about 74.7% at ash content of 49.9%. This sinks fraction was again rewashed to obtain a middlings fraction at 34% ash content. The float and sink tests of the sinks was carried out and the data is depicted in the form of washability and Mayers curve and shown in **Figure-2**. The theoretical yield% at 34% ash content is 43.6%, while the rejects ash content being 62.3%.

The flotability characteristics of the coal fines is good and it may be seen from Table -3 that at about 18.5% clean coal ash content the recovery is about 51.8% and the corresponding tailing ash content is 31.2%.

The overall theoretical recovery at 18% clean coal ash content is shown in **Table-4**.

It may be observed from **Table-4**, that the theoretical recovery at 18% ash content is 27.5% and the characterization of the overall cleans revealed that the moisture content is 1.0% the volatile matter is 18.7%. The carbonization properties revealed that the CSN is 4 and LTGK is 'G'. The petrographic studies had shown that the vitrnite content is 49.3%, inertinite is 41.7 and the Ro is 1.3. This indicates that the clean coal may be used as a blend for metallurgical purposes.

Concept of Washing

In the case concept of washing this particular coal, the ROM coal may be crushed at 50 mm and classified at 13 mm and 0.5 mm. The fraction 50 – 13 mm may be washed in a three product Bath/ Drum to achieve cleans, middlings and rejects, while the fraction 13 – 0.5 mm may be washed in two stage H. M. Cyclone to get three products cleans, middlings and rejects. The coal fines may be washed using flotation technique to recover additional low ash clean coal.

CONCLUSIONS

- ☆ The inferior quality high ash weakly coking coal may be upgraded to the desired quality if the coal is judiciously beneficiated.
- ☆ Detailed laboratory float and sink tests were carried out on the coal crushed to 50mmand laboratory flotation tests of the coal fines.
- ☆ The theoretical recovery at 18% clean coal ash content is 27.5%.

Table-4 : Overall Theoretical Recovery

Size, mm		Wt%	Ash%
50-0.5	Cleans	23.3	18.0
	Middlings	29.9	34.0
	Rejects	38.7	62.3
-0.5	Cleans	4.2	18.5
	Tailings	3.9	31.2

☆ The analyses on the raw coal and the clean coal samples in terms of proximate analysis coking properties and petrography have proved that the qualities of the cleans have improved remarkably and these may be gainfully utilized for coke making and metallurgical purposes.

ACKNOWLEDGEMENTS

The authors are thankful to The Director, CIMFR for permitting to present this paper in the Seminar. They are also thankful to the entire team of Coal Preparation Division at CIMFR, Digwadih Campus for their cooperation, help and attention during testing of the coals.

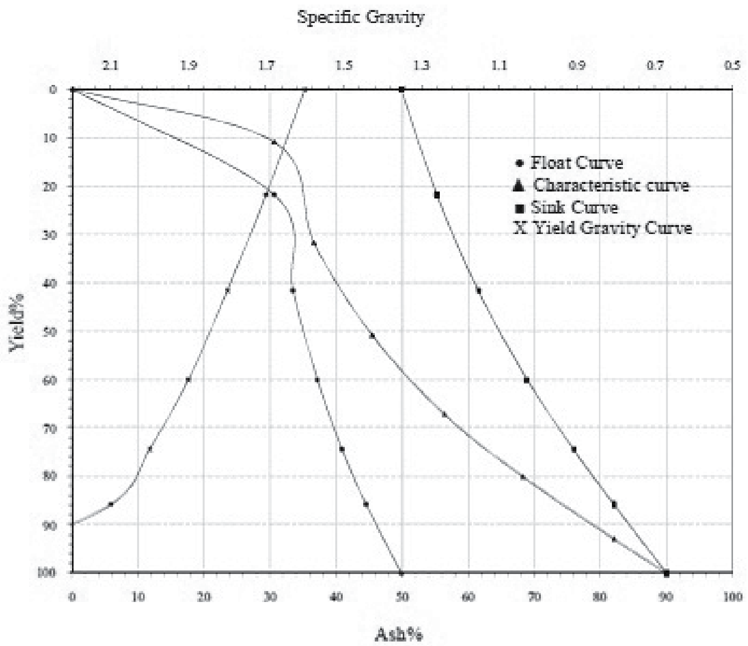

Figure 2 (a) : Washability Curve - Middlings

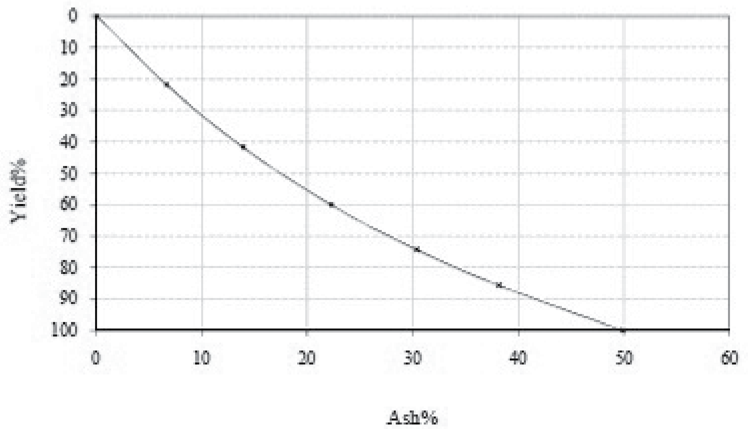

Figure 2 (b) : Mayer's Curve - Middlings

A CASE STUDY ON MAGNETIC SURVEY AT JAYANT OCP, DISTRICT SINGRAULI (MADHYA PRADESH)

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ABSTRACT

Magnetic survey is more reliable and more scientific to detect the buried heavy metallic body under sludges, slits and debris. In 2016 the rainfall was above average in Singrauli coalfield area, which affected most of the open cast coal mines, where most of the heavy machinery such as shovel, drills, pumps, starter and other heavy metallic body are buried in the silt/sludge. Production of the mines are affected due to loss of these machineries and mine advancement. To recover these machinery and find accurate position of the all buried heavy metallic body is very expensive and time taken by manual method. In such conditions magnetic survey become very effective, as it provides accurate position of the buried metallic body in less time with cost effectiveness.

INTRODUCTION

There was large amount of silt/sludge accumulated in the face and main approach roads of coal section due to heavy rainfall during the month of August and September 2016. Equipment like shovels, drills, pumps, starters and other heavy metallic objects got buried in the silt. Reconnaissance survey of the area of concerned was conducted by geophysicist and geologist of CMPDI, RI-VI Singrauli on 27th January 2017. After visiting the sites, the team decided to conduct the magnetic survey which is the most suitable survey under the prevailing condition of the mine working area. The Magnetometer can sense the presence of buried metallic objects over the surveyed area. It requires few manpower and very less time to take the readings. The buried metallic objects can be identified almost instantaneously in the field by a and the locations can thus be marked for silt/sludge clearing operation.

LOCATION

Jayant OCP is located in Waidhan block, Singrauli District of Madhya Pradesh state. The project is located in the south-central part of the Moher Sub-basin of Singrauli Coalfield and is bounded by Dudhichua and Nigahi Projects on the east and west respectively.

The project is well connected to Sidhi in MP about 100 km and Varanasi in UP about 225 km. The nearest railway station is Shaktinagar in UP about 05 km and Singrauli in MP on the Obra-Katni branch line of eastern railway which is about 15 km away and is approachable by an all-weather roads.

The location of survey points at Jayant OCP are given at **Figure-1** and **Figure-2**.

INSTRUMENT

The magnetic survey was conducted by using the GEM GSMP-35 Potassium Magnetometer. The GSMP-35 ground system is the highest sensitivity

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Figure 1 : Survey area of Jayant OCP

with the greatest absolute accuracy of the order of 0.0003 nT(nano-Tesla). The instrument can be operated by a single operator. The Potassium Magnetometer is the latest generation, very sensitive and also is equipped with the integrated GPS system. The inbuilt GPS of the instrument gives the positioning in Latitude – Longitude in WGS -84 format. This allows for highly accurately reading via a 'Waypoint Programming' as well as accurate time synchronization for base station correction.

DATA ACQUISITION

The Magnetic data was decided to acquire over the two predefined sites. One of the site was accessible but other site was not approachable due to presence of water body. The Magnetic data was recorded at the site over the silt/sludge slide affected area which was a main approach road of coal section area. But some area was not approachable due to accumulation of huge water body and heavy moving metallic machinery over

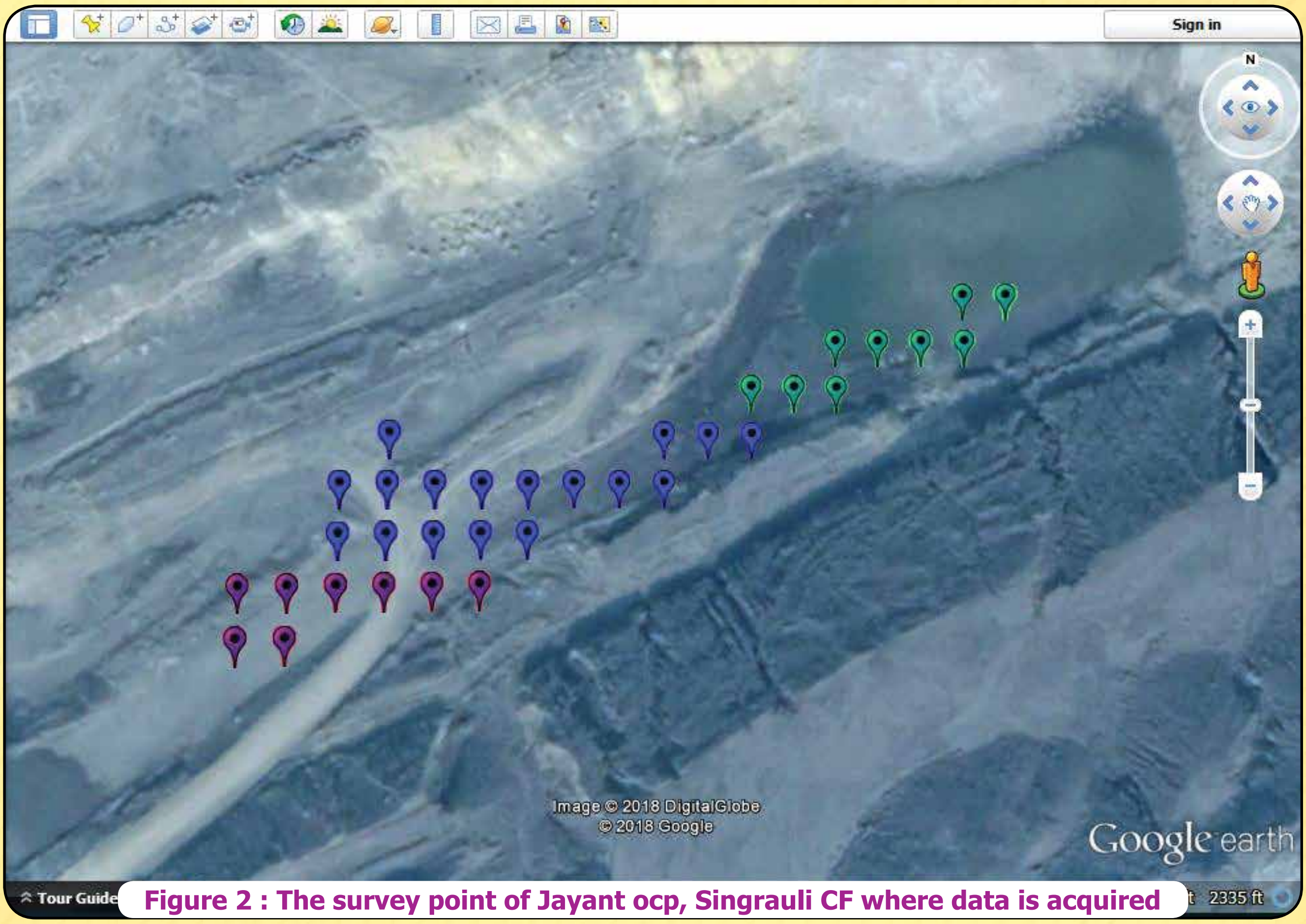

Figure 2 : The survey point of Jayant ocp, Singrauli CF where data is acquired

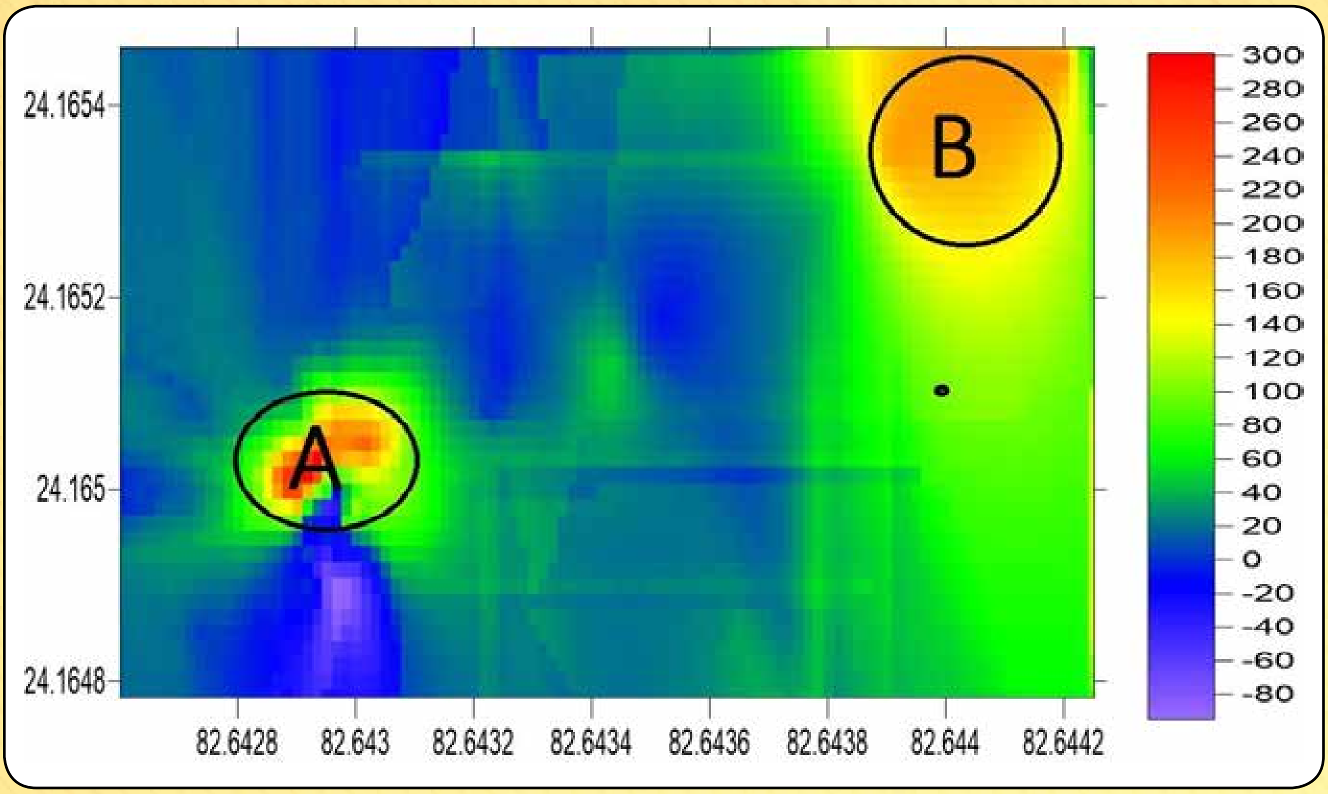

Figure 3

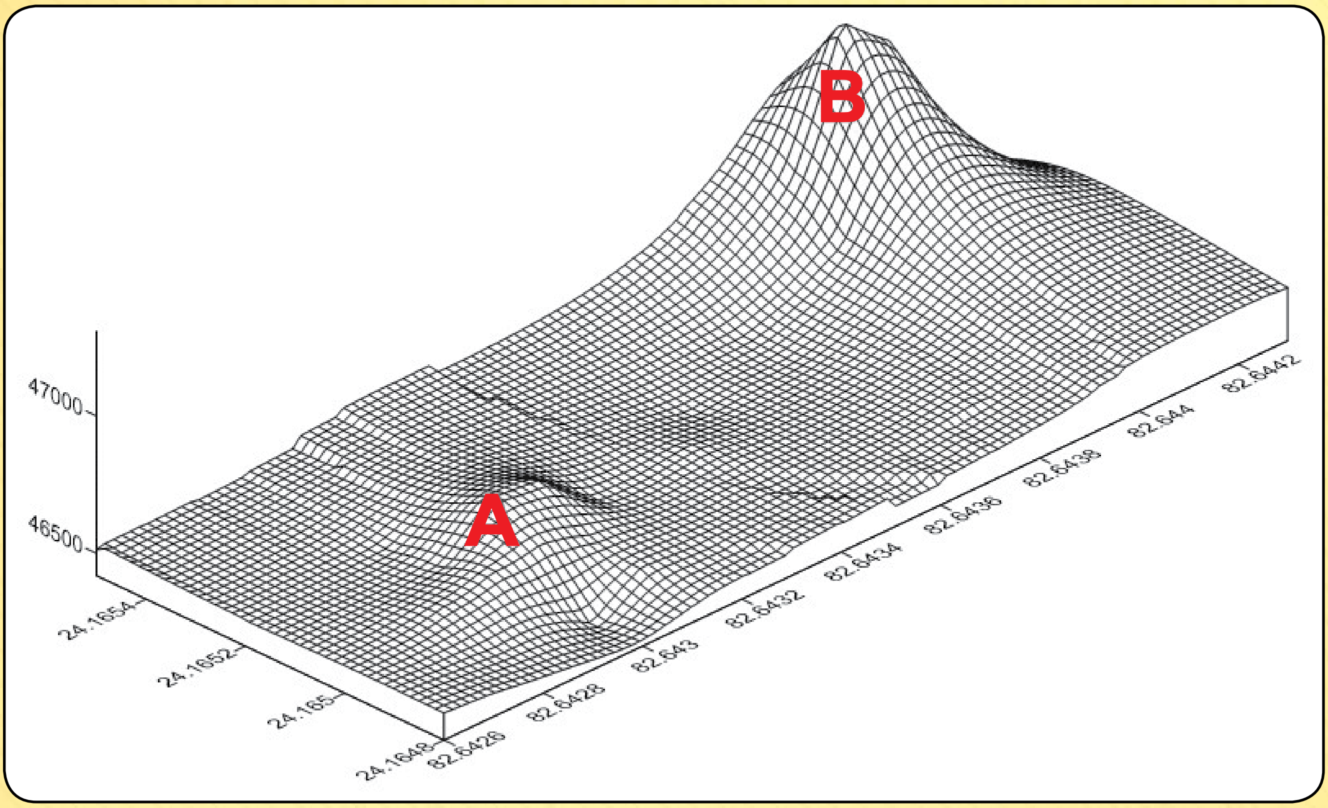

Figure 4

the survey area. Some observation points were affected due to presence of heavy machineries which were working near the survey area. 1315 number of observation points were recorded covering an area of approximately 1200 Square meter. During the data acquisition over the first site, two number of locations were showing the magnetic anomaly. Representative data (640 out of 1315) are tabulated at **Table-1**.

DATA PROCESSING

The data was retrieved by using the GEM Link software and processed by using the ARCGIS software. As a first step in Data processing operations, the Diurnal corrections were applied to take care of the temporal variations in the Earth's Magnetic field. No other corrections to the basic Magnetic field data like Normal or Tidal were applied since the area covered was too small to affect these corrections. After the necessary corrections, the data was plotted against the corresponding observation points and contouring of an iso-magnetic anomaly was done. The contour map was analyzed. Probable locations are given at **Figure-3** and **Figure-4**. After analyzing the contour map two anomalous points were identified on the plan and were demarcated physically on the field also.

RECOMMENDATIONS AND CONCLUSIONS

The WGS-84 coordinates of the two anomalous points i.e. the highest priority points over which the silt/suldge clearance activity was recommended.

The work on two points A and B were carried out and in Point A (**Figure-5**) the buried shovel was found.

Magnetic survey could lead to to-day's mine operation after recovery of the shovel and project could save the huge loss in time, material and natural resources.

Figure 5

Table-1 *(continued)*

S.N.	RL	Magnetic Value	S.N.	RL	Magnetic Value	S.N.	RL	Magnetic Value	S.N.	RL	Magnetic Value
161	285	46534.303	201	287	46499.3428	241	286	46517.4886	281	286	46660.6503
162	285	46537.2349	202	287	46501.921	242	286	46517.7997	282	286	46650.9097
163	285	46539.1894	203	287	46501.0224	243	286	46518.3366	283	286	46643.1123
164	285	46542.4611	204	287	46496.3523	244	286	46518.5991	284	286	46638.836
165	285	46545.3499	205	287	46491.6947	245	286	46518.5073	285	286	46633.1607
166	285	46548.6762	206	287	46490.5023	246	286	46518.4409	286	286	46637.2977
167	285	46552.1576	207	287	46492.9673	247	286	46519.0039	287	286	46652.5527
168	285	46556.2505	208	287	46496.984	248	286	46519.675	288	286	46673.0209
169	285	46561.4322	209	287	46501.332	249	286	46519.8191	289	286	46694.0564
170	285	46567.2728	210	287	46505.7054	250	286	46520.3027	290	286	46710.1431
171	285	46574.7897	211	287	46509.1195	251	286	46521.1183	291	286	46722.0788
172	286	46583.3802	212	287	46511.5588	252	286	46521.8081	292	286	46727.8624
173	286	46591.5386	213	287	46512.2682	253	286	46520.9579	293	286	46729.5982
174	286	46599.7844	214	287	46511.6152	254	286	46520.1027	294	286	46722.7315
175	286	46607.8572	215	287	46509.8836	255	286	46521.4573	295	286	46716.1315
176	286	46612.5223	216	287	46507.2428	256	286	46522.7237	296	286	46711.8608
177	286	46611.8814	217	287	46504.5564	257	287	46523.6518	297	286	46705.0042
178	286	46609.7381	218	287	46503.2231	258	287	46524.2462	298	286	46701.0794
179	286	46608.5414	219	287	46504.2503	259	287	46524.9929	299	286	46697.2546
180	286	46609.7812	220	287	46507.1149	260	287	46525.5879	300	286	46689.975
181	286	46612.6427	221	286	46510.7284	261	287	46525.9285	301	285	46676.9282
182	287	46618.6914	222	286	46513.8325	262	287	46526.5772	302	285	46662.7469
183	287	46622.5701	223	286	46515.1548	263	287	46527.8651	303	285	46650.7436
184	287	46619.8633	224	286	46515.4322	264	287	46529.659	304	285	46639.7799
185	287	46611.1176	225	286	46515.0431	265	287	46532.09	305	285	46631.2456
186	287	46596.6259	226	286	46515.434	266	287	46535.071	306	285	46619.9161
187	287	46575.7139	227	286	46516.9849	267	287	46538.4815	307	285	46609.1225
188	287	46549.5586	228	286	46518.3837	268	287	46542.77	308	285	46599.5501
189	287	46522.4554	229	286	46519.3293	269	287	46547.5671	309	285	46588.6248
190	287	46501.146	230	286	46519.1352	270	287	46553.2697	310	285	46578.1399
191	287	46488.4272	231	286	46519.0893	271	287	46560.0812	311	285	46567.4833
192	287	46482.3664	232	286	46518.6197	272	287	46568.8635	312	285	46558.3466
193	287	46481.2652	233	286	46518.0541	273	287	46579.4286	313	285	46551.0831
194	287	46485.2774	234	286	46517.8067	274	287	46592.4496	314	284	46544.8863
195	287	46489.7484	235	286	46518.053	275	287	46605.0738	315	284	46538.7423
196	287	46492.8386	236	286	46517.8153	276	287	46615.379	316	284	46533.7969
197	287	46493.9557	237	286	46517.5275	277	287	46628.2652	317	284	46529.3305
198	287	46492.6467	238	286	46517.1185	278	287	46644.6784	318	284	46527.2446
199	287	46493.6725	239	286	46517.3721	279	287	46655.646	319	284	46525.8618
200	287	46496.0441	240	286	46517.1719	280	287	46662.8184	320	284	46523.4347

Table-1 *(continued)*

S.N.	RL	Magnetic Value	S.N.	RL	Magnetic Value	S.N.	RL	Magnetic Value	S.N.	RL	Magnetic Value
321	284	46518.6588	361	284	46508.1885	401	284	46519.4237	441	284	46522.122
322	284	46513.3362	362	284	46508.7372	402	284	46519.5561	442	284	46522.4657
323	284	46508.5734	363	284	46509.0978	403	284	46519.6805	443	284	46522.998
324	283	46505.4891	364	284	46509.3771	404	284	46519.8233	444	284	46523.1888
325	283	46503.3136	365	284	46509.7449	405	284	46519.9265	445	284	46523.289
326	283	46501.2825	366	284	46509.9483	406	284	46519.9239	446	284	46523.3839
327	283	46499.9353	367	284	46510.1802	407	284	46520.0293	447	284	46523.4101
328	283	46498.8521	368	284	46510.5173	408	284	46520.1016	448	284	46523.6473
329	283	46498.0314	369	284	46510.5531	409	284	46519.9965	449	284	46523.6682
330	283	46497.5528	370	284	46510.9486	410	284	46520.0704	450	284	46523.7015
331	283	46496.9385	371	284	46511.2165	411	284	46520.2355	451	284	46523.7819
332	283	46496.2813	372	284	46511.3447	412	284	46520.4107	452	284	46524.1067
333	283	46495.8189	373	284	46511.5085	413	284	46520.5802	453	284	46524.4513
334	283	46495.2014	374	284	46511.7508	414	284	46520.9418	454	284	46524.6726
335	283	46494.0927	375	284	46512.1131	415	284	46521.0489	455	284	46524.8148
336	283	46494.068	376	284	46512.7582	416	284	46521.2186	456	284	46524.9673
337	283	46495.6344	377	284	46513.1091	417	284	46521.5349	457	284	46525.1034
338	283	46498.1949	378	284	46513.3995	418	284	46521.6444	458	284	46525.2238
339	283	46500.5906	379	284	46513.5206	419	284	46521.7225	459	284	46525.2648
340	283	46501.9397	380	284	46513.775	420	284	46521.7494	460	284	46525.294
341	284	46503.474	381	284	46514.304	421	284	46521.8748	461	284	46525.3373
342	284	46504.5809	382	284	46514.8464	422	284	46521.9908	462	284	46525.3993
343	284	46504.8277	383	284	46515.0704	423	284	46522.1273	463	284	46525.536
344	284	46504.1936	384	284	46515.4386	424	284	46522.2093	464	284	46525.5614
345	284	46504.0258	385	284	46515.7087	425	284	46522.1923	465	284	46525.6743
346	284	46504.4969	386	284	46515.8723	426	284	46522.184	466	284	46525.8314
347	284	46505.1763	387	284	46516.0002	427	284	46522.2529	467	284	46525.9104
348	284	46505.9185	388	284	46516.1976	428	284	46522.18	468	284	46525.8313
349	284	46506.0296	389	284	46516.1483	429	284	46521.6128	469	284	46525.841
350	284	46506.1027	390	284	46516.3055	430	284	46521.7488	470	284	46525.9659
351	284	46506.1239	391	284	46516.4062	431	284	46521.9746	471	284	46525.9684
352	284	46506.1614	392	284	46516.6073	432	284	46522.0008	472	284	46525.9072
353	284	46506.2116	393	284	46517.0115	433	284	46522.0125	473	284	46525.913
354	284	46506.158	394	284	46517.237	434	284	46521.8596	474	284	46526.0014
355	284	46506.2971	395	284	46517.4999	435	284	46521.6739	475	284	46526.1264
356	284	46506.6187	396	284	46517.7542	436	284	46521.4689	476	284	46526.06
357	284	46506.9317	397	284	46518.1304	437	284	46521.6036	477	284	46525.9869
358	284	46507.3795	398	284	46518.4047	438	284	46521.8299	478	284	46526.0823
359	284	46507.8202	399	284	46518.7422	439	284	46522.1099	479	284	46525.9799
360	284	46507.8751	400	284	46519.08	440	284	46522.1143	480	284	46525.8847

Table-1 *(continued)*

S.N.	RL	Magnetic Value	S.N.	RL	Magnetic Value	S.N.	RL	Magnetic Value	S.N.	RL	Magnetic Value
481	284	46525.9435	521	287	46604.0267	561	287	46515.614	601	288	46535.9861
482	284	46526.1377	522	287	46598.8975	562	287	46515.706	602	288	46534.6131
483	284	46526.179	523	287	46593.0061	563	287	46516.21	603	288	46528.7301
484	284	46526.1875	524	287	46584.9278	564	287	46516.7169	604	288	46510.2432
485	284	46526.0827	525	287	46575.5283	565	287	46516.7514	605	288	46495.6975
486	284	46526.3314	526	287	46575.1594	566	287	46516.7491	606	288	46481.4223
487	284	46526.378	527	287	46573.7298	567	287	46517.0607	607	288	46503.2749
488	285	46526.3162	528	287	46566.9536	568	287	46517.4345	608	288	46525.3631
489	285	46526.2947	529	287	46562.6841	569	287	46517.9494	609	288	46514.6349
490	285	46526.2549	530	287	46563.6528	570	287	46519.1464	610	288	46504.0695
491	285	46526.3143	531	287	46564.8174	571	288	46521.1057	611	288	46493.2911
492	285	46526.4905	532	287	46563.4699	572	288	46522.7043	612	288	46484.5635
493	285	46526.4732	533	287	46565.2803	573	288	46524.1675	613	288	46476.6463
494	285	46526.4463	534	287	46570.7235	574	288	46525.2601	614	288	46411.5421
495	285	46527.7166	535	287	46580.3998	575	288	46526.0657	615	288	46402.3548
496	285	46529.6339	536	287	46595.8004	576	288	46526.6769	616	288	46401.7056
497	285	46531.8785	537	287	46618.2514	577	288	46529.1024	617	288	46405.7988
498	285	46534.5288	538	287	46645.5829	578	288	46533.2192	618	288	46413.3626
499	285	46537.5621	539	287	46668.634	579	288	46538.9114	619	288	46423.4336
500	285	46541.1734	540	287	46689.22	580	288	46547.2297	620	288	46433.0462
501	285	46545.4606	541	287	46700.6465	581	288	46558.2496	621	288	46439.1611
502	285	46549.7876	542	287	46705.1227	582	288	46573.24	622	288	46443.0511
503	286	46555.2986	543	287	46706.1336	583	288	46595.8315	623	288	46450.9897
504	286	46560.2346	544	287	46703.9206	584	288	46626.0836	624	288	46461.8236
505	286	46565.9802	545	287	46695.8503	585	288	46663.3481	625	288	46472.4739
506	286	46572.1687	546	287	46682.841	586	288	46708.1846	626	288	46480.5934
507	286	46577.6595	547	287	46666.0726	587	288	46745.3603	627	288	46489.1229
508	286	46581.5299	548	287	46647.6623	588	288	46758.4729	628	288	46493.5306
509	286	46585.446	549	287	46629.673	589	288	46756.6879	629	288	46494.4704
510	286	46590.4883	550	287	46611.0813	590	288	46750.659	630	288	46491.6928
511	286	46595.6404	551	287	46593.893	591	288	46787.3678	631	288	46486.5684
512	286	46601.2796	552	287	46576.6302	592	288	46748.066	632	288	46483.4268
513	286	46606.8348	553	287	46559.3522	593	288	46704.5507	633	287	46476.2515
514	287	46613.1596	554	287	46544.6812	594	288	46655.7947	634	287	46465.7798
515	287	46617.3693	555	287	46533.3175	595	288	46616.5976	635	287	46456.8534
516	287	46617.1952	556	287	46525.1892	596	288	46597.7157	636	287	46459.3936
517	287	46615.5455	557	287	46520.1757	597	288	46583.9011	637	287	46479.7703
518	287	46613.4031	558	287	46516.324	598	288	46537.9062	638	287	46521.8223
519	287	46611.1201	559	287	46515.1645	599	288	46537.3298	639	287	46577.1824
520	287	46608.1677	560	287	46515.274	600	288	46536.1231	640	287	46635.362

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Table-1

S.N.	RL	Magnetic Value	S.N.	RL	Magnetic Value	S.N.	RL	Magnetic Value	S.N.	RL	Magnetic Value
1	284	46556.164	41	284	46565.6244	81	284	46747.6875	121	285	46494.5558
2	284	46556.3018	42	284	46601.2876	82	284	46720.3677	122	285	46493.191
3	284	46556.1643	43	284	46644.7735	83	284	46693.9178	123	285	46492.1804
4	284	46555.8387	44	284	46696.5648	84	284	46670.1736	124	285	46491.5458
5	284	46555.5581	45	284	46753.892	85	284	46648.6716	125	285	46491.57
6	284	46555.3543	46	284	46821.9379	86	284	46631.2267	126	285	46492.552
7	284	46555.6046	47	284	46899.7944	87	284	46615.4271	127	284	46494.6155
8	284	46553.7836	48	284	46975.2931	88	284	46601.1967	128	284	46498.1607
9	284	46553.7291	49	284	47047.5438	89	284	46588.4424	129	284	46503.6276
10	284	46553.6842	50	284	47108.9391	90	284	46577.9844	130	284	46510.7968
11	284	46553.3181	51	284	47170.0252	91	285	46570.0052	131	284	46519.5088
12	284	46554.357	52	284	47187.1729	92	285	46563.2582	132	284	46529.2513
13	284	46555.6549	53	284	47167.918	93	285	46557.0192	133	284	46538.0404
14	284	46556.123	54	284	47165.8669	94	285	46552.1775	134	284	46544.8929
15	284	46556.4317	55	284	47167.4328	95	285	46548.1636	135	284	46548.6255
16	284	46556.2832	56	284	47169.0892	96	285	46544.5732	136	284	46549.1959
17	284	46555.7012	57	284	47169.4077	97	285	46541.1718	137	284	46547.6921
18	284	46554.992	58	284	47167.7949	98	285	46537.8302	138	284	46544.242
19	284	46549.9374	59	284	47187.2744	99	285	46534.3656	139	284	46539.4915
20	284	46549.1077	60	284	47188.8379	100	285	46531.7616	140	284	46535.012
21	284	46545.6342	61	284	47260.7894	101	285	46529.8094	141	284	46530.9529
22	284	46545.6236	62	284	47334.4793	102	285	46527.8102	142	284	46527.8539
23	284	46547.0831	63	284	47387.1414	103	285	46526.3058	143	284	46525.2128
24	284	46546.836	64	284	47426.3526	104	285	46524.9691	144	284	46522.4356
25	284	46547.3331	65	284	47438.7579	105	285	46523.5527	145	284	46520.7247
26	284	46547.1293	66	284	47421.8961	106	285	46522.1205	146	284	46520.0914
27	284	46547.0656	67	284	47402.3665	107	285	46520.7491	147	284	46519.6807
28	284	46547.6171	68	284	47371.8728	108	285	46519.1987	148	284	46519.6172
29	284	46547.7171	69	284	47326.1633	109	285	46517.7807	149	284	46519.8842
30	284	46545.7411	70	284	47271.9253	110	285	46516.3495	150	284	46520.3416
31	284	46542.4942	71	284	47220.6861	111	285	46514.6824	151	284	46521.0329
32	284	46542.0053	72	284	47171.3617	112	285	46512.8935	152	284	46521.7932
33	284	46542.4959	73	284	47113.8462	113	285	46510.8314	153	284	46522.5489
34	284	46545.6658	74	284	47052.7018	114	285	46508.3888	154	284	46523.6169
35	284	46544.7726	75	284	46995.5413	115	285	46506.1525	155	284	46526.2602
36	284	46541.6697	76	284	46939.0011	116	285	46503.9176	156	284	46526.6631
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38	284	46542.2958	78	284	46841.1218	118	285	46499.2648	158	284	46528.139
39	284	46542.4817	79	284	46804.0211	119	285	46497.7877	159	284	46530.0408
40	284	46545.8556	80	284	46773.64	120	285	46496.084	160	284	46532.0197

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