SCOPE OF APPLICATION OF L.E.D. LIGHTING SYSTEMS OVER CONVENTIONAL LIGHTING ARRANGEMENTS IN OPEN CAST MINES

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ABSTRACT:

This paper presents general requirements of lighting including sources of lighting in surface and underground mines. Performance of various lighting sources such as sodium vapor lamps, tungsten filament, incandescent, fluorescent, mercury vapor, metal halides etc are discussed. Regulations related to mine lighting and advantages of LED system of lighting over conventional system are also discussed in detail. Iluminance Measuring techniques and instrumentation for conducting illumination survey are briefly enumerated. Illumination levels at different working places in Tirap open cast coal mine, NEC, a subsidiary of Coal India Limited are illustrated. Comparison between Conventional Sodium/Mercury vapor lamp Vs. LED Light is presented emphasizing the importance of application of LED system of lighting for effective energy conservation, better illumination, resistant to shock and vibration etc.

1. INTRODUCTION

Countries with a well-established underground mining industry are usually quite specific in their requirements regarding what constitutes a safe mine lighting system. This is particularly true for mines which have methane gas given off from the workings, usually coal mines. Methane gas can ignite and cause an underground explosion with devastating results. Consequently any lights must be designed to be either "intrinsically safe" or "explosion proof". An intrinsically safe light source is one in which the current feeding the light has very little energy so that any short in the circuit would not produce a spark which could ignite the methane gas. For a lamp to be explosion proof, any explosion triggered by the lamp's electrical activity is contained within the device. In addition, the device itself will not become hot enough to cause an explosion. The lamp is more expensive, heavier, with metal parts usually made of castings. Governments usually have test facilities to certify whether lamps can be classified for use in a gassy mine. A low-pressure sodium lamp could not be so certified as the sodium in the lamp could ignite if the lamp were to break and the sodium came in contact with water. Countries also legislate standards for the amount of light required for various tasks but legislation varies greatly in the amount of light that should be placed in the various working places.

For efficient working conditions in the mines adequate illumination is necessary. As per mining laws in the respective countries, mine operators are supposed to provide the required lighting sources and maintain as per the illumination standards complying with the associated electricity rules.. Levels of illumination are only one of the factors that determine the quality, and hence safety, of a visual environment. In coal mining, other factors that have been identified as affecting the overall quality of the visual environment are:

1) inherent vision of the mine population
2) Low surface reflectance, usually less than 5%, which almost eliminates secondary reflections and indirect lighting;
3) suspended dust and water vapor cause backscattering reducing apparent Iluminance.
4) Mounting height restrictions and job tasks place the luminaries in the worker's direct line of sight causing glare;
5) Mounting positions restrict the size, location and light distribution of the luminaries.
6) Luminaries must meet the safety requirements for use in hazardous atmospheres.

(Source: ECSC, 1990)

2) ILLUMINANCE MEASURING TECHNIQUES AND INSTRUMENTATION

Instruments are required to evaluate lighting systems and components. The field of light measurement is called photometry, and the instruments used to measure lighting are called photometers. Many types of photometers are available to measure light energy and related quantities, In the underground mine lighting applications, the photometer is used to verify compliance with mine safety and health administration (MHSA) lighting regulations and in the design and evaluation of lighting systems. Before taking measurements with a photometer, care must be taken to insure that a luminary or illumination system is in the proper condition to satisfy the purpose of the measurements.

This process measures the incident light (in lux) received by a surface. Most countries specify their lighting standard in lux, so this method is most widely used in mine surveys .Three different techniques can be used in mine illumination surveys:

i. Direct planar measurement
ii. Separate measurements for direct and diffused light
iii. Maximum reading method

In the planar measurement method, the general Iluminance level of the work place is measured using photocell photometer. The photometer is laid on the surface and readings are taken on points at regular intervals. In the second method, Separate determinations of the quantity of light reaching the measuring point directly from the source and the light reaching the same point after one or more reflections from the walls and roof are made .The Iluminance due to direct light is measured by pointing the photocell toward the lamp and masking all other light sources. The reading obtained is then resolved normal to the surface and the reading noted is then corrected by using a calibration curve.

In the maximum reading method: in this method the photocell is pointed at the light source and the reading is normally resolved to the plane being considered. The resolved component is assumed to be the illuminance at the point of measurement. Digital Luxmeter (Metravi, 2011) for measuring illuminance is shown in Fig 1

Fig 1 . Digital Luxmeter (Metravi, 2011) for measuring illuminance

3) ASSESSMENT OF WORLD-WIDE VISIBILITY STANDARDS

A review of current world-wide illumination standards and guidelines in coal mines was undertaken to assess their applicability to the conditions in the coal mining industry. Where lighting levels are specified in legislation or standards, the method of specifying actual levels of lighting varies from country to country. The majority specify levels in terms of illuminance.

3.1. International Illumination Levels

In order to expand or clarify legislative requirements, the Inspectorate and/or mining companies of some countries have provided guidance or recommended illumination levels of different areas and operations underground. Good visibility is essential for work persons to carry on any safe job in a safe and efficient manner. Defining appropriate illumination levels for underground coal mines is a complex task. Table 2.6 demonstrates the level of variation across countries for each of the specified areas and operations. In considering health and well being, Odendaal (1997) states that the recommended minimum light level for general underground work is 54 lux, higher than many of the values in the Table 2.

3.2. Indian Standards of lighting in mines

3.2.1. Underground lighting

Good visibility is essential for work persons carry on any job in a safe and efficient manner .Regulations 151 of CMR, 1957 and Reg.146 of MMR ,1961 require adequate general lighting to be provided at specified places both on surface and in underground .It also requires that the lighting provided in a mine shall as far as possible be so arranged as to prevent glare or eye strain .In terms of Reg.154(2)b of CMR ,1957 ,the Director General of Mines Safety may, form time to time by notifications in the official Gazette specify the standard of lighting to be provided in any specified area or place in a mine. Minimum standards recommended for underground lighting(*CMR, 1957)* are shown in Table 3:

Table 2: Summary of International Illumination Levels (in lux) (ECSC, 1990; MVS, 1992; Piekorz, 1997

	Shafts	Loading	Around Machines	Haulages	Headings	u/g workshop
Belgium	20-50	20	25	10		
Hungary	40-100	40-60	20-50	2-10		20-50
Canada (British Columbia)	21			21	53	
Poland	30	30	10	2-10	5-15	30
UK (British Coal)	70	30		2.5		50-150
European Coal & Steel Community	40-90	15-80		5-15	10-30	
West Germany	30-40	40	80	15		
Czechoslovakia	15	20	20	5		
South African Gold Mines	20-160	160		20		400

The roof and side should be properly white- washed and stone dusted on the floor as required under the statue to achieve the illumination to the standards for providing necessary visibility for safe and efficient work at different places. The standard of lighting in depillaring area should be at less 1.5 lumens/Sq.ft at the floor level .Suitable flood lighting may be arranged by 4 or more 250 W bulbs with reflector (matt surface). in degree I gassy mine .In degree II and III gassy seams a cluster of 15 to 20 cap lamps should be placed on suitable stand in the area in addition to individual lights. Some standards of illumination at certain places is provided in table 4.

Table 3: Minimum standards recommended for underground lighting(*CMR, 1957)*

Place	Minimum average illumination level lux
(a) pit bottoms	15-30
(b)Main junctions	12.5
(c) Roadways	4
(d)Haulage engines, control gear and haulage drum	15

3.2.2. Lighting standards for opencast mines

The general lighting scheme of an opencast mine generally connected to common power source. The electric power failure may occur at any time when the whole area may be plunged in absolute darkness which may lead to an accident .Individual lights may, therefore, be provided to individual workers in addition to the general lighting scheme in the opencast mines. The very high benches ,up to 45m high ,made by draglines or other heavy earth moving machinery (HEMM) are very difficult to keep properly illuminated .It may become difficult to pinpoint the places require dressing ,from the working points over the draglines or Shovels .Moving flood lights, akin to the hunters search light on the boom of the draglines or on the bucket of the shovels ,may be mounted and these flood lights may be rotated at will lighting up every nook and corner of the high benches. The Minimum standard recommendations for opencast mines are provided in table 5.

Table 4: Standard of illumination at certain places (*Ghatak.S (1997)*

Sl. no	Place /Area	Minimum	
1.	At the bottom of a sinking shaft	10 Lux	Vertical
2.	At the mechanized quarry face	15 Lux	Horizontal
3.	At coal depot where wagons are loaded	10 Lux 3 Lux	Vertical Horizontal
4.	At fully mechanized longwall face	10 Lux	Vertical

Table 5. The minimum standards recommended for Opencast mines (Ghatak.S (1997):

Sl. No.	Place/Area to be illuminated	Manner in which it is to be illuminated	Minimum standard of illumination(lux)	Plane level in which tha illumination is to be provided
1.	General working area as determined by the manager in writing	-	0.2	At the level of surface to be illuminated
2.	Work place of heavy machinery	So as to cover the depth and height through which machine works	5.0	Horizontal

3.	Area where drilling rig works	So as to illuminate the full height of the rig	10.0	Vertical
4.	Area where bulldozer or other travctor mounted machines work	-	10.0	At the level of crawlers tracks
5.	Places where manual work is done	To be provided at level of the surface on which work is done	5.0 10.0	Horizontal Vertical
6.	Place where loading or unloading or transfer, loading of dumpers, trucks or trains is carried on	-	3.0	Horizontal
7.	Operators cabin of machines or mechanism	To be provided upto a height of 0.8m from floor level	30.0	Horizontal
8.	At hand picking points along conveyor belt	To be provided upto a distance of not less than 1.5m from picker	50.0	On the surface of conveyor belt
9.	Truck hauling roads	To be provided at the level of the roads	0.5 to 3.0	Horizontal
10.	Rail haulage track in the pit	To be provided at he level of the rail heads	0.5	Horizontal
11.	Roadways and footpaths from bench to bench	-	3.0	Horizontal
12.	Permanent paths for use of person employed	-	1.0	Horizontal

Illumination levels at different working places in Tirap open cast coal mine, NEC, a subsidiary of Coal India Limited are illustrated in TABLE 6.

LIGHTING SURVEY- <u>TIRAP COLLIERY</u>

TABLE 6: Illumination levels at different working places in Tirap open cast coal mine

SL.NO.	PLACE	MINIMUM STANDARD OF ILLUMINATION(LUX)	ACTUAL OBTAINED VALUE (LUX)
1.	WORKING PLACES OF HEMM	5.0H 10.0V	
a)	1st OB Bench of East Section.		6.0H 14 TO 15V

b)	2nd OB Bench of East Section.		8.0H 14 TO 15V
c)	3rd OB Bench of East Section.		6.0H 16 TO 17V
d)	4th OB Bench of East Section.		7.0H 14 TO 15V
e)	5th OB Bench of East Section.		7.0H 14 TO 15V
f)	20'Coal Bench of East Section.		6.0H 15 TO 16V
g)	60'Top OB Bench of East Section.		7.0H 14 TO 15V
h)	60' Coal Bench of East Section.		6.0H 14 TO 15V
i)	1st OB Bench of West Section.		6.0H 15 TO 16V
j)	2nd OB Bench of West Section.		6.0H 15 TO 16V
k)	3rd OB Bench of West Section.		6.0H 14 TO 15V
l)	4th OB Bench of West Section.		6.0H 15 TO 16V
m)	5th OB Bench of West Section.		6.0H 14 TO 15V
n)	20'Coal Bench of West Section.		8.0H 14 TO 15V
o)	60'Top OB Bench of West Section.		6.0H 14 TO 15V
p)	60' Coal Bench of West Section.		6.0H 14 TO 15V
2.	Area where Bull Dozer & Other Tractor mounted Machinery working	10.0 Lux at the level Of Crawler Track.	
3.	Railway Siding (where Loading& Unloading & Transfer of Coal is carried out).	3.0 H	13.0H
4.	Roadway & Footpath from Bench to Bench.	3.0 H	
SL.NO.	PLACE	MINIMUM STANDARD OF ILLUMINATION(LUX)	ACTUAL OBTAINED VALUE (LUX)
5.	HAUL ROADS	3.0 H	
6.	Mine - I Diesel Pump House.	3.0 H	
7.	Mine - I 3.3 KV Pump House.	3.0 H	
8.	Mine - II Pump House.	3.0 H	
9.	Drilling site	10 V	

4) VOLTAGE LIMITS IN MINES

Energy shall not be transmitted into a mine at a voltage exceeding 11000 volts and shall not be used therein at a voltage exceeding 6600 volts.**Provided that:**

i) Where hand-held portable apparatus is used, the voltage shall not exceed 125 volts

ii) Where electric lighting is used: -

(a) In underground mines, the lighting system shall have a mid or neutral point connected with earth and the voltage shall not exceed 125 volts between phases;

(b) On the surface of a mine or in an open cast mine, the voltage may be raised to 250 volts, if the neutral or the mid point of the system is connected with earth and the voltage between the phases does not exceed 250 volts;

iii) Where portable hand-lamps are used in underground working of mine, the voltage shall not exceed 30 volts;

iv) Where any circuit is used for the remote control or electric interlocking of apparatus, the circuit voltage shall not exceed 30 volts.

5) PRECAUTIONS IN MINES.

Precautions where gas exists-

(1) In any part of a coal-seam of the first degree gassiness-

(a) All cables shall be constructed, installed, protected, operated and maintained in such a manner as to prevent risk of open sparking;

(b) At any place which lies in-bye of the last ventilation connection, all [signalling or telecommunication and remote control] circuits shall be so constructed, installed, protected, operated and maintained as to be Intrinsically safe.

(c) All apparatus including portable and transportable apparatus including lighting fittings used at any place which lies in bye of the last ventilation connection shall be flame-proof.

(2) At any place which lies in any part of a coal-seam of second and third degree gassiness-

(a) All[signalling, telecommunication and remote control] circuits shall be so constructed, installed, protected, operated and maintained as to be intrinsically safe;

(b) All cables shall be constructed, installed, protected, operated and maintained in such a manner as to prevent risk of open sparking;

(c) All apparatus, including portable and transportable apparatus used at any place within 90 metres of any working face or goaf in case of a second degree gassymine and within 270 metres of any working face or goaf in case of third degree gassymine or at any place which lies in-bye of the last ventilation connection or in ar-y return airways shall be flame-proof;

(d) All electric lamps shall be enclosed in flame-proof enclosures.

6) LIGHT SOURCES IN MINING

In 1879 a practical incandescent filament lamp was patented. As a result light no longer depended on a fuel source. Many startling breakthroughs have been made in lighting knowledge since Edison's discovery, including some with applications in underground mines. Each has inherent advantages and disadvantages. Table 7 below lists the light source types and compares some parameters.

Table 7. Light source types and comparison of some parameters.

Type of light source	Average rated life (h)	DC source	Colour rendition
LED	50,000 to 1,00,000	YES	Excellent
Tungsten filament	750 to 1,000	Yes	Good

Incandescent	5 to 2,000	Yes	Good
Fluorescent	500 to 30,000	Yes	Good
Mercury vapour	16,000 to 24,000	Yes with limitations	Average
Metal halide	10,000 to 20,000	Yes with limitations	Good
High-pressure sodium	12,000 to 24,000	Not advised	Fair
Low-pressure sodium	10,000 to 18,000	Not advised	Poor

Current to energize the light sources may be either alternating (AC) or direct (DC). Fixed light sources almost always use alternating current whereas portable sources such as cap lamps and underground vehicle headlights use a DC battery. Not all light source types are suitable for direct current.

7) DESIGN OF LIGHTING SYSTEM FOR MINES

The environment of an underground coal mine is a dynamic one that includes dust, confined spaces, low reflective surfaces and low visual contrasts. Lighting is critical to miners since they depend heavily on visual cues to spot fall of ground, pinning and striking and slipping and tripping hazards. Consequently, illumination greatly affects miners' ability to perform their jobs safely. Typically, a miners' caplamp is the primary and most important source of light for underground coal mines. Lighting plays a critical role for miners as they visually inspect the mine roof, ribs, back and floor for slip, trip and fall hazards. Objects associated with these hazards are typically of very low contrast and reflectivity. Secondly, there are age-related factors that require a better quality of light. Diminished night vision is one of the most common problems experienced by older people because there are changes in the eye that include decreased pupil size, cloudier lens and fewer rod photo receptors that are very sensitive to light. Designing of good lighting systems for underground coal mines is not an easy task because of the prevailing unique environment and nature of work encountered. Designing of Lighting System on the surface at different levels of light source from the surface is shown in Fig 2.

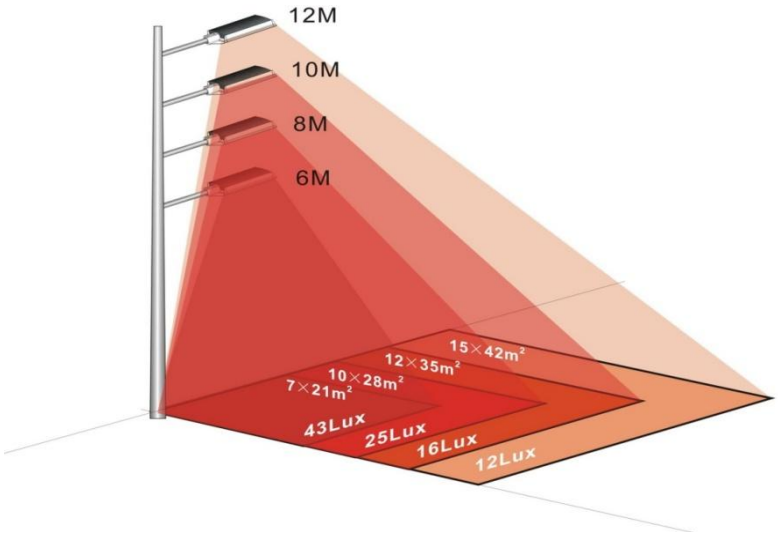

Fig 2: Designing of Lighting System on the surface

Recent Advancement in lighting technology replaces all the defects and shortcomings stated above is met with LED lighting systems. Table 8 shows Comparison of cost and power of incandescent bulb, CFL and LED Lighting systems. Table 8 shows various feature of incandescent bulb, CFL and LED Lighting systems.

Table 8: Comparison of cost and power of incandescent bulb, CFL and LED Lighting systems

Lux	Incandescent bulb	DC/ Power Source	Cost of Power/Day (AC)	**Colour rendition**	CFL	DC/, Power Source	Cost of Power/ Day (AC)	**Colour rendition**	LED	DC/ , Power Source	Cost of Power/ Day (AC)	**Colour rendition**
455	40	Yes	4.32	Good	10	Yes	1.08	Good	3	Yes	0.324	Excellent
810	60	Yes	6.48	Good	14	Yes	1.512	Good	5	Yes	0.54	Excellent
1200	70	Yes	7.56	Good	17	Yes	1.836	Good	8	Yes	0.864	Excellent
1500	100	Yes with limitations	10.8	Average	25	Yes with limitations	2.7	Good	14	Yes	1.512	Excellent
2650	150	Yes with limitations	16.2	Average	30	Yes with limitations	3.24	Good	20	Yes	2.16	Excellent
3000	180	Not advised	19.44	Fair	45	Yes with limitations	4.86	Good	29	Yes	3.132	Excellent
3600	200	Not advised	21.6	Fair	56	Yes with limitations	6.048	Good	30	Yes	3.24	Excellent
4000	250	Not advised	27	Fair	65	Yes with limitations	7.02	Good	40	Yes	4.32	Excellent

8) LED LIGHTING SYSTEM AND ITS ADVANTAGES

Recent Advancement in lighting technology replaces all the defects and shortcomings stated above is met with LED lighting systems. LED light has complete and continuous spectrum similar to daylight. Table 9: shows Comparison between Conventional Sodium/Mercury vapour lamp Vs. LED 80watts Street Light.

9) CONCLUSION

If carefully designed and implemented, lighting systems provide mine workers improved visibility and contribute to improved safety, productivity and morale. Properly designed lighting systems can improve visibility and safety during working in underground coal mines. Also it can prove to be a very cost effective investment for the mine operator. An underground coal mine is the most difficult environment to illuminate. Basically a lighting system designed for underground coal mines should have the following features:

- Intrinsically safe and externally harmless;
- High-levels of brightness and intensity in adverse environment;
- High-efficiency in terms of lumens output per unit of watt
- Low-voltage and current requirements as lightweight battery is recommended;
- Low radiated heat to prevent any electrical hazards

- Resistant to shock, vibration and atmospheric pressure fluctuations;
- No UV rays should be produced;
- Easy to install; and
- The light source should draw constant current instead of constant voltage.

Table 9: Comparision between Conventional Sodium/Mercury vapour lamp Vs. LED 80watts Street Light

Conventional Sodium/Mercury vapour lamp	**LED 80watts Street Light**
Power in watts: 250+34 watt (ballast) total 284 watt	**1. 82 watts**
Light output: 30 at 8 meter height from the lamp	2. Light output: 30~35 at 8~9 mtr height from the lamp
Power consumption watts for 3.42 units/night (12 hrs per night every day) and ~102 units per month	3. Power consumption: 0.98 unit for 1 day and 30 units per month. Approximately 70% of energy savings.
Ballast is required and delay start	4. No ballast and instant glow.
5. No spike protection	5. Spike protection available
6. Average life of less than 4 months.	6. Expected life of 7.5 years and two year replacement warranty.
7. Flickering problem persists frequently and shutoff problem due to thermal protection. High temperature of 200º due to lamp and ballast.	7. Absolutely no flicker and temperature below 70~75º centigrade
8. Recovery on investment is not applicable	8. ROI is within less than 15 months and after that power bill is saved about 70%.
9. The lamp gets damaged due to impact/shock or vibration.	9. Shock and vibration resistant
10. 80 degree view angle	10. 120 degree viewing angle
11. Working voltage ranging from 200~250 volts AC	11. Wide operating voltage ranging from universal AC input
12. UV and other light pollution	12. No light pollution

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