ASSESSMENT OF WET OXIDATION OF SOME INDIAN COALS

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENTS FORTHE DEGREE OF

BACHELOR OF TECHNOLOGY

IN

MINING ENGINEERING

BY

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Roll No. 109MN0646

DEPARTMENT OF MINING ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY

ROURKELA – 769008

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National Institute of Technology

Rourkela

CERTIFICATE

This is to certify that the thesis entitled **Assessment of wet oxidation of some Indian coals** being submitted by Prabhakar Kumar Paswan (Roll No. 109MN0646) to National Institute of Technology, Rourkela; for the award of degree of Bachelor of Technology in Mining Engineering is an authentic work carried out by him under my supervision and guidance. To the best of my knowledge, the matter substantiated in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

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Prabhakar Kumar Paswan

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ABSTRACT

The auto oxidation of coal ultimately leads to spontaneous combustion which is the major root cause for the disastrous of coal mine. It has been a major problem in the leading coal producing countries like Australia, India and China. Therefore the assessment for this combustion is very much necessary. It depends upon different characteristics and properties of coal. Once if the combustion of coal has been occurred, it is very difficult to control which also disturbs the environment of the surroundings of the mine. The spontaneous heating susceptibility of different coals varies over a wide range and it is important to assess their degree of proneness for taking preventive measures against the occurrence of fires to avoid loss of lives and property, sterilization of coal reserves and environmental pollution and raise concerns about safety and economic aspects of mining etc [3].

This project deals with the spontaneous heating tendency of coal using wet oxidation apparatus at various speed of magnetic stirrer. Five coals samples were collected from central Coalfields Limited (CCL) Limited and two coals from Mahanadi coal Limited (MCL) covering some coalfields of India. The collected Indian coals were prepared in a laboratory as per the Indian standards and the susceptibility indices were carried out at low, medium and high speed of magnetic stirrer using wet oxidation apparatus. The parameters of proximate analysis were carried out following the Indians standards and the best correlation was found out using MS Excel among the parameters of proximate analysis and the wet oxidation at low, medium and high speed of magnetic stirrer.

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CHAPTER – 1

INTRODUCTION

1.1 BACKGROUND

Coal mine fire is the underground shouldering of a coal deposit, often in a coal mine. It is proved to be a major problem worldwide, especially in coal rich nations such as China. These fires have serious economic, social and ecological impacts. They are often started by lighting grass, or forest fires, and are particularly insidious because they continue to shoulder underground after surface fires have been extinguished. Coal fires are a serious health and safety hazard as well as affecting the environment by releasing toxic fumes, damaging machinery present inside the mine, reigniting grass, brush ,or afforest fires, and cause subsidence of surface infrastructure such as roads, pipelines, electric lines, bridge supports, buildings and homes. Coal fires continue to burn for decades or even centuries in some cases, which are extremely difficult and costly to extinguish, as they burn underground [3].

All coals are not susceptible to spontaneous heating to the same extent, it is essential to assess their degree of proneness in order to plan advance precautionary measures. Therefore, the determination of susceptibility of coals to spontaneous heating is essential to efficiently run the production and maintenance activities, so that required quantity of coal is available within incubation period. The spontaneous heating of coal is defined as the process by which coal starts burning by itself just by absorbing oxygen from atmosphere and not by any external fire. Some fraction of the exposed coal absorbs free oxygen at a faster rate than others which leads to oxidation with the formation of gases (CO,CO_2), water vapor and some heat during the reaction. The oxidation course of coal takes place even at ambient temperatures [5].

1.2 GENERAL

Coal has been a useful resource for years. It is primarily burned for the production of electricity and/or heat, production of chemicals and is also used for industrial purposes, such as refining metals. At least 40% of the world's electricity comes by coal, and in 2012, about one-third of the United States' electricity came from coal, down from approximately 49% in 2008.It is the largest source of energy for the generation of electricity worldwide. India has some of the largest coal reserves in the world (approx.267 billion tones). The energy derived from coal in India is about twice that of energy derivative from oil, whereas worldwide; energy derived from coal is about 30% less than energy origin from oil. The top coal producing states are Orissa, Jharkhand, Chhattisgarh, West Bengal, Bihar, Andhra Pradesh and Madhya Pradesh. World coal Consumption was about 7.25 billion tones in 2010 (7.99 billion short tons) and is expected to increase 48% to 9.05 billion tones (9.98 billion short tons) by 2030. China produced 3.47 billion tones (3.83 billion short tons) in 2011. India produced about 578 million tons (637.1 million short tons) in 2011. 68.7% of China's electricity comes from coal. The USA consumed about 13% of the world total in 2010, i.e. 951 million tons (1.05 billion short tons), using 93% of it for generation of electricity. 46% of total power generated in the USA was done using coal [3].

It has been estimated that there are over 861 billion tones of proven coal reserves worldwide. This means that there is enough coal to last us around 112 years at current rates of production. Coal reserves are available in almost every country worldwide, with recoverable reserves in around 70 countries. The biggest reserves are in the USA, China and India [3].

Coal mine fire is a major problem for the coal mining industry worldwide. Coal mine fires can be divided into near-surface fires, in which fire extend to the surface and the oxygen required for their ignition comes from the atmosphere, and fires in deep underground mines, where the oxygen comes from the ventilation. Some fires along coal seams are natural occurrences. Some coals may self-ignite at temperatures as low as 40 °C (104 °F) for brown coal in the right conditions of moisture and grain size. The fire usually begins a few decimeters inside the coal at a depth in which the permeability of the coal allows the inflow of air but in which the ventilation does not remove the heat which is generated. Major cause of these fires in different coalfields is spontaneous heating of coal. Globally, thousands of inextinguishable mine fires are burning, especially in China. The spontaneous combustion of coal is responsible for the majority of underground fires in South African collieries. Incidents of spontaneous combustion are also preventing in open cast collieries and its stockpiles dicers dumps, train trucks and ships [4].

Spontaneous heating of coal occurs by self heating (increase in temperature due to exothermic internal reactions), followed by thermal runway (self heating which rapidly accelerates to high temperatures) and finally, ignition. When coal is exposed to air, some of its exposed parts absorb free oxygen at a faster rate than others and oxidation results in the evolution of several gases such as CO CO_2, etc, water vapor, some heat. This takes place at ambient temperatures which leads to open fires [5].

Coal mine fire inside mine creates a lots of problems inside mines such as damage of expensive machines kept in mines, loss of life and property, environmental pollution, various health hazards,, roof fall, damage to the support systems and roadways such as haulage systems etc. These fires occurring every year are a function of the quality of the coal and the circumstances which it is subjected. The first fire was reported in Raniganj Coalfields in 1865.Many fires have been reported from Jharia and Raniganj coal fields having superior non-cocking coal. In 2010, 68 fires were burning beneath a 58-square-mile (150 km^2) region of the Jhairia coalfield in Dhanbad, Jharkhand. This region has also been prone to mine fires. These fires continue to spread to adjoining areas s rapidly destroying the only source of prime coking coal in the country. To adapt some preventive measures against these fires, many researches were carried out to understand the mechanism of spontaneous heating of coal and to run the process of production of coal without any interruption and to save life, property and environment. A proper assessment of the spontaneous heating susceptibility of coal is done so that mine operators are notified well in advance so that production activities could be planned within the incubation period. Different methods have been adopted by various researchers of the world to find out the susceptibility of coal to spontaneous heating based on the measurement of oxidation rate and ignition temperature viz., Crossing point temperature method, Wet oxidation potential difference method, Differential thermal analysis, Differential Scanning Calorimetry Technique and Critical Air Blast [5].

1.3 OBJECTIVE

In sequence to assess the role of wet oxidation in the spontaneous heating of coal; the work was designed with the following objectives.

- Literature review – Collection of all the past works done by various researches in National and international journals, proceedings, books etc.
- Collection of some coal samples covering different coalfields of India.
- Determination of intrinsic parameters by proximate analysis

- Assessment of spontaneous heating susceptibility of the collected coal samples by wet oxidation potential with low, medium, and high speed of magnetic stirrer
- Determination of the role of correlation analysis between parameters of proximate analysis and wet oxidation potential difference.

CHAPTER – 2

LITERATURE REVIEW

2.1 NATIONAL AND INTERNATIONAL STATUS

Various scientists across the world have carried out a lot of studies, experiments and research for assessment of susceptibility of spontaneous heating of coal to avoid these coal mines form fires. The subsequent is the brief evaluation of the work carried out by different researchers to conclude the susceptibility of different coal towards spontaneous heating of coal samples.

Tarafdar et. al. (1989)] carried out wet oxidation of coal using alkaline permanganate solution and analyzed the potential changes between a saturated calomel electrode and a carbon electrode immersed in the coal oxidant mixture within a definite reaction time at a constant temperature. He also suggested that a regular and thorough study is required to assess the significance of this technique

Panigrahi et al. (1996) carried out work on wet oxidation and CPT with respect to intrinsic properties of coal samples covering most of the coalfields of India and determine the susceptibility of coal to spontaneous heating.

Kaymakci and Didari (2002) carried out linear and multiple regression analysis to determine the relationship between spontaneous combustion parameters (derived from time-temperature curves obtained from laboratory tests) and coal parameters (obtained from proximate, ultimate and petro graphic analyses) have been explained. The linear regression analysis have shown that ash (A), volatile matter (VM), carbon (C), hydrogen (H), exinite (E), inertinite (I) and mineral matter (MM) are the major factors affecting spontaneous combustion. According to the multiple regression analyses, these major factors are volatile matter, carbon, hydrogen, nitrogen (N), oxygen (O), sulphur (S) and inertinite. They have derived some empirical equations using statistical models

Beamish and Arisoy (2008) have tested Coals from Australia (Queensland and New South Wales), New Zealand (North and South Island), Indonesia and more recently the United States. They have established definitive relationships and trends for the effects of various intrinsic coal properties on self-heating rates and anomalous coals have also been identified. They developed a propensity rating system which is customarily used in Australia for assessing coals and identifying appropriate mining analogues for spontaneous combustion management planning

Nimaje et. al. (2010) made thermal studies on spontaneous heating of coal. Of all the experimental techniques developed thermal studies play an important and dominant role in assessing the spontaneous heating susceptibility of coal. They made an overview of thermal studies carried out by different researchers across the globe for determination of spontaneous heating of coal and revealed that lot of emphasis on experimental techniques is necessary for evolving appropriate strategies and effective plans in advance to prevent occurrence and spread of fire.

CHAPTER – 3

SPONTANEOUS HEATING OF COAL

3.1 DEFINITION

Spontaneous heating means “self-heating of coal resulting eventually in its ignition without the application of external heat”. Its major cause is the auto oxidation of coal which is accompanied by absorption of oxygen, formation of coal complexes. This results in liberation of heat and finally catches fire [5].

Coal fires require three basic elements to exist as shown in Fig.3.1

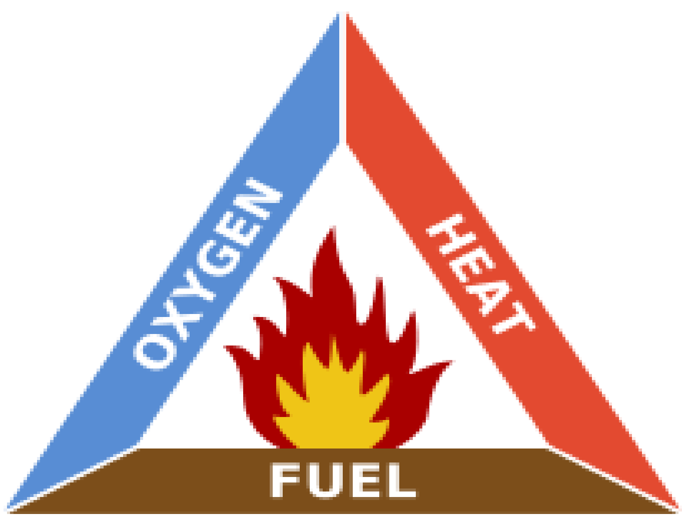

Fig. 3.1 Fire triangle [3]

The process leading to spontaneous combustion can be summarized as follows:

- Oxidation occurs when oxygen reacts with the fuel, i.e. coal
- The oxidation process produces heat
- If the heat is dissipated, the temperature of the coal will not increase
- If the heat is not dissipated then the temperature of the coal will increase
- At high temperatures the oxidation reaction proceeds at a higher rate
- Eventually a temperature is reached at which ignition of the material occurs

3.2 MECHANISM OF SPONTANEOUS HEATING OF COAL [12]

In spontaneous heating, there is no external heat source; natural reactions supply sufficient energy to sustain combustion. Spontaneous combustion in coal is basically related to the oxidation of the coal to form CO_2 and CO. Combustion will occur only if will occur rate of heat generation exceeds the rate of heat loss. Therefore, it is a function of the amount of energy released by a reaction and the rate at which it is released, as well as the rate at which energy is transferred from the reacting mass to the surroundings. The reaction rate is a function of the concentration of reactants, carbon and oxygen, the surface area, element size, temperature and activation energy.

Spontaneous heating susceptibility of coal differs for different ranks of coal. All variety of coal are not equally susceptible to spontaneous exothermic reaction .Some exposed parts of coal absorbs oxygen i.e., adsorption takes place and then chemisorptions results in evolution of CO, CO_2 and heat. The rate of oxygen adsorption at the surfaces is higher during the starting few days which tends to extinguish fresh coal surface to the atmosphere. It then slows down without causing any harm unless the heat generated is accumulated in the atmosphere. If this accumulated heat is not removed, this can catch fire by getting sufficient oxygen supply. An assessment of the self-ignition exposure must be undertaken for each mine site and circumstance. The most important parameters involved in the heat balance, and therefore in self-heating are:

- Size of the coal particles
- Quantity
- Calorific value
- Heat conductivity
- Geometry and size of the mining process or coal storage facility
- Heat transfer coefficient on the outer surface of the bulk
- Ventilation
- Degree of compaction.

Combustible matter may come in contact with the oxygen, undergo oxidation and release heat. Spontaneous heating would be enhanced by the presence of accumulated heat causing rise in temperatures. At normal ambient temperatures, the reaction is so slow that itcanremainunnoticed. However, if the temperature (T) is increased, the rate of reaction increases exponentially, i.e.

Rate of reaction = $c_f\, c_o\, A^{-E/RT}$

Where,

c_f and c_0 are the concentrations of fuel and oxygen respectively

A is the pre-exponential factor

E is the activation energy for the reaction

R is the ideal gas constant

The form of equation indicates a doubling of the rate for each 100 ^{0}C rise in temperature.

The different stages of spontaneous combustion of coal

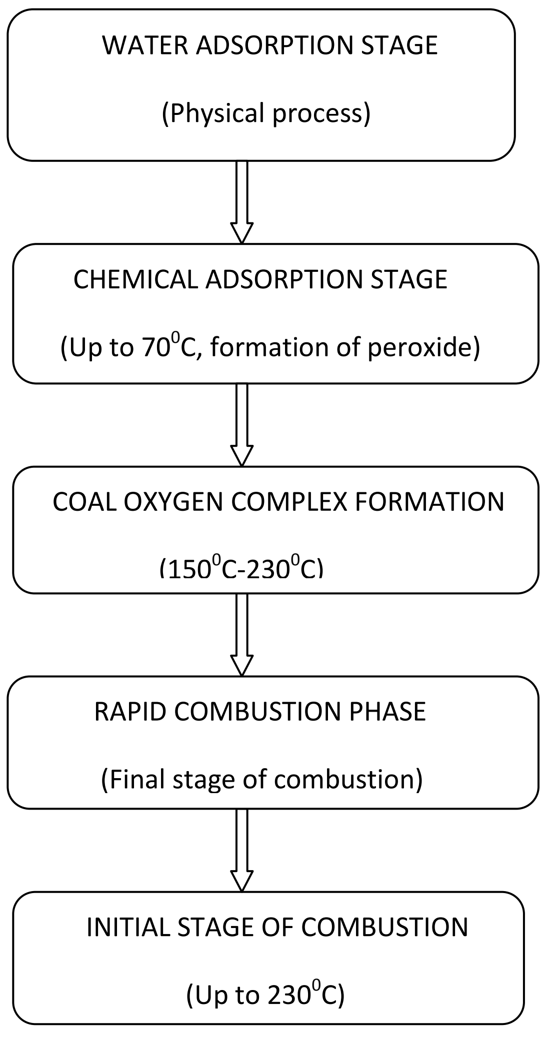

Fig. 3.2 Stages in the spontaneous heating of coal [4]

3.3 FACTORS AFFECTING THE SPONTANEOUS COMBUSTION OF COAL [12]

Spontaneous combustion is one of the major hazards of mining from both the safety and economics aspect it is the essential for every mine to clearly understand the susceptibility of its coal to spontaneously combust and the risks involved in it. Many internal and external factors affects the initiation, development and spreading of coal mine fire. Some of which are listed below.

(a) Intrinsic

- Coal composition, rank and petro graphic constituents
- Coal friability, particle size and surface area
- Moisture content
- The presence of iron pyrites

(b) Extrinsic

- Climatic conditions (temperature, relative humidity, barometric pressure and oxygen concentration)
- Stockpile compaction, as related to height and method of stockpiling
- Dump consolidation, influenced by height, method of formation and equipment used
- Presence of timber or other organic waste material in abandoned areas or dumps
- Excavation stability and maintenance (for open-cut high wall faces)
- Strata conditions, method of working and ventilation (for shallow underground workings).

The result of interactions between these factors in a given situation can lead to open fires. In general, lower rank coals are more liable to self-heating. However, it is the contention that competent mining engineer will design the mine to minimize all risks to the safety of the personnel and property and to maximize profitability. Every incident, however small, if not dealt with effectively and efficiently in the early stages can develop into open fires or into an explosion of gas or dust, with devastating results.

The whole incident of the spontaneous combustion as aggregate effects of the situation which may be classified as:-

Mining Factors

1) Mining Methods
2) Rate of Advance
3) Pillar Conditions
4) Roof Conditions
5) Crushing
6) Packing
7) Ventilation system and air flow rate
8) Roadways
9) Leakage
10) Multi Seam Workings
11) Coal Losses
12) Waste material in abandoned areas
13) Change in Humidity
14) Heat from Machines
15) Stowing
16) Effect of Timber
17) Barometric Pressure
18) Worked-out areas
19) Oxygen concentration

Seam Factors

1) Rank of coal
2) Petro graphic Composition
3) Moisture
4) Thermal Conductivity
5) Particle Size/Surface Area
6) Temperature
7) Bacteria
8) Ash/Mineral Matter
9) the effect of earlier oxidation or heating
10) Physical Properties
11) Heating due to earth movement
12) Sulphur
13) Pyrite Content
14) Available air

Geological Factors

1) Seam thickness
2) Seam gradient
3) Coal Outbursts
4) Geothermal Gradient
5) Caving characteristics
6) Faulting
7) Depth of cover
8) Coal Friability

Other factors

1) Methane contents
2) Oxygen concentration
3) Excavation stability and maintenance
4) Chemical constituents

3.3.1 MINING FACTORS

Mining Methods: In partial pillar extraction underground mining methods usually, some coal is left in the goaf, which may be 15-20% of the panel reserve, which gets crushed, oxidation sets in and eventually fire may break out. Surface mining exposes the coal by advancement of open pits. Here crushed coals are left for long period which may induce spontaneous heating of coal Long wall mining requires well maintained ventilation system because of the amount of dusts and methane produced Dust levels often exceeds maximum allowable limits inspite of advanced dust control technology.

Crushing: Pillar crushing is a major problem to spontaneous heating. Where a pillar is subjected to crush, a situation can develop where leakage paths are created, lending both to the flow of air into the coal and, in some conditions, through the solid to influence a more distant zone. Due to crushing of pillars, loose coal is usually present in worked out areas, and is produced either by pillar spelling or by roof collapses with associated sluggish ventilation. These areas are predominantly spontaneous combustion hazards to the mining area.

Ventilation system and air flow rate: Proper ventilation of mine is necessary air to maintain a safe and healthy environment in which workers may work which generally includes fans, airways; control devices to direct or restrict air flowed. Spontaneous combustion occurs when the amount of heat generated by an exothermic reaction, such as oxidation, exceeds the heat removed by air movement. Oxygen in air oxidises coal.

Spontaneous fire of coal occurs when ventilation pressure draws air through broken coal. This can happen when

- Ventilation pressure is useful across inadequate pillars
- Air leaks by broken ground about ventilation control devices such as overcasts, regulators and stopping's
- Stowed coal oxidises
- Coal is left in goaf areas

Rate of advance: Due to the force of ventilating current, any waste area adjacent to mine will accumulate air coming from mines. In practice, when a working face is operating normally, any individual quantity of coal pass through the zone at a rate equal to the rate of advance of the working place. It is the time taken from entering or leaving the zone that is critical. If the time is excessive, the oxidation may occur to an unacceptable degree and a glob fire could result.

Pillar Size: Pillar size has a straightly influence on the liability to heat. The shape and size of pillars, formed in any seam should be capable of ensure stability. No gallery in a seam shall exceed 3m in height or 4.8m in width at any place. The pillars formed shall normally be rectangular in shape. Ideally, pillars should be of a size to avoid crushing. This size depends on the strength of the coal.

Roof condition: Random mine layout makes ventilation planning difficult, and if the pillars are too small, there is the risk of pillar failure. In coal mines, pillar failures are known as squeezes because the roof squeezes down, crushing the pillars. Once one pillar fails the weight on the adjacent pillars increases and the result is a chain reaction of pillar failures.

Multi seam workings: Multi-seam coal mining' is the mining of coal seams that overlay each other in a vertical depositional sequence. The seams are separated by rock strata. . The seam thicknesses and the parting thickness between the seams provide suitable conditions for designing a multi-seam mine design.

Leakage: For spontaneous heat to occur there must be supply of oxygen and a situation where build –up of heat is possible. This can happen by air escapes through fissures in solid coals which result in a shallow seated heating and this happens where leakage paths exits at air crossings, in and around regulators and doors, and other similar locations where there is out flow in a high pressure gradient and tendency for air to attempt to flow through solid coals The leakage through a stopping depends partly on the difference in the pressure between the two sides of the stopping.

Waste material in abandoned areas: Abandoned mines create negative impacts to the economy Abandoned mines and abandoned mine lands create negative impacts on local economies by destroying recreational opportunity; lower land values; leaving desolate communities once the mines are exhausted .Mine waste material containing sulphide waste is a major threat to the environment. The timber props left in the waste caused the coal roof to disintegrate and created a saving thus encouraging the spontaneous heat of coal. Presence of timbers in mines leads to the chance of catch of fire which gives the heat required for spontaneous heating of coal.

Change in humidity: An increase in the gas supply relative humidity has a marked affect on the self-heating rates of the coal. The effect of relative humidity decreases as oxygen concentration in the gas supply increases. High-moisture low rank coals have been found to be more suitable for domestic use due to low heat output and self-heating problems upon long term storage and transportation. Moisture plays an important role on behavior of coals in stockpiles. The amount of water contained by coal for a given value of relative humidity is described by its adsorption and desorption isotherm. The interaction between water and coal can be exothermic or endothermic depend on whether the water evaporates.

Heat from machines: usually heat from machine is dissipated within the ventilating air stream and the temperature rise of the general body of the air is likely to be extremely small. In some circumstances, the effect of the heat from machines is minor, in that additional air might have to be dispersed and will involve a higher ventilating pressure with consequent increase risk of leakage.

Stowing: Stowing is carried out in a no. of coal fields around the worlds specifically in order to seal mined out areas completely. As such, it has proved to be an effective method of spontaneous combustion control.

Pillar conditions: Pillar conditions mean mainly refer to pillar size and strength. It has a direct influence on the liability to spontaneous heating. Ideally, pillars should be of a size to avoid crushing. This size depends on the strength of the coal, the depth of the cover and the influence of other workings within the locality or panel. Increase in methane emission is an indication of crushing, roughly pillars that consequently spontaneously heated.

Packing: Where packs are used in the seam, coals are more liable to spontaneous combustion. According to the different study it has shown that they must be of the highest possible quality to spontaneous heating

Roadways: Due to proper roadways, the atmospheric pressure and temperature conditions because of air moving in and out of coal seams is changing. This is of particular relevance when old workings are exposed by surface mining. The risk increases with breadth of coal, as this increases the area of coal uncovered Road ways in the seam able to spontaneous heating are areas of bear on due to leakage through crushed solid coal. The risk rises with breadth of coal, as this increases the area of coal disclose. The most universal points for incidents are junction, air crossing, doors, regulators, linking roads, obstruction in the roads, old roadways.

Coal losses: Coal losses – that is, leaving remnant coal in worked-out areas – are a serious heating hazard, and most gob fires result from this factor. There is no normal mining system that can guarantee that remnants will never be left in a waste area. Mainly mining systems effect in a significant loss of coal. The resulting condition, in which the coal is regularly likely to be crushed, finely divided, and in a location where build-up is possible must be considered a potential hazard.

Barometric pressure: Change in Barometric pressure inside the mine due to continuous leakage resulting from a difference in pressure in the return and fluctuations of intake stopping's in ventilating pressure finding from the opening of doors and the movement of cages and mine cars. Although leakage is very frequently responsible for starting fresh heating or the winnowing up of old heating, the influence of barometric changes is believed by many to be of predominate importance.

Oxygen concentration: It need not be explained that the volume fraction of oxygen in the gas plays a key role for the rate of the reaction of oxidation. Higher the oxygen concentration in the atmosphere more rapid is the oxidation procedure as oxygen is readily available. Limiting the supply of oxygen to the active surfaces of the solid matter abates the reaction well.

Worked-out areas: Worked-out areas which are not sealed by ventilation stoppings are potential sources of spontaneous heating. They are likely to have suspension in the ventilation system as result of roof falls or flour lift tending to impairment in rib condition and the presence of loose, small beat coal contributing to potential combustion.

Effect of timber: In the early days of spontaneous combustion generally timber was found at or near the heating in practically every instance and as a result there was thought that was timber was a primary cause of spontaneous combustion. The timber props left in the waste caused the coal roof to disintegrate and produced a saving thus encouraging the spontaneous heating of coal. And in case of collapse of any timber inside of working area that causes roof problem and that causes spontaneous heating of coal.

3.3.2 SEAM FACTORS

Rank of coal: The degree of 'metamorphism' or coalification undergone by a coal, as it matures from peat to anthracite, has an important bearing on its chemical and physical properties, and is referred to as the 'rank' of the coal. Low rank coals, such as sub-bituminous and lignite coals, are typically softer, friable materials with a dry, earthy emergence; they are characterize by high moisture levels and a low carbon content, and thus a low energy content. High rank coals are typically harder and stronger and often have a black vitreous luster. Minor rank coals are extra susceptible to spontaneous heating. The higher the rank, e.g. anthracite, the slower the oxidation process, while lignite of low rank oxidizes so rapidly that is often stated that is cannot be stored after mining without ignition because of the above condition. So, it is widely recognized that lower rank coals are extra susceptible to spontaneous combustion than higher rank coals.

Petro graphic composition: Coal properties mainly depend on their petro graphic composition and rank of coal. The petro graphic composition of coals mainly depends on facial conditions and composition of organic matter in a pale swamp. The coal rank is mostly influenced by temperature, indication of which is a vitrinite reflectance the abnormalities in this relationship may be attributed to the petro graphic constituents of coal.

Moisture: Changes in moisture content; i.e., the drying or wetting of coal, have obvious effects in spontaneous heating of coal. The impression of moisture on spontaneous heating is in certain. A small quantity looks to assists slightly than prevent the heating whilst large quantities of moisture prevent the heating. though, as in a surface stockpile, reserve drying and wetting of the coal speeds up the heating process. On the other hand a support of self-ignition by the wetting of materials prone to this has been observed.

Dry coal + moisture → wet coal + heat

Thermal conductivity: Due to the conductivity property of coal, heat transfers from one place to other. The conductivity of moist-coal having about 5-7% moisture is at the highest. If the coal is more compact then the conductivity is more and heat changes according to that.

Particle size/surface area: A solid coal face generally presents very little danger of spontaneous combustion, partly due to the small surface area and partly due to the very low permeability of solid coal gases. It is however, usually when coal is crushed in mining, or busted by roof pressure, when falls and faulting occur that spontaneous combustion is likely to take place. It is the small size coal that is mainly responsible for heating. The air pass into the mass oxidizes a little of the coal close to the outer surface.

Temperature: Higher neighboring temperature leads to increase in oxidation process and ultimately in spontaneous heating of coal. There is a pronounced temperature coefficient of oxidation and the average rate of oxidation approximately doubles for every rise of 18 degree Fahrenheit.

Bacteria: The contribution of heat due to the action of bacteria cannot be completely ruled out. In fact, spontaneous heating observed in haystacks and in wood are known to be mainly due to bacterial action. It is observed that thiobaccillus Ferro-oxidants and ferro-baccillus thao-oxidants are the bacteria which play the role for spontaneous heating of coal.

Ash/Mineral matter: Ash content generally decreases the liability of coal to spontaneous heating. Certain parts of the ash, such as lime, soda and iron compounds, can have an accelerating effect, while others, such as aluminum and silica, produce a slowing losing effect. It is clear that some chemicals promote combustion while others suppress its development. And, it is known to oil shale bands adjacent coal seams play an important role in mine fires. However, mineral matter may also create obstruction of access to oxidation sites; lower the nature-heating rate of the coal even further.

The effect of earlier oxidation or heating: A fresh coal is relatively reactive to oxygen than a weathered coal. The ignition temperature of fresh coal is much lower than that of such a weathered coal. On the other hand, a fresh coal which is continuously getting oxidized would ignite at a much higher temperature due to higher oxidation rate provided the heat dissipation is much lower than the heat generation.

Physical properties: A number of physical properties such as porosity, hardness, thermal conductivity and specific heat can affect the rate of oxidation of coal. More porous coal tends to higher spontaneous heating of coal.

Heating due to earth movement: In site the mine the heat is generated by the movement of the earth. That is the cause of spontaneous heating of coal.

Sulphur: It may be relevant to add that the green crystals of ferrous sulphate formed as shown below, often gets neutralized with carbonates of Ca , Mg, or Fe++ present in the coal.

$2FeS_2 + 7O_2 + 16H_2O = 2H_2SO_4 + 2FeSO_4.7H_2O + 316Kcal$

It observed that Sulphonate coal has greater reactivity towards oxygen, particularly in the presence of iron oxide. They explained the role of pyrite to sulphonate the coal from the liberation of, in the presence of moisture.

Pyrite content: Heating due to oxidation of pyrites has been known to be a common phenomenon in pyrites mines. It was suspected earlier that heat evolved from aerial oxidation of pyrites is the cause of spontaneous heating of coal. However, it has now been proved that pyrite present in coal might support the oxidation of its carbonaceous content by breaking down coal into smaller fragments and exposing larger surface area to the air, in addition to by elevating the temperature due to heat liberated from its own oxidation.

Available air: Where there is a small amount of air, the rate of oxidation is very slow and there is no appreciable rise in temperature. Where there are huge quantities of air passing over or through the coal, any heat produced will invariably be carried away so that the temperature does not rise and the rate of oxidation remains at a low level.

3.3.3 GEOLOGICAL FACTORS

Seam thickness: The area where the seam thickness is greater than that which can be completely mined in one part is more susceptible to spontaneous combustion since the un mined area tends to be subjected to sluggish ventilation flow .Other physical factors such as thickness of the seam, friable nature of coal, ventilation arrangements, etc., also affects the possibilities of spontaneous heating of coal. Even in thick seams there may be certain bands within it which is more liable to mine fires than others. In certain cases, it becomes necessary to mine the waste.

In certain cases, a coal roof and floor way thus be left where,

a) The natural floor or roof tends to be weak

b) The seam is thick, or

c) There are inferior coals over or below the seam.

d) There are inferior coals over or below the seam, in those cases there will undoubtedly be coal in a broken form places where it can heat, and the points of dander presented.

Coal outbursts: Coal outbursts usually occur in the harder formations and higher rank coals rather than in the softer and lower rank coals. Coal outburst may be defined as a spontaneous and violent ejection of gas (mixture of methane and carbon dioxide), broken rock and coal from the solid face and surrounding strata in an underground coal mine Outburst occurs without triggering, when an outburst can be provoked with the use of explosives or during the cutting of coal. When outbursts occur, they can be very serious events, which may lead to multiple fatalities. It may range in severity from being barely perceptible, to cause the destruction of an complete mining panel, and throw pieces of machinery weighing tens of tones several metres. That's why several preventive measures should be taken in outbursts prone areas the incidence of both spontaneous combustion and outburst increases with depth of the coal seam.

Faulting: Faults pose potential problems in mining coal. Detection of faults at early stages of development is necessary as it may affect the stability of roofs and ribs in underground working, which may be responsible for generation of other problems such as, trapping of gas inside the walls, wearing out of expensive mining machinery, etc.Pre detection would help mining companies in extra reinforcing of their working place and thus save money, time and increase production. Any trapped gas may induce spontaneous heating of coal by oxidizing the fine coal. To the coal industry, a small fault is defined as one having a displacement of less than the coal seam thickness, while a large fault is considered to have a displacement of more than the seam thickness A fault generally slows down the rate of face advance to a safe smallest, with the incidental risk of heat development.

Coal friability: Friability of coal is the tendency of coal to be broken into smaller pieces. The more friable the coal is the larger the surface area exposed to oxidation, thus attention to yield more heat per unit volume of coal. The coal generally breaks during removal process, which thus increases the surface area exposed to air and in turn increases the tendency to spontaneous heating of coal.

Geothermal gradient: Geo-thermal gradient do not have any direct impact on mines ,but it has been noticed that the regions having high geothermal gradients have comparatively greater tendency towards spontaneous heating of coal, as the strata temperature tend to increase the temperature of coal.

Seam gradient: Board & pillar and long wall method is dominant mining method in India used in flat seams which are less susceptible to spontaneous heating of coal. Underground pillar extraction in India, generally, encounters strong and massive roof stratum, which yield after a large overhang Magnitude and range of the mining induced stresses influence manner of depillaring, support planning, efficacy of rock mass reinforcement and, virtually, controls every norm related to production, productivity and safety of a u/g working. During development of a coal seam, small amount of stress relocation takes place, which barely threats safety of a coal pillar. However, during final extraction (depillaring), there is large amount of stratum movement in and about the goaf area, which becomes an area of interest for the safety of a depillaring face. The strata symmetry dynamics in and about an extraction line becomes complex for a depillaring face under strong and massive roof strata. In an inclined seam control of combustion becomes more complex, since convection current resulting from the difference in the temperature must tend to cause air currents in the goaf. In adding, within the extract areas, flow may be due to irrepressibility as a result of the differing methane densities, carbon dioxide, nitrogen and natural ventilating pressure.

Caving characteristics: Caving properties of coal as well as caving properties of overlying strata need to be considered .If the strata does not cave with the coal there is a possibility of large voids forming with detrimental effects on support loading, ventilation, likely accumulations of gas close to the face and possible wind blast effects. Breakdown to cave adequately would result in an expensive failure of the system. It is essential for good recovery that the top coal caves readily immediately behind the support canopies, fractures into small enough pieces to allow good flow through the raise canopy doors or openings

Depth of cover: The depth of cover does not of necessity affect the risk of spontaneous combustion. With the increase in depth of cover base temperature of insight coal increases With increase in depth, strata temperature increases with a rate of 40 m per 1ºC.Under deep cover, special precautions are required to accommodate these elevated stress levels

3.3.4 OTHER FACTORS

Methane contents: The presence of methane in macro and micro pores of coal inhibits the oxygen access and thus the oxidation process is retarded, particularly, in highly gassy seams. However, as degasification takes place with time, more and more surface becomes available for aerial oxidation. Coals containing less than 5 cubic meters of methane per tons of coal show high rates of oxygen absorption and are more liable to spontaneous heating.

Oxygen concentration: The heat generate from coal is from the oxidation of coal in presence of oxygen. It need not be explained that the volume fraction of oxygen in the gas plays a key role for the rate of the reaction of oxidation. Higher the oxygen concentration in the atmosphere more rapid is the oxidation procedure as oxygen is readily available.

Excavation stability and maintenance: It is required to excavation the material in safety way and maintenance of the roadway, machineries used in site the mine and the ventilation also.

Chemical constituents: Ash generally decreases liability for spontaneous heating but certain parts of ash such as lime, soda; iron compounds have accelerating effect whereas alumina and silica have retarding effects. Many other chemicals bear upon the rate of oxidation to some extent, either accelerating or preventing it. Alkalis can act as accelerators, and borates and calcium chloride as retardant

CHAPTER – 4

EXPERIMENTAL INVESTIGATIONS

To study the effects of various parameters of coal that affect the spontaneous heating tendency of coal, the following experiments are needed to be carried out

- Proximate analysis
- Wet oxidation potential

4.1 SAMPLE COLLECTION AND PREPARATION [7]

4.1.1 Sample Collection

Sampling is a process by which very small portions of an ore body are collected and analyzed to calculate approximately the average mineral content of the ore body. In the case for coal it covers the properties ascertained by proximate and ultimate analysis such as fixed carbon, volatile matter, ash, caking index and calorific value etc. Sometimes the physical nature of the ore need to determined and the sampling process assumed should be able to give this information too. Samples are generally collected at regular interval. The interval of sampling point is regulated by the regularity of the deposits as well as the accuracy for sampling projected. Four routine sampling methods are suitable for specific objectives in the daily mine routine.

1. Channel or groove sampling.
2. Chip sampling.
3. Grab sampling.
4. Bulk sampling.

Out of the four sampling methods mentioned above, channel sampling method is most commonly adopted and used to collect sample from the insitu coal seams after preparation for collection.

4.1.2 Channel sampling

The part of seam to be tested shall be exposed from the roof to the floor. The same sample shall be taken in a channel sampling procedure representing the entire cross-section of the seam having the dimensions of 30 x 10 cm, that is, 30 cm in width and 10 cm in depth. For this purpose, two parallel lines, 30 cm apart end at right angles to the bedding planes of the seam shall be marked by a chalked string on the smooth, newly exposed surface of the seam. Dirt bands exceeding 10 cm in thickness shall be excluded. The channel between the marked chalk lines in the seam shall be cut to a depth of 10 cm and the coal sample collected on a clean strong cloth or tarpaulin placed immediately at the bottom so that the chances of pieces flying off during excavation of coal are understated.

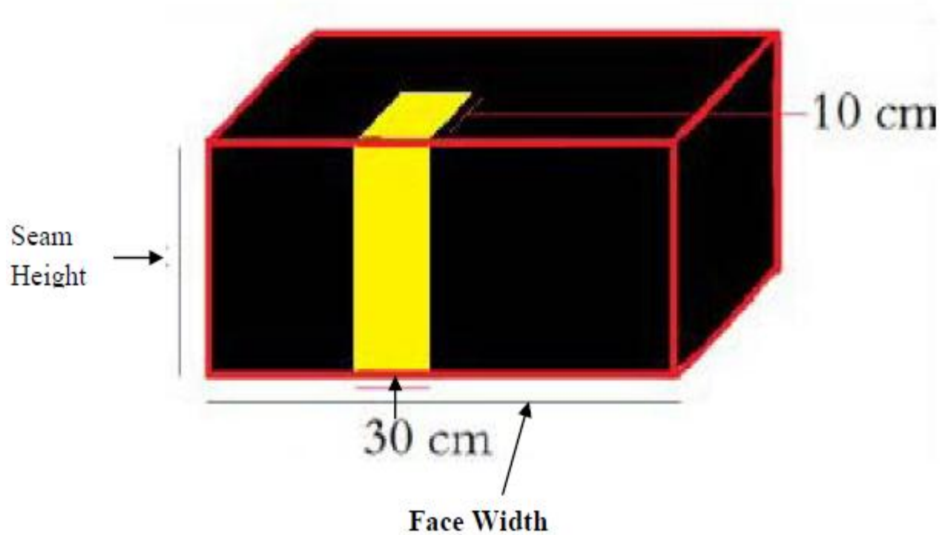

Fig. 4.1 Channel Sampling [10]

The samples are collected from different coalfield of India i.e. CCL and MCL using channel sampling method and are listed in Table 4.1

4.1.3 Sample preparation

The samples received from the field via channel sampling after coning and quartering at the site are crushed in the laboratory as per the experimental requirements following the Indian standard without getting into oxidized. The crushed sample is then sieved to required sizes and packed in an air tight polythene zipper. The zippers are kept in air tight containers for further use in experimentation as per their size and marked with label on the containers so that it should be differentiated easily. Care should be taken at the time of storing in an air tight container so that coal sample should not be coming in contact with atmospheric air and it should not be oxidize.

Table.4.1 List of coal samples

Sl. No	Sample	Coalfields
1.	CCL-1	CENTRAL COALFIELD LIMITED
2.	CCL-2	
3.	CCL-3	
4.	CCL-4	
5.	CCL-5	
6.	MCL-1	MAHANADI COALFIELD LIMITED
7.	MCL-2	

4.2 METHODS FOR DETERMINATION OF INTRINSIC PROPERTIES OF COAL

Proximate analysis [6]

Proximate analysis of coal was developed as a simple method for characterizing and determining the distribution of various constituents found in coal. Here the coal sample is subjected to heat under specified conditions, and the generated products can be grouped into: i) moisture; ii) volatile matter iii) fixed carbon, iv) ash, the inorganic residue remaining after combustion. The method determined by IS (Indian Standard) 1350 (Part- I)-1984 was followed for the proximate analysis, i.e. for the determination of volatile matter, moisture, ash and fixed carbon

Determination of Moisture Content (M)

As all coals are mined wet they are always associated with some amount of moisture. The moisture can be physically or chemically bound, due to its nature, origin and occurrence. Extraneous and inherent moisture must be properly differentiated. Extraneous moisture evaporates just by exposing coal to sunlight, even then coal still have moisture inside it or it should be removed while keeping the sample in a furnace for 2 hours at 35 to 40^{o}C.. This internal moisture can be removed by heating coal above 100^{0}C. The mode of occurrence and handling of coal is responsible for the quantity of external but the air-dried moisture is associated due to the inherent hygroscopic nature of the coal.

Procedure

- About 1g of air-dried coal sample finely powdered (-212µ) and weighed in a silica crucible.
- It is then placed inside an electric hot air oven (Plate 4.1) which was maintained at $108^{o}C$ and allowed to remain there 1.5 hours
- It was then taken out with a pair of tongues, and cooled in desiccators for about 15 minutes and then weighed.
- The loss in weight was reported as moisture (on percentage basis).

Moisture is calculated as per the following formula.

$$\text{Mosture\%} = (Y-Z/Y-X)*100$$

Where,

X= weight of empty crucible, g

Y= weight of crucible and coal sample before heating, g

Z= weight of crucible and coal sample after heating, g

Plate 4.1 Oven for Moisture Content Determination

Determination of Ash Content (A)

The residue left after the combustion of coal under some specified conditions is called the coal ash. It is formed as the result of chemical changes that take place in the mineral matter and does not occur as such in coal. Hence ash and mineral matter of coal are not identical. Two types of ash forming materials in coal are mainly the extraneous and inherent mineral matters.

The extraneous mineral matter comprises of materials like calcium, magnesium and ferrous carbonates, pyrite, marc site, clays, shale's, sand and gypsum. The extraneous mineral matter builds on its origin by two types that are given below:

- The substances which got coupled with the rotting vegetable material during its alteration to coal, which is difficult to remove by mechanical methods,
- Rocks and dirt that mixed up during mining and handling of coal.

The intrinsic mineral matter is the inorganic elements linked with organic components of coal. The origin of such materials is most probably from the plant materials from which the coal is produced. When the total quantity of ash is pertained ash from intrinsic mineral matter becomes insignificant as far as the total quantity of ash is pertained. Indian coals suffer from the major shortcoming, that the mineral matter content is not only high, but of intimately linked type, due to its drift origin. Ash is quantitatively and qualitatively different from the mineral matter originally present in coal because the numerous modifications that occur, such as loss of water from silicate minerals, loss of carbon dioxide from carbonate minerals, oxidation of iron pyrite to iron oxide, and fixation of oxides of sulphur by bases such as calcium and magnesium. In fact, combustion circumstances determine the amount to which the weight change takes place and it is necessary that standardized operations should be closely followed to ensure productivity.

Procedure

The empty crucible was cleaned by heating in a muffle furnace for one hour at 800^0C so that other mineral matter if presents get burnt. It was taken out, cooled to room temperature and the weight is taken. Approximately 1gm of coal sample was weighed in the crucible and placed in a muffle furnace at 450^0C for 30 minutes and the temperature of the furnace was raised to 850^0C for 1hour. The crucible was taken out and placed in desiccators and weighed.

Ash is calculated as per the following formula:

$$Ash\% = (Z-X/Y-X)*100$$

Where,

X = weight of empty crucible in grams

Y = weight of coal sample and crucible in grams (Before heating)

Z = weight of coal sample and crucible in grams (After heating)

Plate 4.2 Muffle Furnace for Determination of Volatile Matter and Ash Content

Determination of Volatile Matter (VM)

When a coal sample is heated in specified equipment's under prescribed conditions in Indian standard, the loss of mass in coal, corrected for moisture, is referred to as volatile matter of coal. Some of the components of coal that are transformed to volatile matter are hydrogen, carbon monoxide, methane and other hydrocarbons, vapours, ammonia, some organic sulphur and oxygen containing deepens and some incombustible gases, such as carbon dioxide and water vapor, all of which come from the disintegration of organic matter in coal. Inorganic materials in coal are responsible for the presence of the water of hydration of mineral matter, carbon dioxide from carbonates and hydrogen chloride from inorganic chlorides to the volatile matter.

Procedure

For the determination of volatile matter a special volatile matter silica crucible (38 mm height, 25 mm external diameter and 22 mm internal diameter) was used. The empty volatile matter crucible was weighed. 1g of coal sample (-212µ size) was weighed in the volatile matter crucible and it was placed inside a muffle furnace maintained at 925^{o}C with the lid covering the crucible. The heating was carried in the muffle furnace **(Plate** 4.2) out exactly for seven minutes, after which the crucible was removed, cooled in air, then in desiccators and weighed again. The calculation was done as per the following formula:

% Volatile Matter = (Y-Z/Y-X)*100

Where,

X = weight of empty crucible, g

Y = weight of crucible and coal sample before heating, g

Z = weight of crucible and coal sample after heating, g

Determination of Fixed Carbon (FC)

After the determination of moisture, volatile matter and ash the mathematical remaining is fixed carbon by definition. Fixed carbon plus ash present the approximate yield of coke from coal. The value of fixed carbon is evaluated by subtracting the resultant summation of moisture (M), volatile matter (VM) and ash (A) from 100 with all parts on the same moisture reference basis

FC=100-(M+VM+A)

4.3 Wet oxidation potential [1, 9, 11, 13]

The coal molecule may consist of two parts: one is condensed aromatic structure, which are resistant to oxidation and other one is the aliphatic or hydro aromatic structure that are more prone to oxidation .Coal structure becomes sensitive to oxidation due to the presence of hydroxyl group in the aromatic structure and this property becomes the cause for low rank coals because low rank coals carry more branch aliphatic hydro-carbons. Since the high rank coals possess structure very similar to that of graphite, it is less prone to oxidation. Lower rank coals on being oxidized produces large amounts of aliphatic acids compared to higher rank coals. When coal is made to react with alkaline permanganate, oxidation takes place and the concentration of magnetite ion in solution tends to increase comparative to permanganate and there will be outcome change in the potential till all the oxidation possible in coal molecule is finished. Thus it is observed that, addition of coal to alkaline permanganate solution results in a change of potential of carbon electrode sank in the solution. It is based on the chemical reaction of coal sample with solution of $KMnO_4$ and KOH.

The solution of alkaline potassium permanganate and potassium hydroxide with coal sample forms an electrochemical cell which on stirring produces EMF against a standard potential of 0.56V. The plot of the EMF's versus time gives an idea of the propensity of the coal sample towards spontaneous heating. [13]

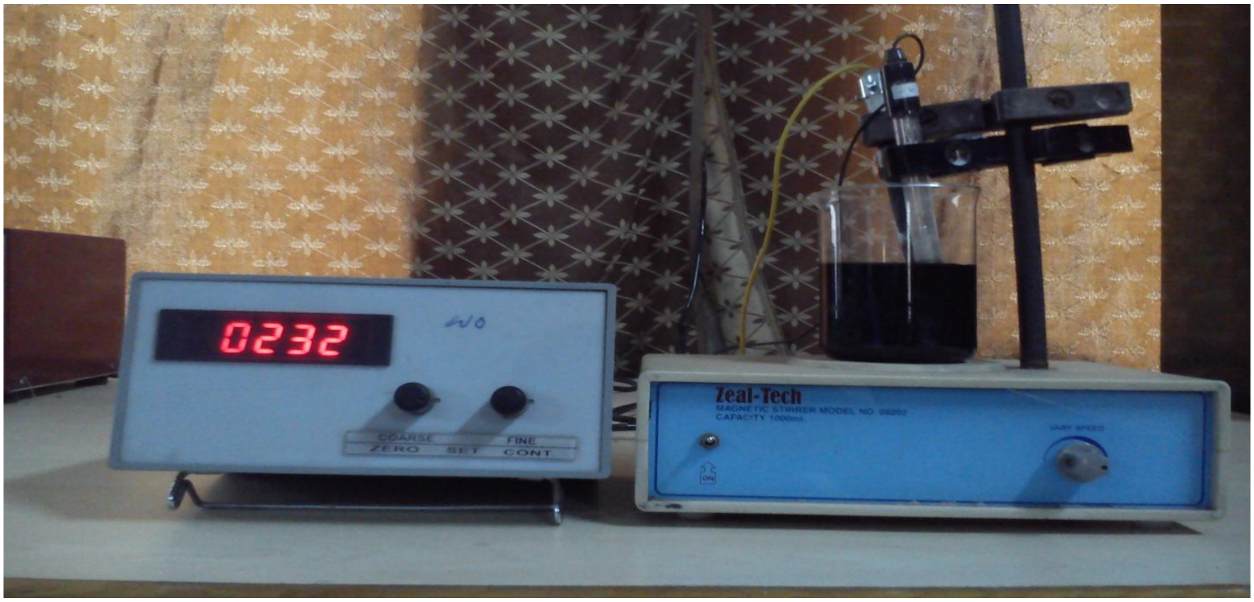

Plate.4.3 Wet oxidation potential apparatus

Principle of Wet oxidation

In wet oxidation process strongly alkaline solution of potassium permanganate ($KMnO_4$) is taken. The permanganate ion undergoes one electron reduction to magnate ion by the following reaction:

$$MnO_4^- + e \rightarrow MnO_4^{2-}$$

The standard electrode potential of this redox couple (E^0) is 0.56V. The electrode potential (E) is related to the concentrations of magnate and permanganate ions present in the solution and is given by the following equation:

$$E = E^0 - \frac{RT}{F} \ln \frac{[MnO_4^{2-}]}{[MnO_4^-]}$$

Where,

R = Universal gas constant

T = Temperature

F = Faraday's constant

When coal is added to alkaline permanganate, oxidation takes place and the concentration of magnate ion in solution increases relative to permanganate and there will be resultant change in the potential till all the oxidation possible in coal molecule is complete. Therefore, addition of coal to alkaline permanganate solution results in a change of potential of carbon electrode dipped in the solution. The electrode can be represented as carbon/Mno_2^-

Procedure:

The beaker along with the electrodes was placed over a magnetic stirrer such that homogeneity of the mixture of coal and alkali solution is maintained. The Teflon coated fish of the magnetic stirrer was placed inside the beaker. 0.5 g of coal sample of -212 (μ) sizes was mixed with 100 ml of deci-normal solution of potassium permanganate ($KMnO_4$) in 1N potassium hydroxide (KOH) solution in a beaker and the coal sample was subjected to wet oxidation process. The coal-oxidant suspension was continuously stirred using the magnetic stirrer. The potential difference (EMF) was recorded between the calomel and carbon electrodes over a period of time by using a millivolt meter till the potential difference attained a nearly constant value.

The graphs between Times vs. EMF (millivolt) for all the samples are plotted in Figs. Different samples require different time duration for attaining a nearly constant potential difference (ΔE). It was observed that almost all the coal samples attained a constant value after 30 minutes. Therefore this time period was chosen to find out the wet oxidation of the collected coal sample carried out at low, medium and high speed of the magnetic stirrer and the result are illustrated in Table.5.2

CHAPTER- 5

RESULTS AND ANALYSIS

5.1 RESULTS

The results of the parameters of proximate analysis (Moisture, Volatile matter, Ash and Fixed carbon) after removing the extraneous moisture are calculated using the standard procedure of all the collected coal samples covering some coalfields of India and are listed in Table 5.1.

Table.5.1 The results of the parameters of proximate analysis

SL NO	SAMPLE	M (%)	VM (%)	A (%)	FC (%)
1.	CCL-1	6.7	28.1	36.6	28.6
2.	CCL-2	5.4	29.2	38.2	27.2
3.	CCL-3	5.1	28.2	27.4	39.3
4.	CCL-4	2.7	23.9	41.1	32.3
5.	CCL-5	4.8	30.5	32.7	32
6.	MCL-1	6.88	44.95	11.5	31.62
7.	MCL-2	6.5	42.1	18.89	28.51

The results of the wet oxidation potential difference of all the collected coal samples at different speed (low, medium and high) of magnetic stirrer using the wet oxidation apparatus are listed in the following table 5.2.

Table.5.2 The results of the wet oxidation potential difference at low, medium and high speed of magnetic stirrer

Sample	WOPD at low speed of magnetic stirrer(mv)	WOPD at medium speed of magnetic stirrer(mv)	WOPD at high speed of magnetic stirrer(mv)
CCL- 1	87	85	87
CCL- 2	75	73	74
CCL- 3	74	77	75
CCL- 4	75	76	78
CCL- 5	79	83	81
MCL- 1	98	99	102
MCL -2	92	95	96

5.2 The Results of WOPD at Different Speed of Magnetic Stirrer

The graphical presentations of all the wet oxidation curves at various speed of magnetic stirrer are shown below:

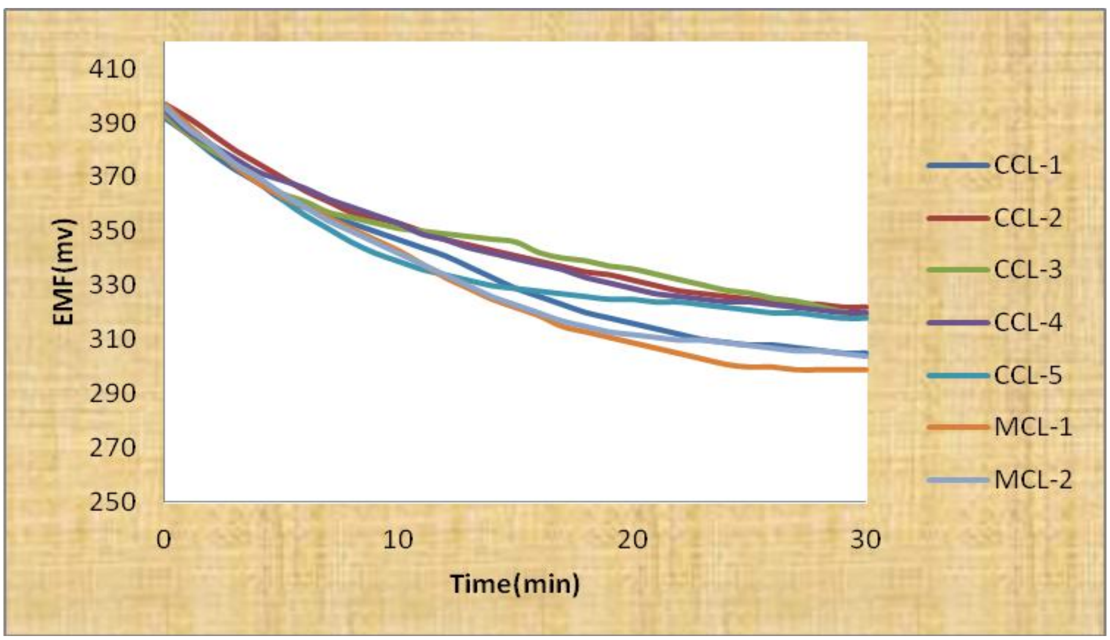

Fig. 5.1 WOP Curve of CCL and MCL samples at low speed

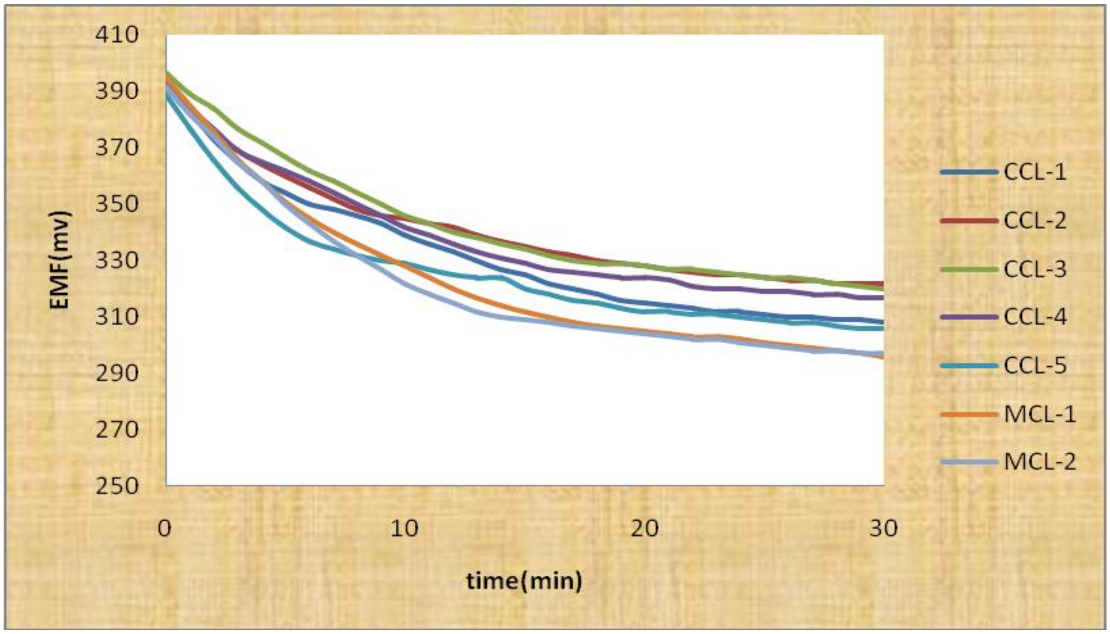

Fig. 5.2 WOP Curve of CCL and MCL samples at medium speed

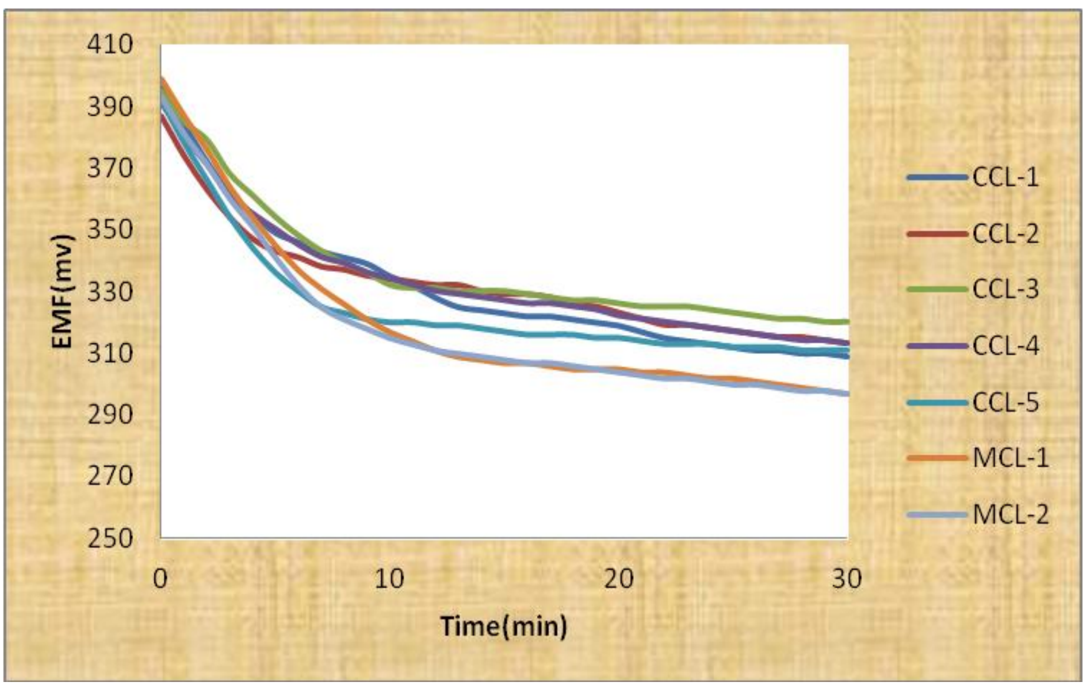

Fig. 5.3 WOP Curve of CCL and MCL samples at high speed

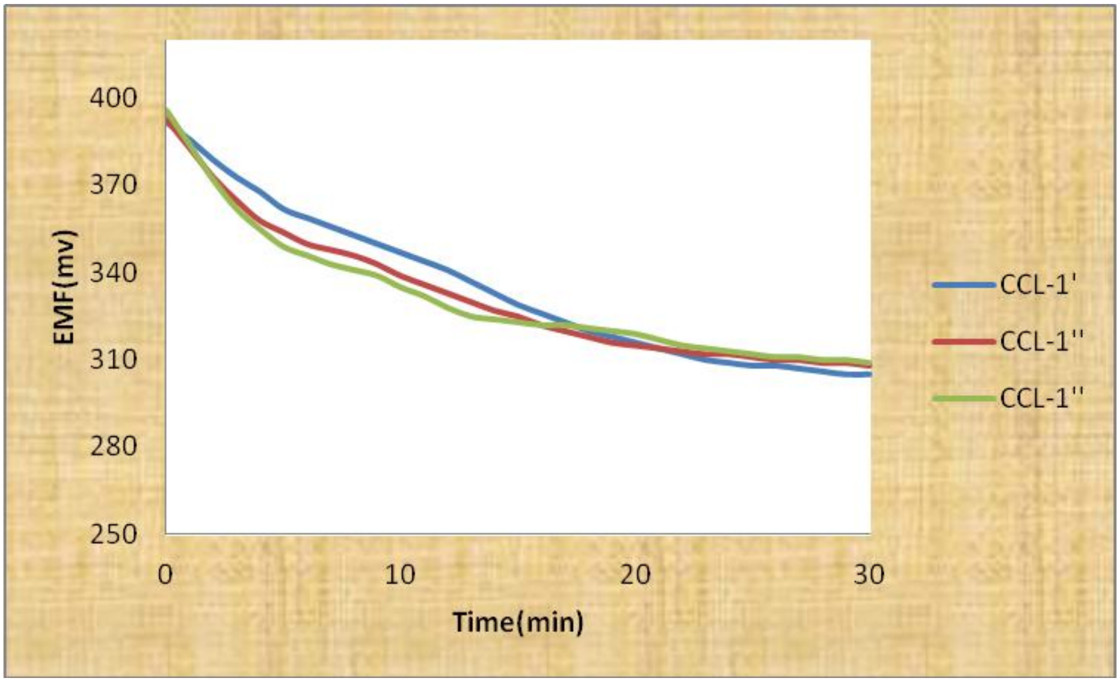

Fig. 5.4 WOP Curve of CCL -1 at low, medium and high speed

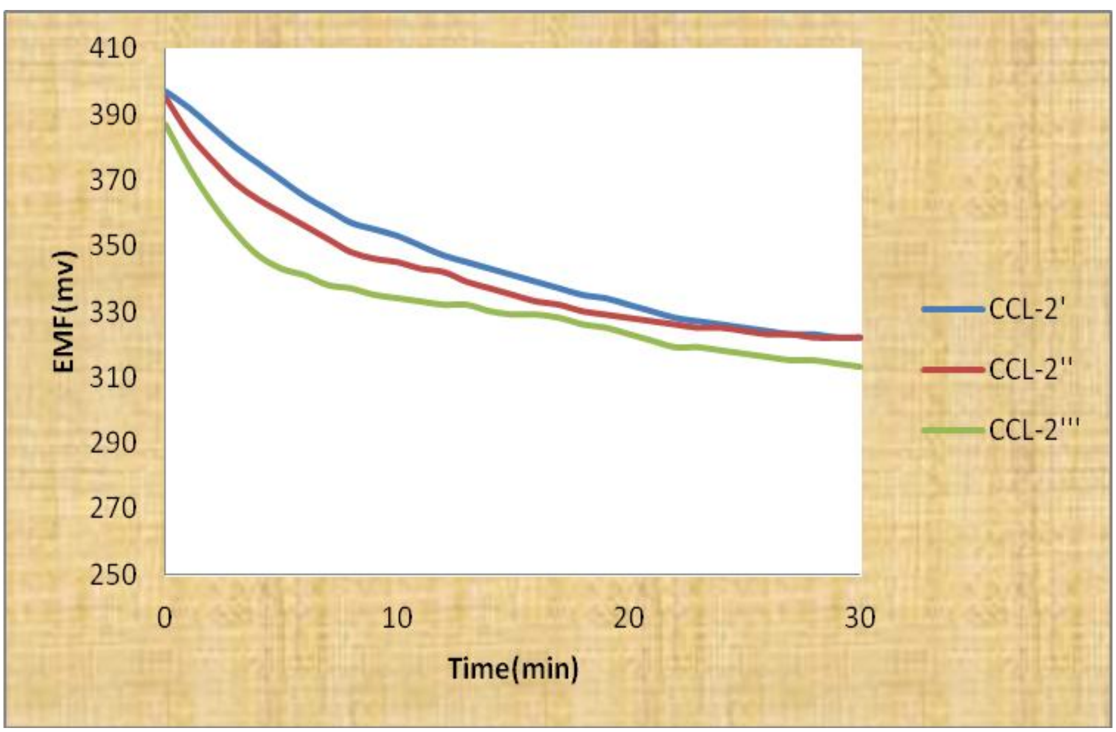

Fig. 5.5 WOP Curve of CCL -2 at low, medium and high speed

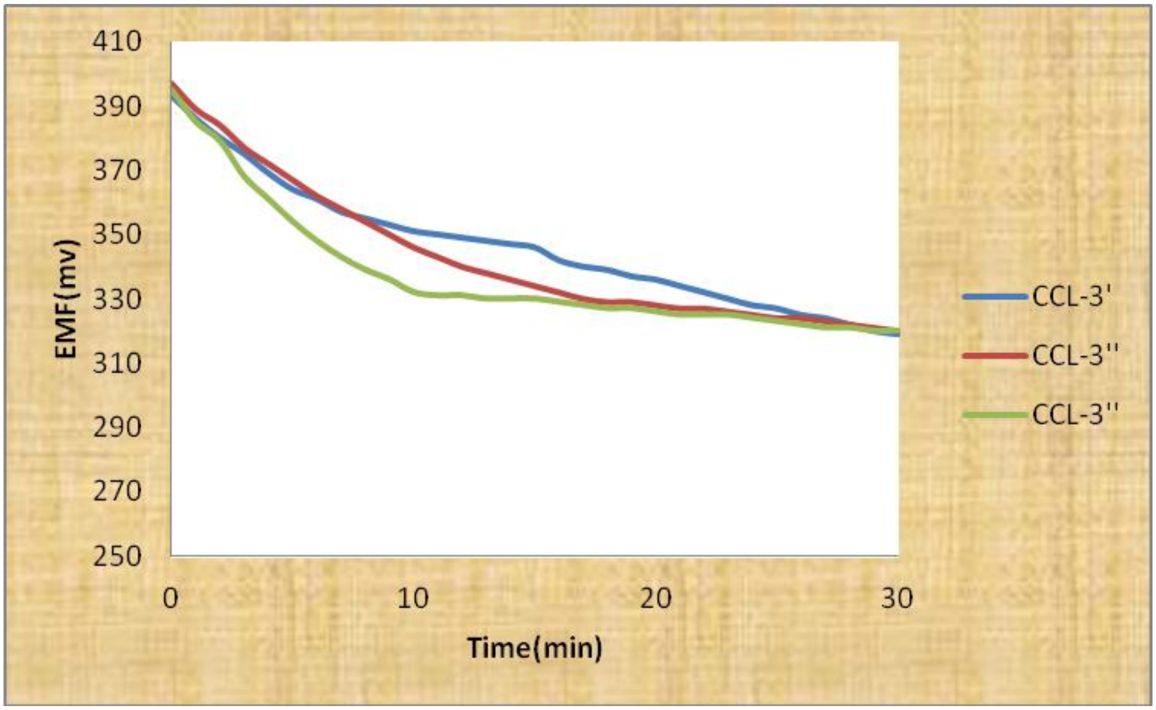

Fig. 5.6 WOP Curve of CCL -3 at low, medium and high speed

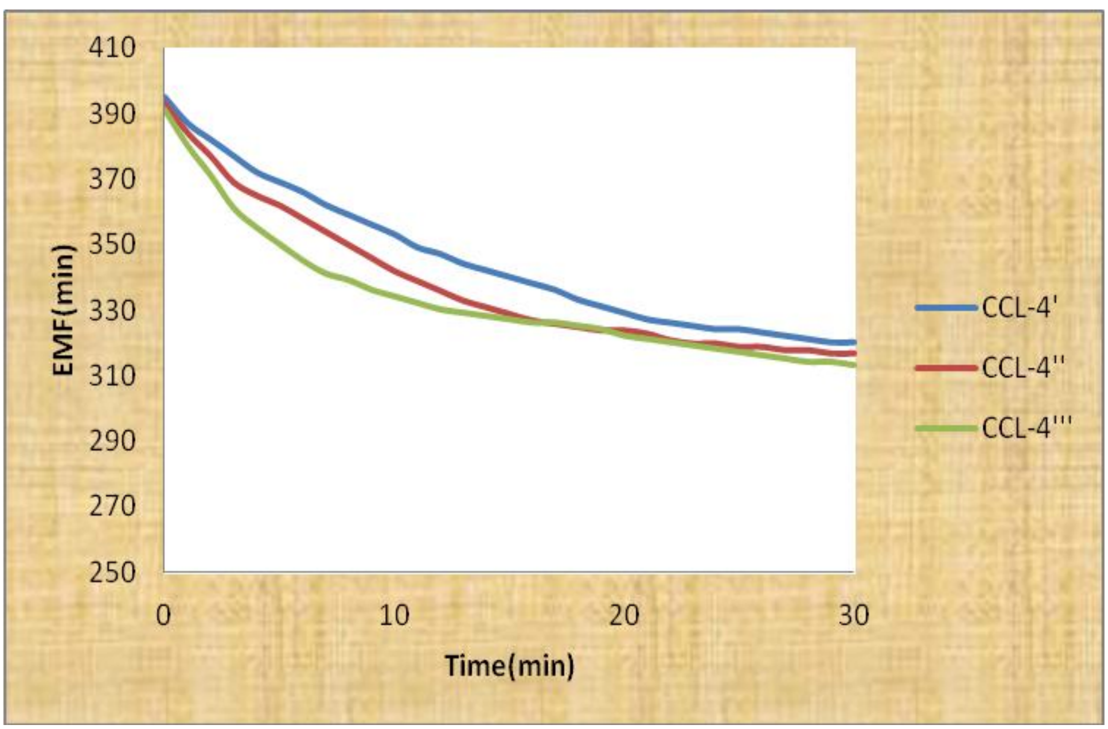

Fig. 5.7 WOP Curve of CCL -4 at low, medium and high speed

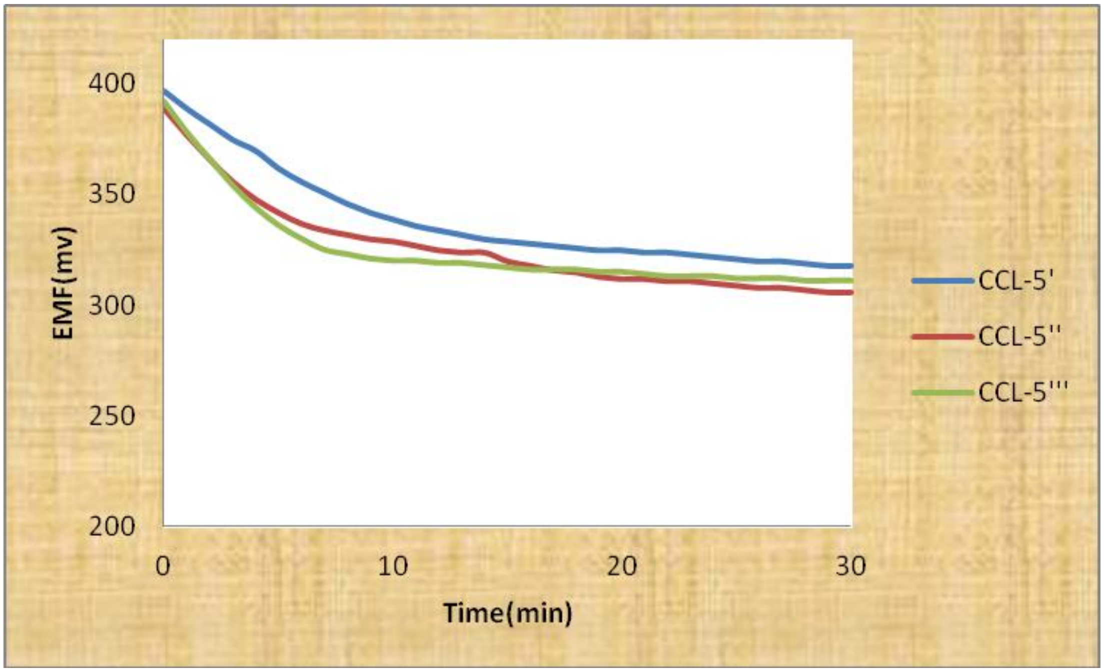

Fig. 5.8 WOP Curve of CCL -5 at low, medium and high speed

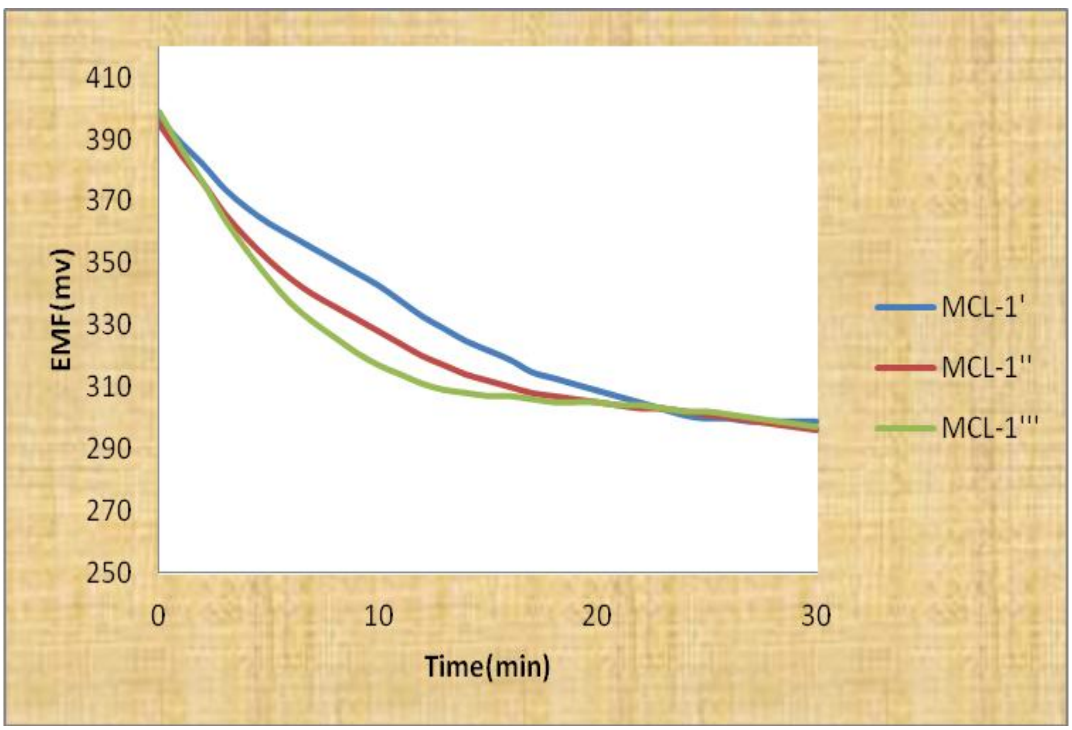

Fig. 5.9 WOP Curve of MCL-1 at low, medium and high speed

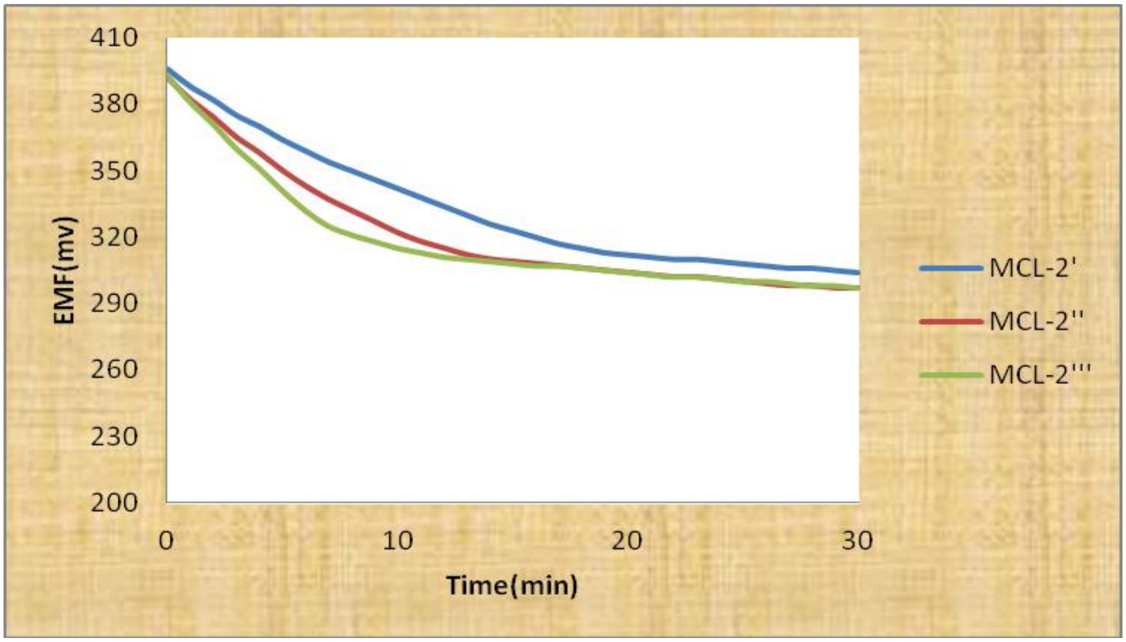

Fig. 5.10 WOP Curve of MCL -2 at low, medium and high speed

5.3 CORRELATION ANALYSIS

Correlation analysis was done using the MS Excel 2007 package. Microsoft Office Excel 2007 provides powerful tools and features that one can use to analyze, share, and manage data with ease. Commands and features that were often buried in complex menus and toolbars are now easier to find on task-oriented tabs that contain logical groups of commands and features.

The following table shows the correlation between the parameters of proximate analysis and WOPD.

Table.5.3 Results of correlation analysis of coal samples

Proximate analysis parameter	WOPD at low speed of magnetic stirrer (mv)	WOPD at medium speed of magnetic stirrer (mv)	WOPD at high speed of magnetic stirrer (mv)
M	0.764863	0.693481	0.678427
VM	0.878879	0.911486	0.891384
A	-0.79058	-0.86467	-0.81786
FC	-0.35109	-0.20235	-0.28815

Where,

M – Moisture

A – Ash

VM – Volatile matter

FC – Fixed carbon

WOPD-Wet oxidation potential difference

5.4 FINDINGS

The following observations are drawn from Table.5.3

- ❖ Moisture shows good correlation with Wet oxidation potential difference at all speed of magnetic stirrer but shows very good correlation at low speed of magnetic stirrer.
- ❖ Volatile matter shows good correlation with Wet oxidation potential difference at all speed of magnetic stirrer but very good correlation with medium speed of magnetic stirrer.
- ❖ Wet oxidation potential shows a negative correlation coefficient with Ash at all speed of magnetic stirrer but very good negative correlation with medium speed of magnetic stirrer.
- ❖ Wet oxidation potential shows poor negative correlation coefficient with FC at all speed of magnetic stirrer.

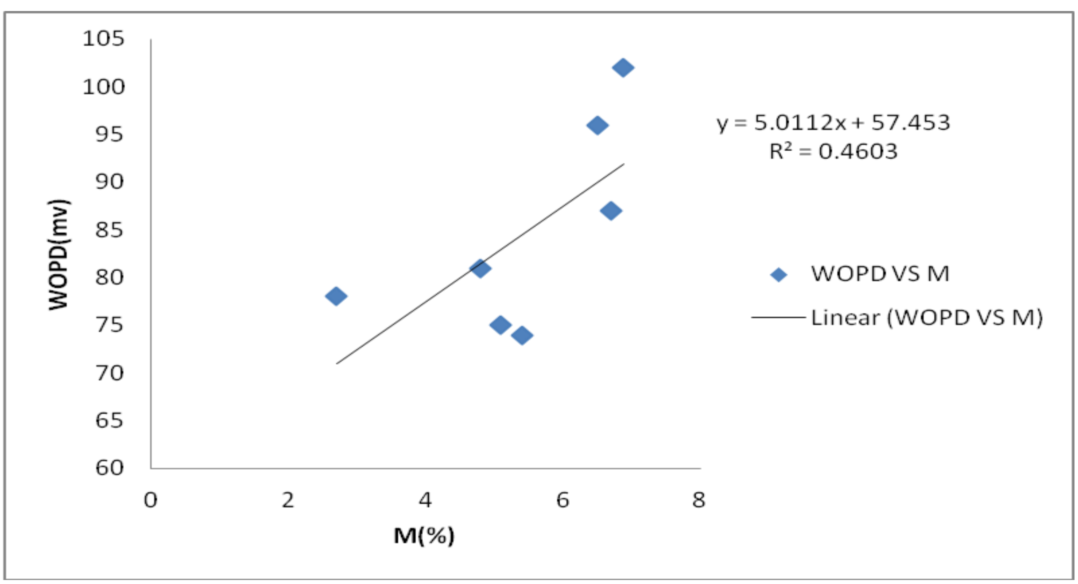

Fig. 5.11 Correlation between M and WOPD at low speed

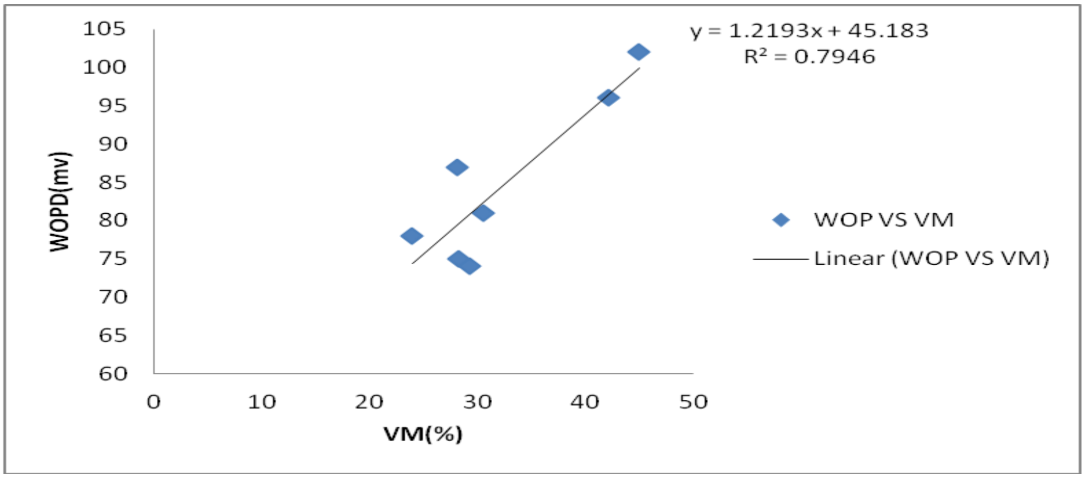

Fig. 5.12 Correlation between VM and WOPD at low speed

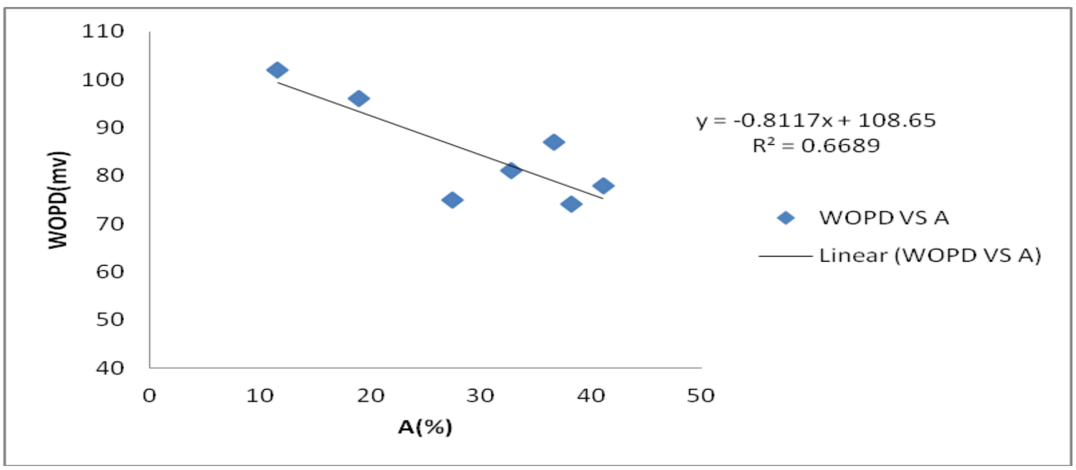

Fig. 5.13 Correlation between A and WOPD at low speed

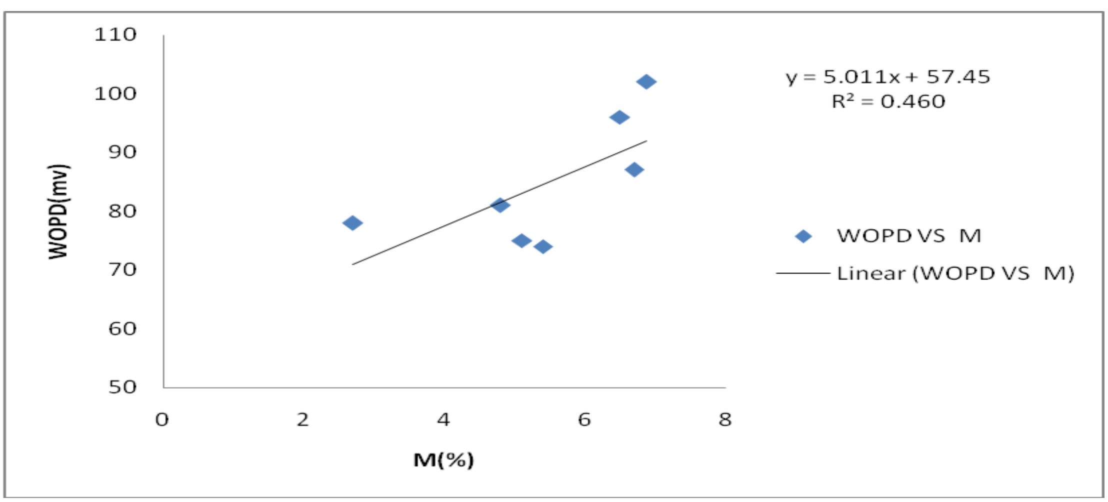

Fig. 5.14 Correlation between M and WOPD at medium speed

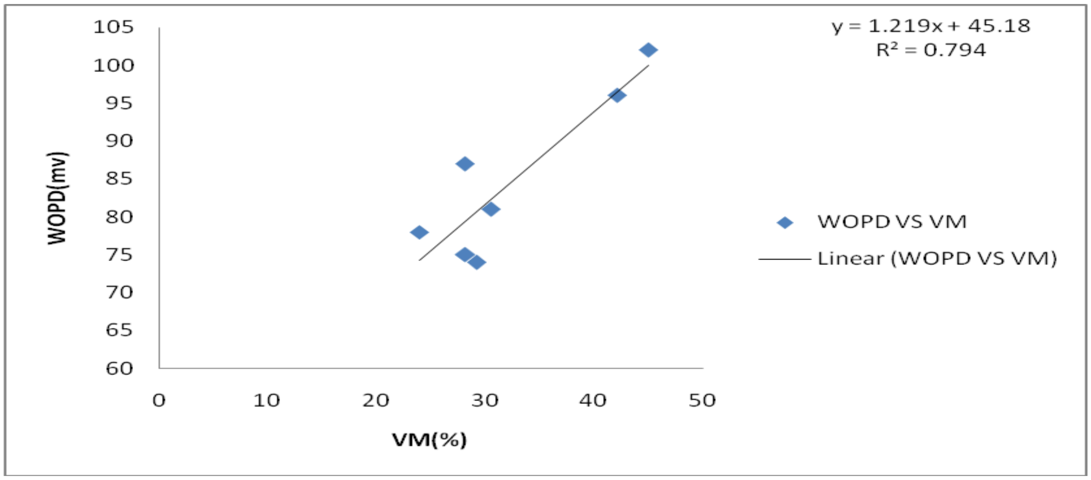

Fig. 5.15 Correlation between VM and WOPD at medium speed

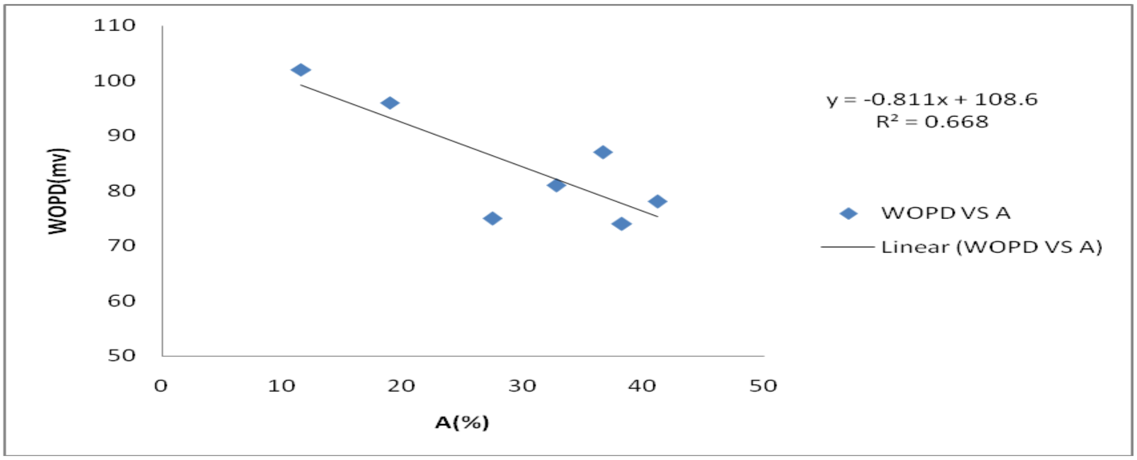

Fig. 5.16 Correlation between A and WOPD at medium speed

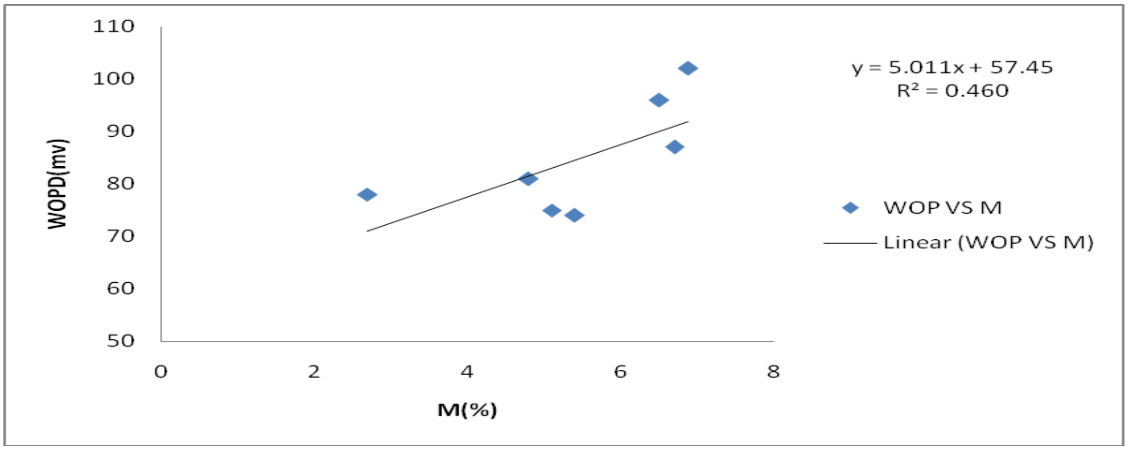

Fig. 5.17 Correlation between M and WOPD at high speed

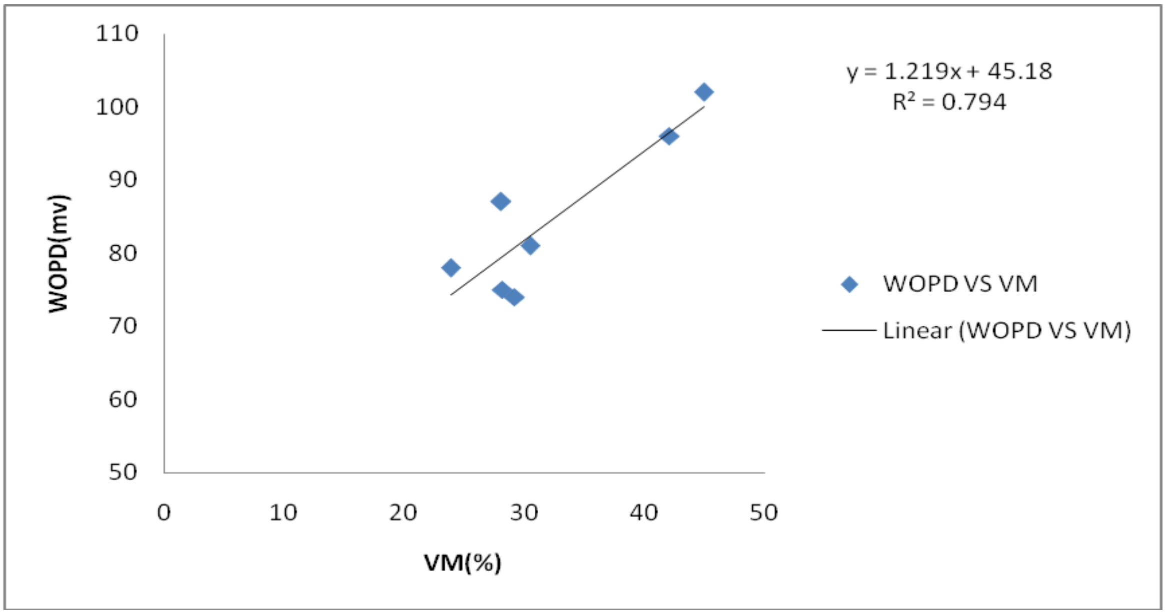

Fig. 5.18 Correlation between VM and WOPD at high speed

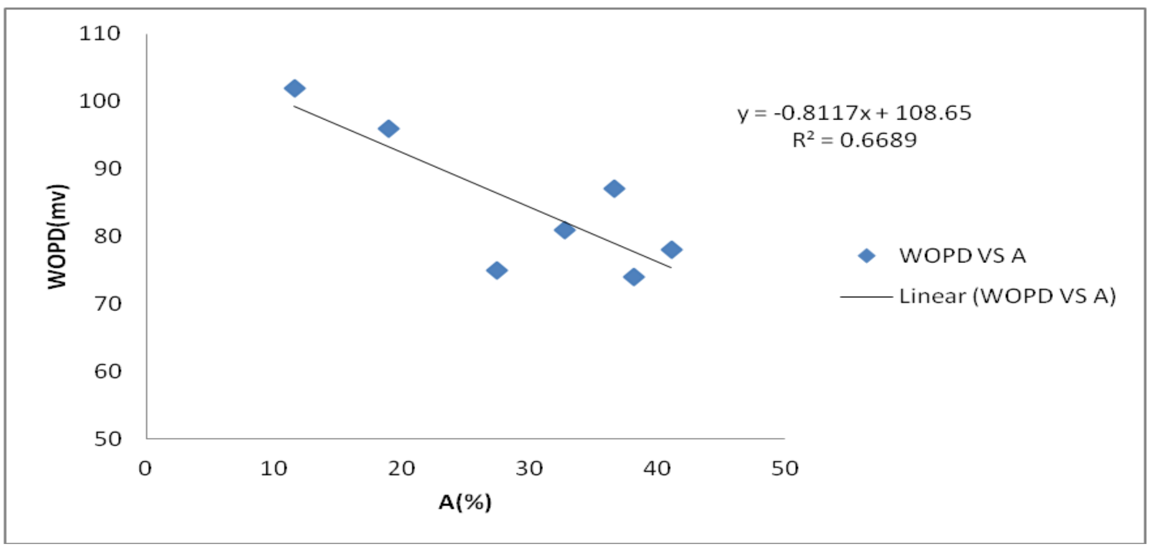

Fig. 5.19 Correlation between A and WOPD at high speed

CHAPTER-6

CONCLUSIONS

In order to evaluate the role of intrinsic factors in the spontaneous heating of coal, 7 coal samples were collected from different mines of our country. Out of the 7 coal samples collected for analysis, 5 from CCL and 2 from MCL using the standard sampling method.The intrinsic properties were measured by proximate analysis and the spontaneous heating susceptibility of the coal samples were determined by wet oxidation apparatus at low, medium and high speed of magnetic stirrer in the laboratory and Correlation studies have been carried out using MS Excel to find out the correlation co-efficient and linear curve drawn between proximate analysis parameters and WOPD and also find out the best R^2 (correlation factor).

- From the wet oxidation potential analysis, the varying speed of magnetic stirrer showed that the potential difference constantly decreases for some time and then becomes constant and also EMF value is low for high speed rotation of the magnetic stirrer where as EMF value is higher if stirrer speed is low.
- At low speed of magnetic stirrer, we found that after 20 minutes, most of the wet oxidation potential curve attains constant EMF where as for medium and higher speeds; the time is between 10 and 15 minutes.
- For the coal samples, the potential difference follows a particular trend with increase in magnetic stirrer speed, i.e. Linear or continuously increasing trend is shown by CCL-3, CCL-4, MCL-1, MCL-2 samples but the samples from CCL-1, CCL- 2 and CCL-5 shows an increasing trend followed by a decrease in EMF.
- From the correlation analysis between the intrinsic properties. it is found that the wet oxidation potential is varying with respect to Moisture, Volatile Matter and Ash content following the trend $y=5.0112x+57.453$ with $R^2 = 0.463$, $y= 1.2193x+45.183$ with R^2 value 0.796 and $y=-0.8117x+108.65$ with R^2 value 0.6689 respectively.
- From the correlation analysis, it is also found that with increase in Moisture percentage and Volatile Matter, the WOPD increases linearly but decreases with increase in Ash content at low ,medium and high speed of the magnetic stirrer

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