SUSCEPTIBILITY OF SOME WCL AND NECL COALS WITH RESPECT TO SPONTANEOUS HEATING

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

BACHELOR OF TECHNOLOGY
IN
MINING ENGINEERING

BY

PABERUS TOPPO

107MN005

DEPARTMENT OF MINING ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY

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CERTIFICATE

This is to certify that the thesis entitled **"SUSCEPTIBILITY OF SOME WCL AND NECL COAL WITH RESPECT TO SPONTANEOUS HEATING"** submitted by **Sri Paberus Toppo** in partial fulfillment of the requirements for the award of Bachelor of Technology degree in Mining Engineering at National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

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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 is a slow process and the heat evolved is carried away by air. This process of self heating of coal or other carbonaceous material resulting eventually in its ignition is termed as “spontaneous heating” or “auto oxidation”. The auto-oxidation of coal is a complex physico-chemical process which is accompanied by the absorption of oxygen, formation of coal oxygen complexes and their decomposition leading to the liberation of heat. Therefore the assessment for this combustion is very much necessary. It depends upon different characteristics and properties of coal. Coal mine fire is a major problem worldwide and has been a great concern both for the industry and researchers in this field. Majority of fires existing today in different coalfields are mainly due to spontaneous combustion of coal. . It has been a major problem in the leading producing coal countries like Australia, India and China. Of the total coal inventory of 276.81 billion tonnes, only 40 per cent, or 110 billion tonnes, falls into the proven category. Of this, around 55 billion tonnes is considered extractable, which the Coal Ministry says would last for about 100 years at the current production rate of 550 million tonnes. Coal India, the world's largest coal miner, has said it will likely miss a government-set production target of 460.5 million tonnes for 2010/11 due to inadequate transport infrastructure, which has led to a stocks pile-up. 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. Although much research has been done on the subject, a proper assessment of the spontaneous heating susceptibility of coal needs to be done so that mine operators are notified well in advance and plan the working properly. Therefore, the determination of susceptibility of coals to spontaneous heating and their classification is essential to plan the production activities and optimise coal mine production within the incubation period. The project deals with the assessment of various parameters of coal with the spontaneous heating tendency of coal. Ten coal samples were collected from western coalfield limited(WCL), of Coal India Limited and another six samples were collected from NECL .

The project deals with susceptibility of different coal samples determined by experimental techniques. The intrinsic properties as well as susceptibility indices of the coal samples have historically been considered to be prediction of self heating liability. Most of the methods are based on the measurement of the oxidation rate and ignition temperature. The propensity of different coal to self heating has been studied in the laboratory were determined by experimental techniques: bomb caloriemeter ,Differential thermal analysis, olpinski index ,proximate analysis,wet oxidation potential.

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CHAPTER – 1

INTRODUCTION

1.1 Background

Coal is the prevailing energy supply source in India and meets 56% of country‘s primary commercial energy supply. Mine fires in Indian coalfields is generally induced by spontaneous heating of coal .now a days various preventive technologies being adopted. In order to determine the liability of coal to spontaneous heating different methods have been followed by various researchers of the world. A number of experiments have been done for valuating the spontaneous heating susceptibility of coal viz., Crossing point temperature method (Didari et.al., 2000), Wet oxidation potential method (Tarafadar et.al., 1989), Differential thermal analysis (Nimaje et.al., 2010), Flammability temperature (Nimaje et.al., 2010). A number of approaches have been found over the years to valuate the proneness of coal to spontaneous heating. The tendency to auto oxidation of coal also decide the incubation period of coal seam, which settle the size of the panel to be formed, which is a most crucial safety measure in mine planning. It is imperative that the planners of a mine finds in advance the spontaneous heating susceptibility of the seam to be mined so that either the coal has been drew out before incubation period, or advance precautionary measures are planned to rig this menace. The methods used to determine the tendencies of coals to spontaneous heating in the present study are Proximate analysis, Calorific value, Flammability temperature, Wet oxidation potential, Differential thermal analysis (DTA - TG).

1.2 Objective of the project

The objective of the project is to carry out susceptibility of all the non coking coal samples of **WCL** and **NECL** area. The parameters of coal in order to determine the properties that influence of spontaneous heating tendency of coal. The project was grouped into the following parts –

- **Literature review** – aggregation of all the past works done by varoius authors both national and international and also obtaining information on the topic.
- **Sample collection and preparation** – Sixteen samples were aggregated from WCL, and NECL for the purpose of analytic thinking and the samples were collected and fixed as per the Indian Standards.
- **Experimentation –** The experimentation are grouped into two stages:

  - Finding out of the intrinsic properties of coal – proximate analysis, calorific value .
  - Finding out of susceptibility indices of coal – wet oxidation potential, differential thermal analysis, flammability temperature,and olpinski index .
- **Analysis –** analyse the parameter of the different collected coal samples of various experimental technique of various experiment was done to find out susceptibility of coal to spontaneous heating.

CHAPTER-2

LITERARATURE REVIEW

2.1 Coal mine fire

Mine fires are linked mostly with coal mining, though fires in pyrite mines and casual timber fires in some metal mines are not unknown. Mine fires are common appearance in coal mines but are uncommon in metal mines. Mine fires can be induced either by spontaneous heating of coal, explosion of gases, electrical failures and blasting cause etc.. In coal mines the main cause of mine fire is spontaneous heating of coal. An analysis of the causes of coal mine fires expose that they may begin either from open fires over the external mining delegacies or originate due to very nature of coal (Pal et.al., 1998). Tendency of coal is releasing heat when come in contact with oxygen of air and its poor thermal conductivity prefering heat accumulation, may give rise to latter kind of self heating. The first type of fire from external agencies is known as Exogenous Fires and the second type i.e. due to self-heating character of coal is known as Endogenous Fires or Spontaneous Combustion.

2.1.1 Endogenous fire

1. Pyrite fires: The iron ore of pyrite bearing chemical formula of FeS2 is a polysulphide of iron. Pure pyrite occurs 46.37% Fe and 53.33% S. as with coal pyrite also responds with oxygen of air at room temperature releasing heat which under favorable conditions of heat assemblage gives rise to spontaneous fires. Susceptibility to heating of pyrites is much less than that of coal but it increases if carbonaceous materials are acquaint in pyrites. There are instances when pyrites with 5 - 6 % C and 10 – 12 % S have arrested fire due to spontaneous heating (Amjhore Field, India). 2. Endogenious heating timber- decomposed timber is under extremely suitable conditions give rise to spontaneous heating considered to be mainly from bacterial origin.

2.1.2 Exogenous fires

Electricity is one of the main causes of mine fires. It may begins from short circuiting, over heating of machines, candles, flames from ignition or explosion while blasting and ignition of inflammable gases and materials like timber, oil or wastes. At times crushing of sulphide ores or fires from surface may also be the ancestry.

2.2 History of coal mine fires

Self heating of coal extends to spontaneous heating is the most substantial cause of fires in coal mines across the world (Ramlu et.al., 1985). Self heating of coal can appear in underground cola mines, opencast mines, coal stockpiles, transportation and during the disposal of barrens from coal applying industries in heap wastes (Bowes, 1984 and Carras et.al., 1994).

World scenario

Up to 10 coal fires per year in the Ruhr area of Germany are induced by spontaneous heating (Pilarczyk et.al., 1995). china underground coal fire are bedspread within a region debasing 5000 Km east – west and 750 Km north – south. It is accepted that fires in northern China consume an calculated amount of 100 – 200 MT of underground coal which is about 2 – 3 % of world CO_2 production (Huang et.al., 2001).surveys in the West Riding of Yorkshire (England) reveals that 45 of the county‘s 153 collieries were on fire in 1931 (Sheail, 2005). A more recent epoch examples are the spontaneous heating of spoil buses at Middleburg colliery in Witbank coalfield in South Africa (Bell et.al., 2001).

China

In China, the world‘s biggest coal producer with an annual output around 2.5 billion tons, coal fires are a dangerious problem. It has been calculated that some 10-20 million tons of coal uselessly burn annually, and that the same amount again is built inaccessible to mining. They are centered in provinces of Xinjiang and Inner Mongolia and Ningxia. except exits from burned and unaccessible coal, these fires add to air pollution and substantially increased levels green house gas expellings and have thereby become a problem which has gained international attention.

Germany

In Planitz, now a part of the city of Zwickau, a coal seam that had been burning since 1476 could only be allayed in 1860. In Dudweiler (Saarland) a coal seam fire caught fire around 1668 and is still burning today. Also known is so-called Stinksteinwand (stinking stone wall) in Schwalbenthal on the eastern slope of the Hoher Meibner, where various seams ignites fire centuries ago after lignite coal mining ended; combustion gas continues to reach the surface today .

Indonesia

Coal and peat fires of Indonesia are often caught fires by forest fires near outcrop alluviations at the surface. No exact numbers of coal seam fires has been realized in Indonesia. Only a minuscule 5 fraction of the country has been reviewed for coal fires. The best data available come from a brief study based on systematic, on-the-ground notice. In 1998, a total 125 coal fires were placed and mapped within a 2-kilometer strip either side of a 100-kilometer extend of road north of Balikpapan to Samarinda in East Kalimantan, using hand-held Global Positioning System (GPS) equipment. inferring the data to areas on Kalimantan and Sumatera underlain by known coal deposits, it was considered that more than 250,000 coal seam fires have been burning in Indonesia in 1998 .

United States

Many coalfields in USA are leads to spontaneous heating. The Federal Office of opencast Mining (OSM) asserts a database (AMLIS), which in 1999 named 150 fire zones. In Pennsylania, 45 fires zones are known, the most famed being the fire in the Centralia mine in the hard coal region of Columbia County. In Colordo coal fire have found as a consequence of variations in the groundwater level, which can increase the temperature of the coal up to 30 °C, enough to induce it to spontaneously ignite. The Powder River Basin of Wyoming , Montana have some 800 billion tons of brown coal, and already the Lewis and Clark Expedition (1804 to 1806) described fires there .

India

History of coal mine fires can bedrew back to the year 1865, when the first fire was described in Raniganj Coalfields. Over 140 years fire have been reported till the year1967 from both Jharia and Raniganj coal fields and higher-up quality of non-cocking coal in Raniganj coal fields. Fire appears whenever and wherever combustible material is present in mine working. They endanger not only worthful lives of men in mines but also induce considerable economic losses to the organization involved by them. These fires are not only carry on to bedspread to adjoin areas, adding to the losses but also combat economic exploitation of the seam in the locality . Again open fires in these fields induces environmental pollution by emission of vast quantities of steam, smoke and deadly gases posing a serious health hazards. In Indian coal mine 75% (Singh et.al., 2004) of the coal fire appears due to spontaneous combustion. The main facets of starting the fire in India is that the coal seams are thicker and there is a propensity of spontaneous heating during the extraction operation.

The problem of extraction of thick seam and coal standing in pillars is a dabgerious one particularly in cases where they are with eminent moisture, high volatile and low ash which are more liable to spontaneous combustion of coal. It is not feasible to extract all the coal by caving method or even by complete packing under Indian mining condition. Pillars standing for long time are liable to devolve in straight and slopping may occur.

2.3 Mechanism of spontaneous heating

The oxidation of coal, alike all oxidation reactions, is exothermic in eccentric. The exact mechanism of the reaction is still not well observed. However, scientists accord that the nature of the interaction between coal and oxygen at very low temperatures is fully physical (adsorption) and changes into a chemosorption form beginning from an ambient temperature (Munzner and Peters, 1965; Banerjee, 1985 and Postrzednik et.al., 1988). When coal is disclosed to air it occupies oxygen at the disclosed surface. Some fraction of the exposed coal substance gains oxygen at a faster rate than others and the oxidation outputs in the production of gases. Mainly CO, CO2, water vapor along with the release of heat during the chemical reaction. The rate of oxygen consumption is extremely high during the first few days (particularly the first few hours) abiding the exposure of a fresh coal surface to the atmosphere. It then downs very slowly except causing problems unless produced heat is allowed to assemblage in the environment. Under certain conditions, the accumulation of fire cannot be combated prevented, and with sufficient oxygen (air) supply, the process may reach higher stages. The coal-oxygen-water complex made during the initial stage (peroxy-complexes)breaks down above 70-850 C,producing CO, CO2 and H_2O molecules. The rate of chemical reactions and exothermicity change with the rise in temperature, and radical changes take place, beginning at about 1000 C, major due to loss of moisture (Oresko, 1959; Banerjee, 1985 and Handa et.al., 1985). This process leads with the rise in temperature, producing more stable coal-oxygen complexes until the critical temperature is achieved. The ignition temperature of bituminous coal is about 160-1700 C and of anthracite coal nearly 1850 C. Once the coal achieves it ignition point, the air supply to it will only increase the combustion.

2.4 FACTORS AFFECTING SPONTANEOUS HEATING OF COAL

Spontaneous heating appears only in certain seams and these capable/susceptable seams are frequently adjacent to seams acted by the same method and submitted to the same tectonics, but which have never been the site of combustion. some seams have only been susceptible in one area and, again, some seams are more susceptible than others. In this chapter the effect of all the factors on spontaneity of coals are described.

Every cause of spontaneous combustion, however small, if not deal with effectively and efficiently in the early stages can produce into open fires or into an explosion of gas or dust, with ravaging results.

The whole phenomenon of the spontaneous combustion as combine effects of the situation which may be classified as:-

A) **Seam factors**

1) Rank
2) Petrographic Composition
3) Temperature
4) Available Air
5) Particle Size
6) Moisture
7) Sulphur
8) Effect of Previous Oxidation
9) Physical Properties
10) Heating Due To Earth Movement
11) Bacteria
12) Other Minerals

B) Geological factors

1) Seam Thickness
2) Seam Gradient
3) Caving Characteristics
4) Faulting
5) Coal Outbursts
6) Friability
7) Depth of Cover

C) Mining Factors

1) Mining Methods
2) Rate of Advance
3) Pillar Conditions
4) Roof Condition
5) Crushing
6) Packing
7) Effect of Timber
9) Multi-Seam Working
10) Coal Losses
11) Main Roads
12) Worked Out Areas
13) Heat from achines
14) Stowing
15) Ventilating Pressure

8) Leakage	16) Change In Humidity

1.seam factors

The rank of the coal counts on the character of the actual plant debris from which it was produced and the amount of change that its organic matter has undergone during the period of formation. An increasing carbon content and with its decreasing oxygen content is the most commonly assumed criteria of increasing rank. The greater the rank, e.g. anthracite, the slower is the oxidation rate. Whilst lignite of low rank, oxidizes so quickly that it is often declared that it can't be put in after mining without ignition.

Petrographic composition: Among the petrographic elements of coal, fusain is the least responsive and durain is more reactive than vitrain.

Temperature: The absorption of oxygen is more speedy as the temperature increases. There is a marked temperature coefficient of oxidation and the intemediate rate of oxidation about doubles for every rise of 18 degree Fahrenheit.

Available Air: Where there is a little amount of air, the rate of oxidation is very slow and there is no considerable rise in temperature .Where there are large quantities of air passing over or through the coal, any heat acquired will invariably be conducted so that the temperature does not arise and the oxidation rate continues at a low level.

Particle size: A solid coal face generally represents very little danger of spontaneous combustion, partly due to the small disclosed area and partly due to the very low permeableness of solid coal gases. It is however, broadly when coal is tattered in mining, or broken by roof pressure, when autumns and faulting appear that spontaneous combustion is probable to take place. It is the small coal that is chiefly responsible for the heating. The air clears into the mass oxidizes a little of the coal approach the outer surface. They produces a slight inrise in temperature, so that as the air imbues deeper and deeper, it turns warmer and warmer and although part of its oxygen has been assimilated there is still enough to produce oxidation. accordingly, it is at some distance inside the mass that heating arises most rapidly

Moisture: The impression of moisture on spontaneous heating is incertain. A small quantity looks to assists rather than prevent the heating whilst large quantities of moisture prevent the heating. However, as in a surface stockpile, substitute drying and wetting of the coal speeds up the heating process.

Sulphur: It was considered that sulphur in the form of pyrites was the major cause of spontaneous heating of coal. However, it was latter demonstrated that coal even in the absence of sulphides would gain oxygen and heat spontaneously. However, further research work altered this view and lead to the present theory that pyrites brings a subsidiary role in promoting declension and spontaneous combustion.

Other minerals: Many other chemicals bear upon the rate of oxidation to some extent, either accelerating or preventing it. Alkalis can behave as accelerators, and borates and calcium chloride as retardant.

2. GEOLOGICAL FACTORS:

Seam thickness:

Where the seam thickness is greater than that which can be entirely mined in one part, the area is more amenable to spontaneous combustion, since the unmined area runs to be subjugated to sluggish ventilation flow. It was found that spontaneous combustion was evidently dependent upon the physical factors affected by the thickness of the seam, the methods acting of working type of ventilation and the friable nature of the coal. Also, in thick seams sure bands within the section can be more liable to self hating capacity than others cases. In certain cases, a coal roof and floor way thus be left where,

a) The natural floor or roof leans to be weak

b) The seam is thick, or

c) There are deficient coals over or beneath the seam.

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

Seam gradient:

Flat seams where bord & pillar and long wall methods are involved are less susceptible to spontaneous heating. In an inclined seam assure of combustion becomes more complex, since action current resulting from the difference in the temperature must lean to cause air currents in the goaf. In addition, within the drew out areas, flow may be due to perkiness as a result of the differing densities of the methane, carbon dioxide and nitrogen.

Caving characteristics: In the mines where partial extraction is applied, adequate pillars are allowed to support the superincumbent strata, and the caving characteristics are generally of little significance. In order to decrease the amount of leakage air flow within the extracted areas, it is worthy for waste to be fullfilled with as fine a material as possible .Thus, this material invades the greatest volume and packs the void. The case of friable waste and enough emphasis should aid on the non- combustible or non-carbonaceous material.

Faulting: Faulted group frequently has an influence on spontaneous combustion. Any cranching action along the fault plane, with the resulting production of the fine coal, may tends to spontaneous heating. A fault generally retards down the rate of face advance to a safe minimum, with the ensuant risk of heat development.

Coal outburst: Coal outbursts usually go on in the harder formation rather than in the softer one and lower coals are more liable to spontaneous combustion. However, great care must be accepted where there is a possibility of coal outbursts and spontaneous combustion occurring at the same time, as the danger of the products of an outburst i.e. finely fine grained coal and /or methane, passing over the site of an active agent heating are very great.

Coal friability: The more friable the coal is the greater the surface area exposed to oxidation, thus leading to yield more heat per unit volume of coal.

Depth of cover: The depth of cover does not necessarily pretend the risk of spontaneous combustion. In general, the larger the depth of cover, the greater the natural strata temperature and thus higher is the base temperature of insight coal. With increase in depth, strata temperature growths with a rate of 40m per 0C.

3. MINING FACTORS

Mining methods: An advancing method of mining on the long wall system exits extracted areas lying between the entries serving the working places .the ventilating pressure differences will advance air to flow across these areas, with the coming with risk of combustion. In high-risk situation a retreat system of working is normally chose. However, the most important advantage gained by assuming a retreating system is lost if an attempt is made to ventilate the waste using a bleeder entry system.

Rate of advance: Within any waste area adjacent to working place there will be air coming in the waste, either by the force of ventilating current or deliberately caused by a bleed action.

In this area, the rate of flow can be vital. In practice, when a working face is functioning normally, any individual piece of coal cracks through the zone at a rate equal to the rate of advance of the working place. It is the time taken from coming or leaving the zone that is b15 vital. If the time is excessive, the oxidation may occur to an unacceptable degree and a glob fire could outcome.

Pillar Size: Pillar size has a direct influence on the liability to heat. Ideally, pillars should be of a size to deflect crushing. This size depends on the strength of the coal, the coal, the depth of the cover and the sct upon of other workings with in the vicinity. Increase methane emission is an indication of crushing, around pillars that subsequently spontaneously heated. Generally in coalmines, depending upon the depth of the seam from the surface, size of the pillar is decided. In bord and pillar working at average depth, if the pillar size is 30m × 30m center to center, then chances of beating will be minimized.

Roof condition: Poor roof brings out the shock waves to pass though easily and the development of crack increases, so poor roof conditions increases the liability to spontaneous combustion .these falls cavities, which have to be confirmed and are often filled with timber. Such areas are often sites of localized heating.

Crushing: Crushing is important in two types of locations: at pillar and rib edges and at worked out areas. Where a pillar is subjected to crush, a situation can arise where leakage paths are made, leading to the flow of air into the coal and in some circumstances, through the solid to involve a more distant zone. Loose coal is usually present in worked out areas, and is generated either by pillar importing or by roof collapses with associated sluggish ventilation.

Packing: Where, backpacks are used, in seams, are liable to spontaneous heating. Experiences have shown that they must be of the greatest possible quality. It was largely as a result of improvements in gate side packing the incidence of spontaneous combustion is generally decreased in most of the heading in a very short time.

Effect of timber: The timber props left in the waste caused the coal roof to disintegrate and produced a saving thus encouraging the spontaneous heating of coal.

Road ways: Road ways in the seam liable to spontaneous heating are areas of bear on due to leakage through crushed solid coal. The risk rises with thickness of coal, as this increases the area of coal disclosed. The most general points for incidents are junction, air crossing, doors, regulators, connecting roads, obstruction in the roads, old roadways.

Leakage: To generate the circumstances in which spontaneous combustion can occur, there must be a supplying of oxygen and a situation where a built-up of heat is possible. This can be brought about by air escapes through fissures in solid coals and result in a shallow seated heating .this situation can happen where leakage paths exits at air crossings, in and around regulators and doors, and other similar locations where outflow there is a high pressure gradient and propensity for air to attempt to flow through solid coals.

Multi seam working: Where a multi seam situation involves both during the first seam and of subsequent seam, condition can arise with spontaneous combustion hazards for the seam currently being work carried out, and any other seams above or below of it .for example, where a seam has been extracted with another un worked seam underlying it, leakage path can be generated in to the lower seam, with a consequent risk of heating.

Coal losses: Coal losses that leave oddment coal in worked out areas is a series hazard and most gob fires result from this factor. There is no normal mining system that can guarantee that remnant will never be left in a waste area. Most mining systems result in a significant loss of coal.

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 deterioration in rib condition and the presence of loose, small beat coal contributing to potential combustion.

Heat from machines: Normally heat from machine is spread within the ventilating air – stream and the temperature rise of the general body of the air are likely to be very small. In some circumstances, the effect of the heat from machines is secondary, in that additional air may have to be broadcasted and will require a higher ventilating pressure with consequent increase risk of leakage.

Stowing: Stowing is behaved to seal mined out areas completely. It has considered to be an effective method of spontaneous control.

Ventilating pressure: The flow of air in the mines is necessarily involved with pressure difference. This pressure difference is generated by the mine fans and the natural ventilation, whist the pressure distribution underground depends upon the resistance of the air ways and dispersion of the quantity. Air will try to pass wherever there is a path and a pressure difference, and this means that air will pass along any break or crack in the strata that is open to a pressure difference. A high ventilating pressure differential comes out to be an important factor contributing to the spontaneous heating.

Barometric Pressure: It is generally accorded that air may find its way into a sealed-off areas as a result of at least one of the following causes

a) Continuous leakage, resulting from a difference in pressure on the return and intake stopping.

b) Barometric changes

c) Fluctuation in ventilating pressure resulting from the opening of doors and the movement of edges and mine cars.

Humidity: If coal absorbs moisture from the ventilating air it will heat up due to the discharge of the latent heat of condensation and chemisorptions effects. On the other hand, if the coal loses water by desiccation to the ventilating air, the reverse occurs if there is any imbalance between moisture in the air.

The balance between the complex mining condition that can bring about condensation or evaporation has not fully been searched but it is becoming increasing evident that changes in environmental moisture play a vital role in tipping the balance between adsorption and heating an evaporation and cooling.

Table 2.1 Set elements of mining conditions (Banerjee,1985)

Sl. No.	Mining parameter conditions	Set elements	Probability of spontaneous fire risk	
			High	Low
1.	Category of coal (Chemical nature)	a) Highly susceptible b) Poorly susceptible	High -	- Low
2.	Friability of coal	a) Highly friable b) Poor friability	High -	- Low
3.	Method of working	a) Bord and Pillar b) Longwall	High -	- Low
4.	State of stowing	a) Extraction with caving b) With complete stowing	High -	- Low
5.	Seam thickness	a) High (>5m) b) Low (<4m)	High -	- Low
6.	State of extraction	a) Partial extraction b) Complete extraction	High -	- Low
7.	Nature of extraction	a) Extraction with more than one slice b) In one slice	High -	- Low
8.	Geological disturbances	a) Present b) Absent	High -	- Low
9.	Rock bumps	a) Present b) Absent	High -	- Low

10.	Dykes	a) Present b) Absent	High -	- Low
11.	Overburden	a) Greater than 300m b) Less than 300m	High -	- Low
12.	Parting	a) Shale structure b) Rocky and consolidated	High -	- Low
13.	State of consolidation of barrier	a) Fractured and crushed b) Well consolidated	High -	- Low
14.	Scope of accumulation of fines	a) Fine accumulation sustained b) Fines avoided	High -	- Low
15.	Method of ventilation	a) Advancing type b) Retreating type	High -	- Low
16.	Quantity of ventilation	a) Intensity of pressure difference high b) Low pressure difference	High -	- Low
17.	Humidity	a) Wet mines b) Dry	High -	- Low
18.	Source of hot spots	a) Present b) Absent	High -	- Low
19.	Gas emission rate	a) Low b) High	High -	- Low
20.	Size of panel of the face	a) Large b) Small	High -	- Low
21.	Rate of face advance	a) Slow	High	-

		b) Fast	-	Low
22.	Chances for blockage of face advance	a) Present b) Absent	High -	- Low

The following is the brief view of the work carried out by different researchers to determine the spontaneous heating propensity of coal samples.

National and International status:

Banrjee and Chakravarty (1967) have hinted differential temperature Analysis(DTA) for the study of spontaneous combustion of coal, particularly in grouping coals with respects to their susceptibility to self heating. A standard experimental procedure for carrying out DTA studies had been described by them. Calcined alumina is advocated as inert reference material for DTA experiments. A heating rate of 50C/min was notified for such studies. Typical temperatures found from various coals are includes in this study to explain self heating phenomenon.

Bhattacharya (1971) carried out laboratory experiments to evaluate the rates of heat produce from different coals by a calorimeter during sorption of water vapour in isothermal conditions. It was discovered that the rate of heat generation in a particular coal increases with the equilibrium humidity deficiency of the coal, i.e. with the difference of equilibrium humidity of air and coal. For a given coal, the rate of heat generation due to oxidation has been detected to be negligible in comparison with that due to sorption of water vapour. A small peak‘ at the starting of the rate curves has been observed during the tests with dry coals, with the exception of anthracite; explanations for this phenomenon have been sought. The results also show that under a given test condition the characteristic rate of heat production is dependent on the type of coal, its particle size and its weathering.

Banerjee (1972) determined the Crossing Point Temperature (CPT) of a number of Indian coal samples following the Crossing Point Temperature method. He conveyed that coals with crossing points temperatures between 1200C & 1400C could be concieved to be highly susceptible to spontaneous heating and those above 1600C are poorly susceptible. The moderately susceptible ones depicted values in between the above mentioned.

Nandy et al. (1972) mentioned the variation in Crossing Point Temperature values with the volatile matter, oxygen percentage and the moisture content of coal. He got that CPT normally decreases with the increase in each of these constituents of coals. But beyond 35% V.M, 9% oxygen, or 4 to 6% moisture content there is not much change in CPT values. In fact, above 4 to 6% moisture content in coal (on as received basis), the CPT values reveals a rising trend.

Feng et al (1973) discovered a composite liability index using the results of Crossing Point Temperature experiments, called FCC index. This is calculated using the following equation

$$\text{Liability index} = \frac{\text{Average heating rate between 110 C and 220 C}}{\text{Relative investigation temperature}} \times 10$$

Mishra et.al. (1980) presented a critical analytic thinking of different genetic and physical factors involved with certain Early and Late Permian and Oligocene coal seams and early Eocene lignite seams of India shows that the high secondary porosity and small particle size, irrespective of petrographic and rank properties in sub-humid climate, favour spontaneous combustion. Large particle size, high rates of gas discharge and highly wet or dry seams, in combination with each other lead to subdue spontaneous heating in sub-humid, per-humid and semi-arid conditions. The susceptibility to auto-ignition of a coal or lignite seam is not uniform throughout its lateral extent and a high inherent porosity at any given rank stage and a high content of susceptible or oxidizable constituents are not sufficient to cause auto-ignition.

Ghosh (1985) made an attempt to acquire a method to identify coal's proneness to spontaneous combustion. It has been shown that if pyrite is present in a coal in finely divided form, the proneness of coals towards spontaneous combustion increases; and the temperature of a coal bed increases if water is added to it, which leans to indicate that water spraying or even flooding cannot be considered as an effective assess to control spontaneous combustion. Moreover, it was also revealed that if a coal body is chilled (to − 193 °C) the micropores and microcracks in the coal are possibly contracted. Atmospheric oxygen is less likely to come in the coal through micropores and microcracks; and hence chances of spontaneous combustion due to auto-oxidation are diminished.

Mahadevan and Ramlu (1985) objected to the impulsive selection of ranges in FCC index and proposed an index known as MR index as:

$$\frac{\text{Heating rate at the crossing point}}{\text{Time to reach the crossing point}} \text{ x } \frac{\text{Time to reach the inflection point}}{\text{Average heating rate between the inflection point and crossing point}} \text{ x } 10$$

Tarafdar et.al. (1987) reported results of wet oxidation of coal using alkaline permanganate solution affecting measurements of differential temperature at different temperatures, at a constant heating rate, and potential changes between a saturated calomel electrode and a carbon electrode absorbed in the coal oxidant mixture within a definite reaction time at a constant temperature. The measurements were arrieved at on seven coal samples coalfield of known crossing point temperatures (CPT). Four samples, considered to be highly susceptible to spontaneous heating, had CPT in the range 132-1370C, and three, considered poorly susceptible to spontaneous heating, had CPT values in the range 162-1680C, showing two distinct zones of correlation between CPT values and the represensting differential peak temperatures, and between CPT and the observed potential changes. It was suggested that differential temperature and potential difference measurements during wet oxidation of coal may be used as alternative techniques for the assessment of tendency to spontaneous heating.

Tarafdar and Guha (1989) carried out a preliminary investigation using wet oxidation method in 1989 and they reported that a systematic and thorough study along this line is required as the significance of this technique.

Chandra et.al. (1990) carried on a preliminary survey of the frequency of occurrence of fire due to spontaneous combustion in the various seams of the Raniganj Coalfield and showed the 14 possibility of a relationship between coalification and spontaneous combustion of coals. Besides rank, as manifested from reflectance studies, the amount of vitrinite and exinite contents of the coal seams also determined the spontaneous combustibility of the coal seams. The found that pyrite of the Raniganj Coalfield had no influence on the combustibility of the coal seams. It was revealed that the proneness to spontaneous combustion of the coals is related to coalification. As the coalification increases, the intensity of spontaneous combustibility decrements gradually from highly susceptible to moderately susceptible to least susceptible to the spontaneous combustion stage.

Panigrahi, Ojha, Saxena and Kejriwal (1997) guided experiments for the determination of Russian U-index, 10 samples from Jharia coalfields have been examined using this method.

The carbon, hydrogen, nitrogen and sulphur contents for this samples have been determined by using Fenton's method of ultimate analysis, in addition to this, the crossing point temperature of these samples have also been determined. Then, attempts have been made to correlate the Russian index and CPT of coal samples with its basic constituents viz. carbon, hydrogen and ash conents. It has also been observed that from point of susceptibility of spontaneous heating, Russian index shows similar relation with the basic constituents of as the crossing point temperature, which may prove to the handy method of coal categorization in Indian context.

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

Panigrahi et.al. (2004) carried out extensive field studies to look into the pillar fire problems in one coal mine in India. A Thermal IR gun and a Thermo vision camera have been applied for thermal scanning to assess the state of heating in selected pillars. Special sampling setups have been planned to collect gas samples from the holes drilled into the selected pillars and the multi gas detector is used to analyse the composition of samples in situ. In order to anticipated the spontaneous heating in coal pillars, different gas ratios have been calculated and it has been observed that some of the established gas ratios, viz. Graham's ratio, Young's ratio etc. have resulted in negative values in samples containing high amounts of methane. The modified gas ratios have been aimed which will be useful for predicting the pillar fires. These ratios may also be used for evaluating the condition of fires in sealed-off areas.

Singh, et al. (2004) observed that exploitation of coal seams from underground mines has become a major challenge to Indian coal mining industries. The problem of spontaneous heating in blasting gallery (BG) panels during extraction is a major threat to safety and productivity in SCCL mines. Most of the BG panels have been varnished due to the occurrences of spontaneous heating during extraction of the panel. After sealing of the panel, it is much difficult to re-open the panel.

Singh, et al. (2007) discovered in opencast mines, coal instantly oxidises and catches fire due to the intrinsic characteristics of coal, such as low rank, high moisture, high volatile matter, presence of sulfur in the form of pyrites, low crossing point temperature (CPT) and ignition point temperature (IPT) value and less brooding period. In opencast mines, when the coal benches are left idle for a longer time, heat collection takes place in favourable conditions and sometimes leads to fire. The purpose of this paper is to present the different successful case studies regarding the safety management of open pit coal mines from occurrences of spontaneous heating.

Ahmed, et al. (2008) calculated Liability index using CPT for studying the tendency of coal towards spontaneous heating. CPT that has been in lab needs extra precaution for repeatable results. To overcome the troubles, efforts were made to study the relationship between peripheral oxygen groups or the functional oxygen groups in coals and their correlation with propensity to auto-oxidation using liability index (LI).Also the correlation between liability index and crossing point temperature have been delivered in this paper.

Sahay et.al. (2008) proposed realistic characterization of coal towards spontaneous heating for taking appropriate measures. They developed a methodology based on thermo-de compositional study of coal sample for finding of minimum temperature at which coal bed temperature starts self-propellant known as critical temperature and a new liability index based on it. They presented a brief description of different liability index specially based on thermal study, a critical analysis of dependency of vital temperature on moisture content, ash content, volatile matter, carbon content, surface area and porosity, new liability index based on thermo de compositional study of coal sample and correlation with liability index model based on coal close analysis results of coal sample including surface area and porosity.

Mohalik, et al. (2009) presented the review of application of three thermal techniques viz; differential thermal analysis (DTA), thermo gravimetric (TG) and differential scanning calorimetric (DSC); for studying the susceptibility of coal to spontaneous heating and fire. It also critically analyses the experimental standards adopted by different researchers, while using these methods in studying thermal behaviour of coal samples. The paper also presents the next focus of research in this subject area.

Nimaje et.al. (2010) made thermal studies on spontaneous heating of coal. Of all the experimental techniques developed thermal studies play crucial and dominant role in evaluating spontaneous heating susceptibility of coal. They created an overview of thermal studies carried out by many researchers across the globe for finding of spontaneous heating of coal and reported that lot of stress on experimental techniques is necessary for evolving appropriate strategies and effective plans in advance to retard occurrence and spreading of fire.

International status:

Peter, et al. (1978) Reported **t**he oxidation of the weathered substances has an apparent activation energy lying between 63.9 and 69.0 kJ/mole which is independent of their moisture content. However, the rate of oxidation of char raises with increasing moisture content and decreases with increasing carbonization temperature of the parent coal, and with the extent of the char's weathering.

Singh, et al. (1984) outlined the present techniques of assessment of spontaneous combustion risk indices for sorting coal seams liable to self-heating. Factors affecting liability of coal to spontaneous combustion depend upon intrinsic factors as well as external factors promoting the self-heating. An adiabatic oxidation test was explained which can be used to assess the liability of coal according to intrinsic reactivity. Systems of risk classifications are based on the synthesis of ratings assigned to intrinsic as well as extrinsic factors. Precautionary measures to assure spontaneous combustion hazard in underground long wall mining, stockpiling and seaborne transport of coal are reported together with the techniques of fire-fighting by the use of liquid nitrogen.

Gouws et.al. (1988) gave three features on a differential thermal analysis thermo gram (i.e., the crossing-point temperature, stage II exothermicity gradient and the transition temperature to high-level exothermicity) are commonly known to be indicative of the self-heating propensity of coal. A new index was formulated and utilized to 58 coals, enabling known dangerous and safe coals to be identified.

Olayinka, et al. (1990) demonstrated the CPT of Nigerian coals were found to decrease with increase in coal rank. The liability index, which gives a better evaluation of susceptibility of coal to spontaneous heating, was also found to decrease with increase in rank and with decrease in oxygen content and moisture applying capacity of the coal. Of the four coals studied, the high volatile bituminous coal had the lowest susceptibility to spontaneous combustion while the subbituminous was the most capable.

Gouws, et al. (1990) designed an adiabatic calorimeter to enable the spontaneous combustion propensity of coal to be set up. Various indicators of self-heating potential, such as total temperature rise, starting rate of heating, minimal self-heating temperature, and kinetic constants were investigated. Results obtained from the adiabatic tests were compared with the results of crossing-point temperature findings and various thermal analysis (DTA) tests for the same coals, with a view to formulating a mathematically consistent spontaneous combustion liability index. This paper summarises the major components of the adiabatic calorimeter.

Anthony, et al. (1995) said that self-heating of coal mainly takes exothermic reactions of oxygen at reactive radical sites within the coal and the enhancing or controlling effect that water had on these reactions. The thermal raction of samples of low-rank coals, dehydrated by heating under nitrogen flow at 105°C and revealed to dry oxygen, is similar to or slightly less than that observed when they are flow-dried at 30°C and tightly bound moisture remains. The most likely reason is that moisture impacts the nature of the radical sites where oxidation occurs. By blocking the formation of stabilized radicals, it promotes faster oxidation which may lead to enhanced thermal response, although some of the extra heat may be taken up by the residual moisture. When loosely bound moisture is granted to remain in the coal, the thermal response on exposure to dry oxygen decreases very quickly, due mainly to blocked access to responsive sites and dissipation of heat brought forth by any oxidation that does occur. The effect of action is comparatively minor and the course of the oxidation reaction responsible for generating heat does not looks to be changed by the presence of small amounts of loosely bound moisture.

Jose, et al. (1995) used differential thermal analysis (DTA) as a method to study the self-heating behaviour of fresh and oxidized coals. Oxidation was performed in air at 200°C for duration of up to 72 h. As the rank of the coal increases, both the self-heating and the end of combustion temperatures also rise up. The total heat loss (area under the DTA curve) increases with the rank of the coal. Rise in the self-heating temperature, a decrease in the temperature of the end of combustion and a decrease in total heat flow were observed as a result of coal oxidation. A relationship between the total heat loss and the calorific value as determined using the ASTM standard method is pointed out.

Vancea, et al. (1995) work investigates the effect of the moisture content of coal on its spontaneous ignition in oxygen (40°C–140°C). It has been found that the highest heating rate is attained at a medium moisture content of 7 wt% for an starting inherent moisture content of the coal before drying (in dry nitrogen at 65°C) of 20 wt%. This is especially noticeable at temperatures below 80°C and inclines to support previous studies showing that a maximum oxidation rate takes place at such moisture content in the same temperature range.

Ren, et al. (1998) used adiabatic calorimeter for the propensity of 18 pulverised coals (Australia, UK, US, Indonesia, South Africa, South America) to spontaneous combustion. All the coal samples were tested at an starting temperature of 40°C and three samples at 60°C. Their propensities to spontaneous combustion were ranked to their initial rate of heating (IRH) and total temperature rise (TTR) values. The results presents that, air humidity is an important factor is determined whether a heating will move on rapidly or not. The particle size dispersion of the coal affects the IRH and TTR values, with comparatively smaller particles inclined to be more reactive. Aged and pre-oxidised coals have higher IRH and lower TTR values, and the coal becomes less reactive. The magnitude of the temperature raises (TTR) with increasing starting temperature.

Rosema et.al. (2000) developed a numerical simulation model ―COALTEMP‖ to study the oxidation and possible spontaneous combustion of coal that is brought out to the atmosphere and the daily cycle of solar irradiation. First the differential equations that describe heat flow, oxygen flow and oxidation in the coal matrix, and the equations explaining the exchange of heat, radiation and oxygen with the atmosphere, are demonstrated.

Kuçuka, et al. (2001) evaluated the spontaneous combustion characteristics of Askale lignite from Turkey. The imact of the gas flow rate, the moisture of the piles of coal, the humidity of the air and particle size on the spontaneous burning characteristics of coal samples were tried out using Crossing Point Methods adapted to their laboratories conditions. The liability of spontaneous combustion of this lignite was found to increase with decreasing particle size, increasing moisture content of the coal and decreasing humidity of the air.

Yucel et.al. (2001) conducted an experimental study focused at evaluating the spontaneous combustion characteristics of two Turkish lignites moistured and air-dried at varying times. The content of three predominant oxygen functional groups (carboxyl, hydroxyl, and carbonyl) of unprocessed, moisten and air-dried coal samples were also determined with wet chemical methods. The content of oxygen functional groups in moisten coal samples do not vary significantly that of unprocessed coal samples, for realized in vacuum desiccator to moisture of coal samples. The liability of spontaneous combustion of the two coals were found to reduce when moisture content increased with increase in reached time to water vapour.

Kaymakci and Didari (2002) carried out linear and multiple regression analysis to determine the relationship between spontaneous combustion parameters (derived from time-temperature curves found from laboratory tests) and coal parameters (obtained from proximate, ultimate and petrographic analyses) have been explained. The additive regression analysis have shown that ash (A), volatile matter (VM), carbon (C), hydrogen (H), exinite (E), inertinite (I) and mineral matter (MM) are the main factors impacting 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 gained some empirical equations using statistical models.

Nelson et.al. (2007) used a large variety of methoda to earn insight into the processes that govern the self-heating of coal. These include oxidation mechanisms, ranking the propensity of various kind of coals to self-heat, and the catching and suppression of self-heating. Moist coal in coal mines and stockpiles have very different combustion characteristics than those predicted on the basis of dry testing. Consequently, methods for ranking the propensity of coal to spontaneously burn in literal mining conditions require to be enhanced.

Daiyong et.al. (2007) assumed that spontaneous combustion of coal seams is a complicated process that is a function of the interplay of internal and external conditions. Based on geologic field investigations and understandable analyses, four models of spontaneous combustion for coal were build up: A genesis-type model, a coal-fires propagation model, a model for the liberal stages and products of a coal fire and a cross-sectional model of zones.

2.5 THEORIES OF SPONTANEOUS COMBUSTION OF COAL

Pyrite theory

Heating due to oxidation of pyrites has been known to be a common phenomenon in pyrite mines. Heating of coal can be caused by iron pyrites (only when present in considerable proportion) and in finely powdered and dispersed state in the presence of moisture. The reaction of iron pyrites with oxygen and moisture is exothermic yields substances of greater volume than the original pyrite thus opening more pore area for oxygen. The reaction can be given as

$2Fe\,S_2 + 7O_2 + 16H_2O = 2\,H_2SO_4 + 2\,Fe\,SO_4.7\,H_2O + 316$ kcal

The oxidation of pyrite during weathering of coal seam may be represented by

$Fe\,S_2 + 15/4\,O_2 + 9/2\,H_2O = Fe\,O.OH + 2\,H_2SO_4$

The equations show that both oxygen and moisture, two prime weathering agents, contribute to pyrite alteration and the sulphuric acid is made as a by-product of the alteration. In comparison to dry coals in the presence of moisture, the reactivity of coal is found to be double and if pyrite is in finely dispersed state, it becomes 10 fold. It was seen that pyrite bellow 5% showed paltry effect.

Bacterial Theory

Bacteria were also believed to promote self- ignition of coal. Later investigations revealed that bacteria had little influence on the self – heating tendency of coal. The contribution of heating due to the action of bacteria cannot be completely ruled out. Spontaneous heating observed in haystacks and in wood are known to be mainly due to bacterial action. However, there is no essential proof to authenticate or cast out this theory.

Phenol Theory

Experiments have shown that phenolic hydroxyls and poly phenols oxidize faster than many other groups. This theory is interesting because it offers a process of finding out liability of coal to self -generated heating.

Electro-chemical Theory

It explains auto-oxidation of coals as oxidation-reduction processes in micro galvanic cells formed by the coal substances.

Humidity theory

It says, the quantity of heat liberated by atmospheric oxidation of coal is much less than the amount of heat required removing water from the coal. If the evaporation of water can be induced at the seat of heating, then the temperature of heating would decrease. When it is recalled that water is an oxidation product of low temperature oxidation of coal, the above scheme well explains other possible sources of CO and CO2 in low temperature reaction between coal and oxygen. Nordon et al (1979) measured the heat of wetting with water of an Australian low rank bituminous coal with different moisture content. Although dry coal showed a substantial rise of temperature, heat of wetting (6 KJ / Kg) values decreases rapidly with increasing moisture content and heat. For a normal moist coal (65% relative humidity) heat of wetting could cause a temperature rise of only 2° C, which would be unlikely to contribute importantly to self-heating in store coal.

Coal-oxygen Complex Theory

Oxidation of coal is believed to be initiated at native radical sight. Formation of peroxyl radical and hydro peroxides is commonly to be thought to be they mechanism by which oxygen and moisture are initially in corporate into organic matrix. These species may react, rearrange or decayed to form wide range of oxygen functionality in the matrix or gaseous product.

CHAPTER-3

EXPERIMENTAL INVESTIGATION

3.1 SAMPLE COLLECTION AND PREPARATION (IS 436 Part 1/Section 1-1964 and IS 436 Part II-1965)

It is the process by which the physical and chemical properties of the mineral or ore can be observed with the desired accuracy. It is the process of collecting the small portion of a whole such that consistence of that portion presents that of a whole. Different types of sampling are:

a. Channel sampling
b. Chip sampling
c. Grab sampling
d. Bulk sampling
e. Drill hole sampling

Chip sampling is done in hard ores where it is tough to cut the channels. It can be taken in case of uniform ores and where the rock structures are independent of the values. The samples collected by breaking of small same sized chips from a face at points usually equally spaced both vertically and horizontally.

Grab sampling is applied to the broken ore in the stope or at the face, ore transported. Usually grab sampling of the ore broken in the stope is undependable as accurate estimation of the volume of broken ore is impossible. Grab sampling of tubs or ships is however more representations since samples are collected from units of regular volume. Bulk sampling is done where schematic sampling methods do not give a representative scale; large scale sampling or bulk sampling repaired to. Bulk samples eradicate the effect of irregular distribution of value or minor.

Sampling is the process by which physical and chemical characteristics of a mineral or ore are assured with the desired accuracy. It is the process of collecting a small portion of a whole such that the consistency of that portion represents that of the whole. In the case for coal it covers the properties defined by close and ultimate analysis such as fixed carbon, fickle matter, ash, caking index and calorific value etc. the physical nature of the ore is sometimes necessary to be ascertained and the sampling process adopted should be able to give this information too. Samples are generally collected at regular interval. The interval of sampling point is governed by the regularity of the deposits as well as the accuracy for sampling designed. The samples were accumulated by following channel sampling procedure.

Before cutting a channel, the face is brushed clean by a whisk or wire brush, cleaning the face with water may be necessary where there is soluble efflorescence on the face. Sometimes efflorescence may have to be scraped before cutting channels. A clean canvas sheet usually 2 meter square is placed on the floor and groove is cut so that the material falls on the canvas. Channel sampling comprises cutting grooves of uniform rectangular section across the face usually at right angles to formation. The grooves are generally 25 mm deep and vary from 40 to 100 mm in width across the seam. Usually a hammer and a moil are used to cut the grooves. The hammer weight should be 1.5 kg for single-handed work and 3.5 kg for double-handed work. Sufficient no. of moils should be kept so that work is not delayed owing to blunting of moils. If the quantity is large it should be coned and quartered on the sampling sheet before collecting it sampling bags. There is always change that missing of collected samples so far this reduction in volume of samples has to be done separately.

For assaying the volume of sample has to be substantially reduced. This has to done that the reduced volume retains the true composition of the original volume and for this it is necessary to comminute the samples so that no particle in the samples exceeds a certain maximum size. Samples can be comminuted mechanically but for size reduction on the spot particularly with channel sampling a hammer and an anvil may be used to break the large pieces in the samples. Usually steel, ring of 15 mm diameter with a handle is used to surround the sample and prevent flying particles when breaking should be on the sampling canvas an quartering floor so that pieces do not fly away and get lost. The sheet should be brushed clean by a whisk brush so as not lose any fines for reduction of samples coning and quartering process should be used until the desired size and volume of samples is obtained.

Eleven samples were collected from South Eastern Coalfield Limited, six samples from Mahanadi Coalfield Limited, three samples from Eastern coal field Limited, three samples from Bharat Coking Coalfield Limited, two samples from Central Coal field Limited and one each from Western coal field Limited and Northern Coalfield Limited. Some of the samples collected were well known for their high and low susceptibility in Indian coalfields.

3.2 Channel sampling (IS 436 Part I/Section I - 1964)

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 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. Obvious 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 minimized.

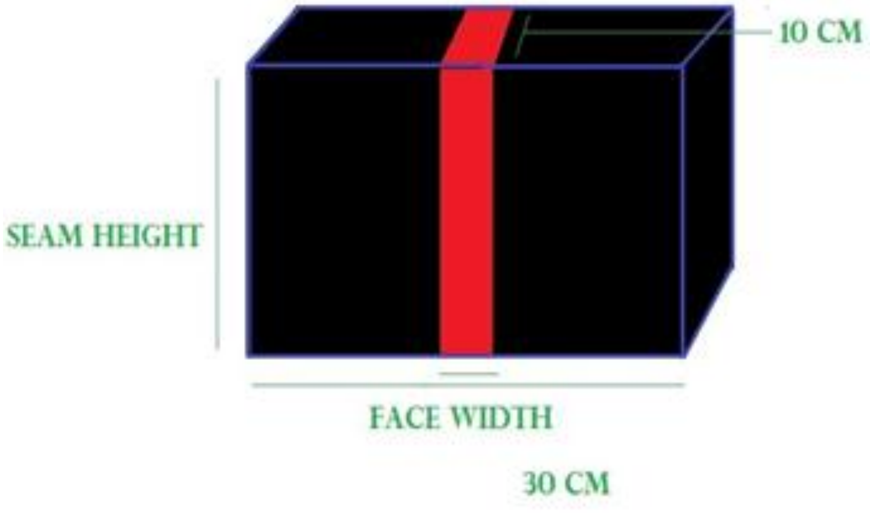

Plate 3.1 channel sampling

Plate 3.1 area map of wcl

3.3 PROXIMATE ANALYSIS

Proximate analysis of coal was developed as a simple mean of determining the distribution of products obtained. When the coal sample is heated under specified conditions, it separates the products into four groups: i) moisture; ii) volatile matter iii) fixed carbon, the non volatile fraction of coal; and iv) ash, the inorganic residue remaining after combustion.

For proximate analysis, i.e. for the determination of moisture, volatile matter, ash and fixed carbon, the method specified by IS (Indian standard) 1350 (Part-I) – 1969 was followed. The experimental procedure is presented as follows.

3.2.1 Determination of moisture content (M) :

Theory :

Coal, due to its nature, origin and occurrence, is always associated with some amount of moisture, which is both physically and chemically bound. It is customary to differentiate between external and internal moisture.When a wet coal is exposed to atmosphere, the external moisture evaporates, but the apparently dry coal still contains some moisture, which can be removed only on heating above 1000C. External moisture is also called accidental or free moisture, where as inherent moisture is termed as equilibrium or air-dried or hygroscopic moisture. The quantity of external moisture depends mainly on the mode of occurrence and handling of coal, but the air-dried moisture is associated to the inherent hygroscopic nature of the coal.

Experimental Procedure :

About 1g of finely powdered (-212 micron) air-dried coal sample is weighed in a silica crucible and then placed inside an electric hot air oven, maintained at 108 2oC. The crucible with the coal sample is allowed to remain in the oven for 1.5 hours and is then taken out with a pair of tongues, cooled in a desiccator for about 15 minutes and then weighed. The loss in weight is reported as moisture (on percentage basis). The calculation is done as per the following.

$$\% \text{ Moisture} = \frac{Y-Z}{Y-X} \times 100$$

Where,

X = weight of empty crucible, g

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

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

Y -X = weight of coal sample, g

Y- Z = weight of moisture, g

Determination of volatile Matter (VM):

Theory :

The loss of mass, corrected for moisture, which results when coal is heated in specified equipment under prescribed conditions, is referred to as volatile matter. The matter lost is composed of materials that form upon the thermal decay of the various components of coal. Some of the components of coal volatile matter are hydrogen, carbon monoxide, methane and other hydrocarbons, tar vapours, ammonia, some organic sulphur and oxygen containing compounds and some incombustible gases, such as carbon dioxide and water vapour, all of which come from the decomposition of organic materials in coal. Inorganic materials in coal contribute the water of hydration of mineral matter, carbon dioxide from carbonates and hydrogen chloride from inorganic chlorides to the volatile matter.

Experimental Procedure:

For the conclusion of volatile matter a special fickle matter silica crucible (38mm height, 25mm external diameter and 22mm internal diameter) was used. First the empty silica crucible along with the lid uncovered was heated at 800oC for an hour in the damp furnace and then cooled on room temperature. The empty volatile matter crucible was then weighed.

Approximately 1g of coal sample was weighed in the volatile matter crucible and it was placed inside the damp furnace maintained at 925oC with the lid covering the crucible. The heating was carried out precisely for seven minutes, after which the crucible was removed, cooled in air and then in a desiccator and weighed again.

$$\% \text{ Volatile matter} = \frac{Y-Z}{Y-X} \text{ X } 100 - M\%$$

Where X = weight of empty crucible, g

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

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

Y -X = weight of coal sample, g

Y- Z = weight of volatile matter + moisture, g

Determination of Ash (A)

Theory :

Coal ash is the residue remaining after the combustion of coal under specified conditions. It does not occur as such in the coal, but is formed as the result of chemical changes that take place in the mineral matter during the ashing process. Ash and mineral matter of coal are therefore not identical.

There are two types of ash forming materials in coal: external and inherent mineral matters. The extraneous mineral matter consists of materials such as calcium, magnesium and ferrous carbonates, pyrite, marcasite, clays, shales, sand and gypsum. The extraneous mineral matter owes its origin to I) the substances which got associated with the decaying vegetable material during its conversion to coal, which is difficult to remove by mechanical methods, and ii) rocks and dirt getting combined during mining and managing of coal. Inherent mineral matter represents the inorganic elements combined with organic components of coal. The origin of such materials is probably the plant materials from which the coal was formed. Ash from inherent mineral matter is undistinguished as far as the total quantity of ash is concerned. But

Indian coals going through major disadvantage, that the mineral matter content is not only high, but of intimately associated type, due to its drift origin.

Ash is qualitatively different from the mineral matter originally present in coal, because of the various 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, incineration circumstances determine the extent to which the change of weight takes place and it is mandatory that standardized methods should be closely followed to ensure reproducibility.

Experimental Procedure:

The empty crucible is cleaned by heating in a damp furnace for one hour at 8000C so that other mineral matter if presents get burnt. It is taken out, chilled to room temperature and the weight is taken. Approximately 1gm of coal sample is weighed in the crucible and is placed in a damp furnace at 4500C for 30 minutes and the temperature of the furnace is raised to 8500C for 1hour. The crucible is taken out and placed in a dedicator and weighed.

$$\% \text{ Ash} = \frac{Z-X}{Y-X} \text{ X } 100$$

Where

X= weight of empty crucible in grams

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

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

Determination of Fixed Carbon (FC)

Fixed carbon (FC) is by definition, the mathematical remaining after the finding of moisture, volatile matter and ash. It is, in fact a measure of the solid combustible material in coal after the expulsion of volatile matter. Fixed carbon plus ash represent the approximate yield of coke from coal. The fixed carbon value is determined by subtracting from 100 the resultant summation of moisture, volatile matter and ash, with all percentage on the same moisture reference base.

$$FC = 100 - (M+MV+A)$$

Where

The moisture (M),

Volatile matter (VM),

Ash(A) content of coal.

Calculation of different basis

Dry basis-(100/100-M)

Dry ash free basis-(100/100-(M+A))

Dry mineral matter free basis-(100/100-(M+VM))

3.4 ULTIMATE ANALYSIS (IS 1351 - 1959)

The objective of coal ultimate analysis is to determine the basic chemical elements present in the coal. The last analysis determines the amount of carbon (C), hydrogen (H), oxygen (O), sulfur (S), and other elements within the coal sample.

Determination of Carbon and Hydrogen in coal:

A known amount of coal is burnt in a current of dry oxygen thereby converting C and H of coal into CO2 and H2O respectively. The products of combustion (CO2 and H2O) are passed over weighed tubes of anhydrous CaCl and KOH which absorbs H2O and CO2 respectively. The increase in the weight of CaCl2 tube presents the weight of water (H2O) formed while increase in the weight of KOH tube represents the weight of CO2 formed.

% of H and C in can be calculated as follows as given below :

Let, X = wt. of coal sample taken,

Y = Increase in the wt. of Cacl2 tube

Z = Increase in the wt. of KOH tube

Amount of carbon in the coal sample = $Z \times \frac{12}{44}$

% carbon in coal = $Z \times \frac{12Z}{44X}$

Similarly, amount of hydrogen in coal sample = $\frac{2Y}{18}$

% hydrogen in coal = $100 \times \frac{2Y}{18x}$

Determination of Nitrogen:

It is done by kjeldaha method. A known weight of powdered coal is heated with conc. H_2SO_4 in presence of Potassium sulphate and Copper sulphate in a long necked flask there by converting nitrogen of coal to ammonium sulphate. When clear solution is obtained it is treated with 50% NaOH solution. The ammonia thus formed is distilled over and absorbed in a known quantity of standard sulphuric acid solution. The volume of unused H2SO4 is then determined by titrating against standard NaOH solution. Thus, the amount of acid neutralized by freed ammonia is determined. %of nitrogen in coal = {vol. of acid used X Normality X 1.4} / wt. of coal taken .

Determination of Sulphur:

A known amount of coal is heated with Eschka mixture (which consists of 2 parts of MgO and 1 part of anhydrous Na_2CO_3) at 800˚C.After burning amount of sulphur present in the mix is retained as oxides and it is precipitated as sulphates. The sulphate formed is precipitated as $BaSO_4$ (by treating with $BaCl_2$). % of sulphur in coal = Where, weight of coal sample taken Weight of BaSO4 precipitate formed Determination of Oxygen: It is deduced indirectly as follows. xy 1374 .0100 x y

% of oxygen in coal = 100 – (% of C +H+N+S+ash) .

3.5 CROSSING POINT TEMPERATURE (Banerjee et.al ,1972)

It is the temperature at which the temperature of coal coincides with that of the heating furnace or bath in 0C. In this method, the coal sample is heated in a reaction tube in a furnace at constant or rising temperature with oxygen or air passing through it at a predetermined rate till the coal temperature crosses the furnace temperature.

Experimental Procedure :

20gms sample of size -212 micron was placed in the reaction tube followed by glass wool at the bottom most position. The tube is then lightly tapped a fixed number of times to achieve uniform packing tightness of the samples. The reaction tube is then placed in the tubular furnace and a chromel- alumel thermocouple is inserted at the centre of the sample. The trapped air and occulted gases are removed from the coal samples by passing a mild current of nitrogen through the sample for three minutes, without disturbing the packing. The furnace is switched on and simultaneously air is allowed to pass through the sample, with an average rate heating of 1 ^{0}C per minute and at 80ml/ min. the temperature of the furnace (bath) and the coal sample are recorded at every five minute interval till the temperature of coal crossed over and gone beyond the furnace temperature.

3.6 DIFFERENTIAL THERMAL ANALYSIS (Banerjee et.al, 1967)

Thermal analysis is method in which some physical or chemical changes of a substance are measured as function of temperature as the substance is subjected to a controlled heating rate. In differential thermal analysis, the difference in temperature between a substance and a thermally inert reference material against temperature is recorded as the two specimens are subjected to identical temperature converts in a block which is heated at a linear heating rate.

The experiment executed by a Differential Thermal Analyser (Figure 3.2). The standardized parameters suggested by Banerjee and Chakravorty (1967) were followed while performing the experiments.

Experimental Procedure:

The crucible for sample and reference was put in position on the ceramic post. 6-10 mg of -212 size coal sample was weighed and put into the sample holder. Oxidizing atmosphere was maintained by keeping the coal sample open to air. Alpha alumina powder was applied as the reference material. Then the tubular furnace was lowered. The software was programmed to run until 450 ^{0}C at a rate of 5 ^{0}C per minute. After the heating is terminated thermo gram is obtained from the sample.

Plate 3.2 DTA-TG Apparatus

In the initial stage of heating (stage I), the endothermic reaction predominates, probably due to the release of inherent moisture in coal. In the second stage (stage II), the exothermic reaction becomes important, but the rate of heat release is not steady all through, as it changes with temperature. A steep rise in heat increment is observed in the third stage (stage III).

The rate of temperature rise in stage II is cited by different researchers, viz. Banerjee and Chakravorty (1967), Gouws and Wade (1989); as being less for coals with less susceptibility to spontaneous heating. The exothermicity in stage III is not viewed as a reliable indicator of the self-heating risk, because it may be equally high for low rank coals. However, the temperature of conversion or characteristic temperature or onset temperature is considered to be significant. It is considered that lower is this temperature, more susceptible is the coal towards spontaneous heating. Therefore, all the thermo grams were analysed for the following details.

(i) Characteristics temperature (Tc)
(ii) Average slope of stage IIA
(iii) Average slope of stage IIB
(iv) Overall slope of stage II

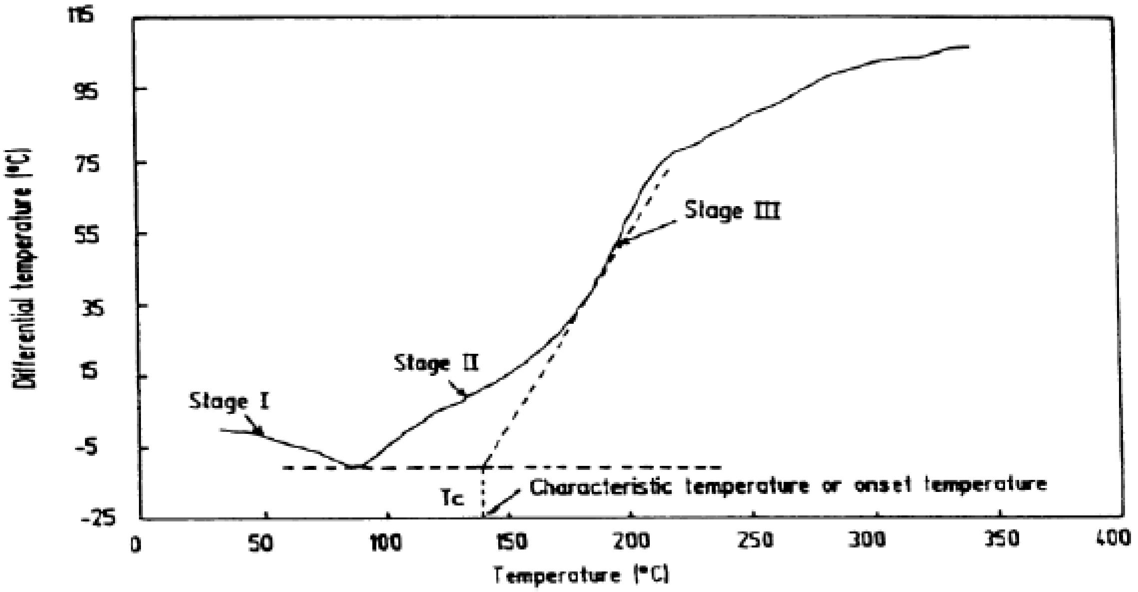

Fig 3.2 DTA-TG curve

Slopes of stage II of the Thermogram:

In the thermograms obtained from the experiments, a linear stage II exothermicity was not observed. In view of the disjointed nature of stage II slopes it was further divided into two different regions, viz. stage IIA and stage IIB. The following three parameters of stage II were determined for further analysis.

a) average slope of stage IIA.
b) average slope of stage IIB.
c) overall slope of stage II.

3.7 DIFFERENTIAL SCANNING CALORIMETRY (Mohalik et.al ,2009)

Differential scanning calorimetric (DSC) is a technique in which the difference in energy inputs into a substance and a reference material is measured as a function of temperature when the substance and reference materials are subjected to a controlled temperature program. In this technique the align value of an output curve at any given temperature is directly proportional to the differential heat flow between a sample and reference material and in which the area under the measured curve is directly proportional to the total differential calorific input. By this technique, coal samples can be studied under experimental conditions that assume spontaneous heating process of materials (Mahajan et al ,1976).

EXPERIMENTAL PROCEDURE:

The cover and the silver lid were removed from the DSC cell. The instrument was fine tuned using standard zinc and indium samples. About 10mg coal sample of -212µ was taken in the perforated aluminium sample pans and weighed accurately using a Mettler AE-240 single pan electronic balance (0.01mg sensitivity). After placing cover on the pan it was crimped using a crimper press. The crimped container with the sample was put on the sample furnace while the reference furnace was kept empty. The DSC thermo gram was now obtained upto 550 ^{0}C at a heating rate of 30 ^{0}C per minute with oxygen as purge gas at a rate of 20cc per minute.

3.8 WET OXIDATION POTENTIAL (Tafdar et.al ,1988)

The coal molecule may be counted as comprising of two parts: the aliphatic or hydro aromatic structure that are more prone to oxidation and condensed aromatic structure, which are resistant to oxidation. Presence of hydroxyl group in the aromatic structure part gives a very high degree of reactivity to coal structure and they get oxidised quicker. Thus, low rank coals are rather easily oxidised due to the above and also due to smaller degree of condensation of aromatic structures in them. Lower rank coals on oxidation produce large amounts of aliphatic acids compared to higher rank coals, because low rank coals contain more branched aliphatic hydro-carbons. Since the high rank coals have structure close to that of graphite, it is less liable to oxidation and the products contain more aromatics than aliphatic.

Broad 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 manganite ion by the following reaction:

$$MnO_4^- + MnO_4^{2-}$$

The standard electrode potential of this redox couple (E0) is 0.56V. The electrode potential (E) is related to the concentrations of manganite and permanganate ions present in the solution and is given by the following equation:

$$E = E^{\circ} - \frac{RT}{F} Ln \frac{(MnO_4^{2-})}{(MnO_4^-)}$$

Where,

R = Universal gas constant

T = Temperature

F = Faraday’s constant

When coal is added to alkaline permanganate, oxidation commences and the concentration of manganite 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 showed as carbon/ Mn_2^- , Mn_2^{2-} .

Apparatus Required:

1. Beaker
2. Saturated calomel electrode
3. Carbon electrode

4. Millivolt meter
5. Magnetic stirrer
6. magnetic fish

Experimental Procedure:

The beaker along with the electrodes is placed over a magnetic stirrer such that a homogeneous mixture of coal and alkali solution is maintained. The Teflon coated fish of the magnetic stirrer is placed inside the beaker. 0.5 g of coal sample of –212 micron size was mixed with 100 ml of decinormal 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 milivoltmeter till the potential difference attained a nearly constant value. The graphs between Time vs. EMF (millivolt) for all the samples are plotted. Different samples require different time duration for attaining a nearly constant potential difference (E). Therefore, the duration of experiment in each case is different. In order to compare the oxidation rate of various samples a stable time frame is chosen based on the analysis of the plots. In the current case it was observed that almost all the coal samples attain a constant potential difference after 25 minutes, so 25 minutes was taken as the time duration to find out the potential difference in order to make a relative study.

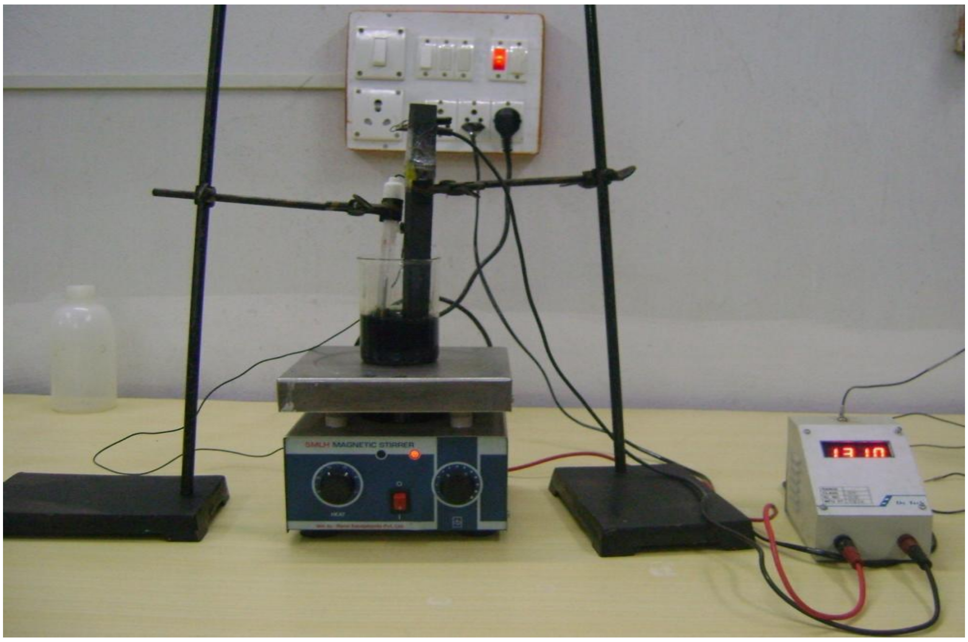

plate 3.3 wet oxidation potential apparatus

Parts of wet oxidation potential apparatus are:

1. Magnetic Stirrer
2. KMnO4, KOH and Coal Solution
3. Calomel Electrode
4. Carbon Electrode
5. Millivolt meter

3.9 BOMB CALORIMETER (IS 1350-1959)

Bomb Calorimetric:

The energy value of coal or calorific value is the amount of potential energy in coal that can be converted into actual heating ability. The value can be calculated and compared with various grades of coal or even other materials. Materials of various grades will produce differing amounts of heat for a given mass. The calorific value of coal is usually assumed by the bomb calorimeter method.

Bomb Calorimeter:

Bomb calorimeter consists of a stout cylindrical chamber known as bomb (Fig. 4.4) of stainless steel. This chamber is fitted with an air tight cover which can be screwed on the chamber. The cover has three terminals; two for sparking and one for the entry of oxygen. After forcing the oxygen into the chamber the passage can be blocked by screwing in the third terminal.

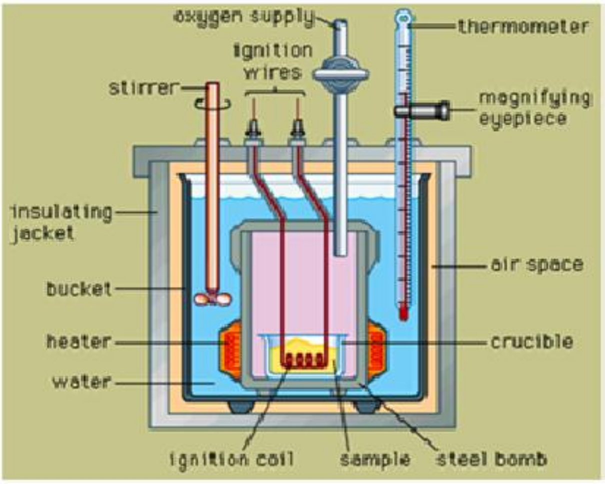

Plate 3.4 Structure of the Bomb

On the other side of the cover, there are two bent rods connected to two terminals. The bent rods have small holes through which two fuse wires are connected. There is the provision for putting the crucible containing the pellet tied to the fuse wire by means of a cotton thread. This whole set-up is placed in a bigger vessel containing a known quantity of water in it. The vessel is jacketed to minimize the heat loss by radiation. A stirrer is used for stirring the water in the bigger vessel. There is a provision for inserting the thermometer.

Experimental Procedure:

Approximately about 1gram of -212 size air dried coal sample is taken by weighing in a balance. A pellet is made with the coal and weighed. The calorimeter cover is taken and about 10 cc of distilled water is poured into it. The pellet in the crucible is brought in contact with the fuse wire by means of a thread. The cover is then tightened. Oxygen is then admitted into the calorimeter at a pressure of about 25 atmospheres. 2 liters of water is put into the bigger vessel. The thermometer is inserted into the pocket. Necessary electrical connections are made and stirrer is adjusted in the corrected position. The stirring is done gently for five minutes. The initial temperature reading is then taken. The bomb is now fired. Sparking and combustion of coal take place in the calorimeter. The maximum reached temperature is then noted. The bomb is removed and the pressure released. The bomb interior is examined for unburnt or sooty deposits. If such material is found, the test is discarded.

The GCV (Gross Calorific Value) is calculated as, GCV = $\frac{2366.5 \text{ x } \triangle T}{m}$

Where ΔT = Difference between Initial and Final Temperatures and m- the mass of the pellet. The constant 2366.5 is the specific heat capacity of water in kcal/^{0C}.

Plate 3.5 Experimental Set up of Bomb Calorimeter

Parts of Bomb Calorimeter apparatus are:

1. Calorimeter vessel
2. Bomb
3. Stirrer
4. Read out unit
5. Cover
6. Firing Cable

20gm sample of size -212 was placed in the reaction tube with glass wool at the bottom most position. The tube was then lightly tapped a fixed number of times to achieve uniform packing density of the samples. The reaction tube was then placed in the furnace and a chromel-alumel thermocouple is inserted at the centre of the sample. The furnace was switched on and simultaneously air is allowed to pass through the sample, with an average rate heating of 50C per minute and at 80ml/ min. The temperature of the furnace (bath) and the coal sample was recorded at every five minute interval till the temperature of coal crossed over and went beyond the furnace temperature.

3.10 FLAMMABILITY TEMPRETURE METHOD (Nimaje et.al., 2010)

The set up for the determination of the flammability temperature of coal consists of vertical tubular furnace of internal diameter 50mm, length 300mm, open at both ends, a dust dispersing unit, a solenoid valve a reservoir for air, a mercury manometer, a drying tower and an aspirator bulb. Coal dust sample is kept in the helical dust disperser. Air from the reservoir is made to pass through the disperser and on emergency from the divergent mount, forms a uniform dust-air mixture inside the furnace. The minimum temperature at which this mixture catches fire, which is indicated by the appearance of flame coming out of the bottom of the tubular furnace is the flammability temperature of the coal dust.

Experimental Procedure:

Place 200 mg sample of coal having mesh size -200 mesh (BSS) in a helical tube. Maintain mercury column difference of 8 cm by aspirator bulb and turn off the tap. At desired temperature of furnace, switch on the solenoid valve, which allows the air to pass through it very fast and find out the status of coal sample (spark, smoke or flame). If flame appears then find out the exact temperature in lower temperature range by trial and error method, if not then go for higher temperature range.

Plate 3.6 Flammability temperature apparatus

CRITICAL AIR BLAST (CAB) (Panigrahi et.al, 2005)

Different coals vary in their reactivity to oxygen/ air. Highly reactive coals oxidize faster and this oxidation once started may even be sustained at low temperatures. The reaction of coal with oxygen is termed as oxy-reactivity and this is determined by the critical air blast (CAB) test4. The critical air blast is a measure of the reactivity of coal to air. It is the minimum rate of air supply, which maintains combustion of closely graded coal in an ignition bed 'of specified dimensions. The more reactive the coal towards air, lower is its CAB value, and the coal is more susceptible to spontaneous heating.

EXPERIMENTAL SET-UP:

The experimental set-up for the determination of critical air blast valu~s of coal is shown in Fi!,rure1. The combustion chamber [Figure 1(b)] consists of a transparent fused silica tube having 20-cm long and internal dia of 40-mm with wall thickness of 1 mm - 2 mm. It is provided with three lugs on the inside wall of the tube to hold the metal gauge disk. Metal gauge disk is made from wire cloth having aperture of 425 f.l- 600 f.lto fit inside the combustion chamber and rest on the lugs on indentations. Heating element consists of a cylindrical frame of insulating and heat resisting material having 50-mm outside dia, 39-mm internal dia and 200-mm long, recessed so as to rest on the top of the combustion chamber. Heating is carried out using a 3-mm thickness of nickel chromium resistance wire inserted helicallyin the holes drilled inside the cylindrical frame. The resistance of the heating wire should be between *38 ohms* and ***40*** *ohms*. Heat dissipated should lie between 175 W - 185 W. Air is supplied directly from a compressor through a reservoir to damp out the pulsation. The rate of air flow through the apparatus is controlled by a needle valve on a screw clip.A gas flow metre is used to measure the rate of air flow.A dome of heat resisting glass of 75 :!:1:5mm internal dia and 190 mm :!::10 mm height is used which covers the combustion chamber. A 25-mm high and 50-mm dia tower with tubular bottom is used which is filledwith calcium oxide for drying the air before it goes to the combustion chamber.

EXPERIMENTAL PROCEDURE:

A coal bed was prepared by pouring the coal sample of +600 micron to -1.18 mm size onto the metallic wire gauge on the lugs, which act as the bed support, through a funnel in order to form a loose and uniformly packed bed in the combustion chamber. Air was supplied at the rate of 4.2 1/min to the coal sample bed and at the same time current to the heating element was switched on, so that heat dissipated in between the glowingzone had spread substantially to all periphery of the coal bed surface. At this moment, the current to the heating element was switched off and the air blast rate was reduced to a value which was thought to be slightlyabove the critical value. Air blast at this reduced rate was continued for 20 min after which it was again increased to 4.2 I/min for 20 min or till resuscitation occurred. If resuscitation takes place, the test is repeated with progressively lower air blast rate with fresh portion of sample for each new rate till the rate is found at which no resuscitation occurred. Similarly,the air blast rate at which resuscitation just occurred, is determined. In this way, two air blast rates are observed which differ by not more than 0.051/ min and are such that resuscitation occurred with one but not with the other. The critical air blast rate is that value at which resuscitation occurred. Finally, the CAB value is calculated using the following relation:

$$\text{Critical Air Blast (CAB)} = ((1549*f*V*(P + a - b)) / ((273.15 + Tw)*d))$$

Where,

P – Atmospheric pressure (mm Hg);

V – Air blast rate at which resuscitation occurs (k l/min of dry air);

d – Diameter of combustion chamber (mm); f – Gas meter correction factor (1.0);

a – Manometer pressure (mm Hg);

h – Aqueous vapour pressure at T C (mm Hg); and

Tw – Temperature of water in gas meter in C.

3.11 OLPINSKI INDEX METHOD

Reactivity of coal is different temperature. This method determines the reactivity of coal at a temperature of 230 ^{0}C. The reactivity at this temperature does not directly characterise the behaviour of coal at a temperature lying below 70^{0}C which is critical for the process of spontaneous combustion. But test has shown that coals having high reactivity index at 230^{0}c energetically react at lower temperature also. Hence susceptibility of coal towards spontaneous heating can be expressed in terms of reactivity of coal in contact with air at a temperature of 230^{0}c.

In this method liquid is heated in an electric oven to boil gently to produce temperature of 230^{0}c quinoline vapour. Small pallets are made of coal powder and heated indirectly by this vapour in an atmosphere of oxygen which passes over the coal pallet at a thermocouple inserted into the coal pallet the temperature of the pallet is noted at a regular interval of time slot the temperature vs time graph. A chart recorder work directly gives the temperature vs time graph. The rate of rise temperature at the moment of equalisation of pallet and surrounding temperature i.e. when the whole quantity of heat of reaction is consumed by the pallet for rising its temperature. It is graphically determined by drawing agent to the curve at the point corresponding to the quinoline vapour temperature. The rate of rise of temperature determined in this way is expressed in ^{0}c / min which is an indication of the spontaneous combustibility of coal. This index called as Olpinski Index, is denoted by SZa. Olpinski method makes correction for ash content of coal and express spontaneous combustion index as:

$$SZb = SZa \left(\frac{100}{100 - Aa} \right)$$

Where,

SZa: Olpinski Index

SZb: Spontaneous combustion Index free of ash

Aa: Ash content of coal expressed in percentage(%)

Suscepyibility of coal to spontaneous combustion increases with increase of SZb Index.

Plate 3.7 olpinski index apparatus

EXPERIMENTAL SET-UP:

The apparatus consists of a cylindrical glass vessel(A) of volume about 280 cc which is connected to another cylinder (B) perpendicular to it. One funnel (C) is attached to B which also acts as a condenser. A reaction tube (D) passes axially through B which can be heated by quinoline vapour. One end of a thermocouple(E) can be introduced to reach upto the central line of quinoline vessel. A glass tube (G) goes spirally over the reaction tube to release at its closed end. The combustion product goes out through the outlet (I). The apparatus is mounted over the electric oven to the heat quinoline vessel. The whole set-up placed in a fume chamber with an exhaust fan to clear the quinoline vapour out of the laboratory.

EXPERIMENTAL PROCEDURE:

The vessel is filled up to the neck with quinoline and placed over the electric oven in a fume chamber. The oven temperature is controlled to boil the quinoline (at 230^0c). Oxygen flow is maintained 80 cc per min. The thermocouple is inserted in the coal pallet to touch its bottom end. The thermocouple along with pallet is carefully introduced in the combustion tube. Next the strip chart recorder is switched on. The temperature of the pallet rises and ultimately it smolders or even burns out. As soon as smoke is visible at the gas outlet, the thermocouple is taken out. Thus for each and every pallet, time vs temperature graph is obtained. Once the quinoline attains its boiling temperature, each pallet takes about 5 to 10 minutes depending on the type of coal.

CHAPTER – 4

RESULTS AND ANALYSIS

ABSTRACTS OF EXPERIMENTS

1. PROXIMATE ANALYSIS (IS 1350 PART-1, 1984)

A. determination of moisture :
- Amount of coal : 1 g coal
- Size of coal : - 212 micron (-72 mesh)
- Heating time : 1.5 hours at 110^0 C

B.Determination of volatile matter :
- Amount of coal : 1 g of coal
- Size of coal : - 212 micron (-72 mesh)
- Heating time : 7 minutes at 900^0 C

C. Determination of ash :
- Amount of coal : 1 g of coal sample
- Size of coal : - 212 micron (-72 mesh)
- Heating time : 30 minutes at 450^0 C and 60 minutes at 850^0 C

2. WET OXIDATION POTENTIAL STUDY (TAFDAR ET.AL ,1989)
- Amount of coal : 0.5 g of coal sample
- Size of coal : -212 micron(-72 mesh)
- System : Coal + 1 N KMnO4 + 0.1 N KOH)= 100 ML

3. FLAMMABILITY TEMPERATURE (NIMAJE ET.AL., 2010)
- Amount of coal : 200 mg of coal sample
- Size of coal : -200 mesh (BSS)
- System : Coal + Air
- Volume of air : 500 ml
- Pressure of air : 8 cm of Hg

4. DTA (NIMAJE ET.AL., 2010)
- Amount of coal : 10 mg of coal sample
- Size of coal : - 212 micron (BSS)
- Heating rate : 5^0 C/min
- Hold time: 450^0 C
- System : coal + air

5. BOMB CALORIMETER (IS 1350-1959**)**

- Amount of coal : 1gm of coal sample
- Size of coal : - 212 micron (-72 mesh)
- pressure :- 300 - 400 PSI

6. OLPINSKI INDEX (KARMAKAR ET.AL ,1989**)**

- Amount of coal : 0.3 – 0.4gm of coal sample
- Size of coal : -200 B.S mesh
- Heating rate : 235^0 C/min
- Air flow rate : 200-300 ml/min

Table 4.1 List of coal samples

Si no	Sample	Name of the organization
1	WCL-1	WCL
2	WCL-2	
3	WCL- 3	
4	WCL- 4	
5	WCL -5	
6	WCL -6	
7	WCL -7	
8	WCL- 8	
9	WCL- 9	
10	WCL- 10	
11	NECL- 1	NECL
12	NECL -2	
13	NECL- 3	
14	NECL- 4	
15	NECL- 5	
16	NECL- 6	

Table 4.2 Results of proximate analysis parameters

sample	moisture	ash content		volatile matter			fixed carbon		
	ar	ar	db	ar	db	daf	ar	db	daf
WCL-1	19.83	9.9	12.34	32.73	40.83	46.57	37.54	46.83	53.43
WCL-2	15.63	19.83	23.50	30.00	35.56	46.48	34.54	40.94	53.52
WCL-3	13.5	13.9	16.07	32.43s	37.49	44.66	40.17	46.44	55.34
WCL-4	14.4	12.03	14.05	17.6	20.56	23.92	55.97	65.39	76.08
WCL-5	10.96	15.26	17.13	32.00	35.93	43.37	41.78	46.94	56.63
WCL-6	12.16	17.7	20.15	29.00	33.01	41.34	41.14	46.84	58.66
WCL-7	11.5	12.1	13.67	30.63	34.61	40.09	45.77	51.72	59.91
WCL-8	12.33	11	12.54	32.20	36.72	41.99	44.47	50.74	58.01
WCL-9	5.9	14.03	14.90	21.7	23.06	27.10	58.37	37.96	72.9
WCL-10	5.8	12.23	12.98	23.46	24.90	28.62	58.51	37.88	71.38
NECL-1	3.9	4.36	4.53	38.1	39.64	41.5	53.64	55.83	58.5
NECL-2	2.93	5.93	6.10	42.87	44.16	47.03	48.27	49.74	52.97
NECL-3	2.6	7.2	7.39	42.4	43.5	47.00	47.8	49.11	53
NECL-4	2.23	9.2	9.40	43.78	44.77	49.42	44.79	45.83	50.58
NECL-5	1.93	3.63	3.70	43.47	44.32	46.17	50.97	51.98	53.83
NECL-6	2.43	7.43	7.61	40.57	41.58	45.00	49.57	50.81	55

Table 4.3 Results of calorific value

SAMPLE	GCV (kCal/kg)	UHV (kCal/kg)	GRADE
WCL-1	5251.14	4797.26	D
WCL-2	4495.75	4006.52	E
WCL-3	5647.23	5118.8	C
WCL-4	5781.28	5252.66	C
WCL-5	5819.59	5281.64	C
WCL-6	5326.87	4779.32	D
WCL-7	6142.81	5643.2	B
WCL-8	6276.19	5680.46	B
WCL-9	6349.53	6149.66	B
WCL -10	6587.29	6411.11	A
NECL-1	6918.25	7760.26	A
NECL-2	7098.28	7677.32	A
NECL-3	6988.16	7547.6	A
NECL-4	6816.86	7322.6	A
NECL-5	7109.7	8132.72	A
NECL-6	7015.26	7539.32	A

Table 4.4 Results of wet oxidation potential

SAMPLE	EMF(mv)
WCL-1	131
WCL-2	149
WCL-3	152
WCL-4	138
WCL-5	161
WCL-6	142
WCL-7	154
WCL-8	114
WCL-9	178
WCL-10	144
NECL-1	113
NECL-2	114
NECL-3	102
NECL-4	111
NECL-5	105
NECL-6	103

Table 4.5 Results of flammability temperature

SAMPLE	TEMPERATURE AT WHICH FLAME OBSERVED(^{0}C)
WCL-1	550
WCL-2	540
WCL-3	560
WCL-4	550
WCL-5	540
WCL-6	550
WCL-7	540
WCL-8	540
WCL-9	550
WCL-10	540
NECL-1	570
NECL2	580
NECL-3	560
NECL-4	570
NECL-5	580
NECL-6	560

Table 4.6 Results of DTA-TG

sample	Stage IIA	Stage IIB	Stage II	transition temp.
WCL-1	1.160	0.711	0.991	159.99
WCL-2	1.302	0.811	0.772	135.79
WCL-3	0.703	1.017	0.836	165.83
WCL-4	0.685	0.400	0.565	133.94
WCL-5	0.593	0.945	0.746	180.16
WCL-6	0.728	0.821	0.792	146.53
WCL-7	0.648	0.585	0.614	137.49
WCL-8	0.527	0.896	0.688	157.65
WCL-9	0.262	0.573	0.378	171.51
WCL-10	0.221	0.670	0.367	184.18
NECL-1	0.243	0.985	0.445	199.55
NECL-2	0.148	0.605	0.268	216.36
NECL-3	0.142	0.484	0.243	178.85
NECL-4	0.106	0.553	0.229	193.18
NECL-5	0.378	0.519	0.433	158.63
NECL-6	0.112	0.766	0.236	206.13

Table4.7 Results of olpinski index

SAMPLE	Sza	Szb
WCL-1	5.23	0.058
WCL-2	4.51	0.049
WCL-3	4.95	0.051
WCL-4	5.35	0.060
WCL-5	4.22	0.039
WCL-6	3.98	0.048
WCL-7	4.67	0.052
WCL-8	5.13	0.062
WCL-9	4.10	0.035
WCL-10	4.68	0.047
NECL-1	4.16	0.032
NECL-2	5.29	0.065
NECL-3	5.37	0.063
NECL-4	4.27	0.045
NECL-5	3.95	0.029
NECL-6	4.19	0.038

ANALYSIS:

The following things are to be summarized from the results of all experiments:

- The calorific value of sample WCL 2 is found to be less so it has high susceptibility towards spontaneous heating.
- WCL-2 has -E grade and its proximate analysis, EMF and Flammability temperature has moderate impact for spontaneity.
- Calorific value of sample WCL-3,4 wcl-5 is found to be medium which shows that it has moderately susceptible to spontaneous heating.
- WCL-4 has -C grade coal which shows poorly susceptible in nature.
- An experimental result shows that sample WCL-10 and NECL-1,2,3,4,5,6 is poorly susceptible and WCL-4 is moderately susceptible to spontaneous heating.

- WCL-2 has low calorific value and low transition temperature which shows highly susceptible.
- An experimental result shows that sample WCL-3,4,5 is moderately susceptible and sample WCL-10 is poorly susceptible to spontaneous heating.
- Results of Flammability temperature and Calorific value of WCL- 7,8,9 shows that it is moderately susceptible to spontaneous heating.

CHAPTER – 5

DISCUSSION AND CONLUSIONS

Discussion: The susceptibility of coal to spontaneous combustion depends on its intrinsic properties. Therefore, susceptibility studies have been carried out between the different susceptibility indices such as wet oxidation potential, differential thermal analysis and flammability temperature. The susceptibility indices are taken as dependent variables and each constituent obtained from the proximate and ultimate analyses as an independent variable. In general following things are to be noted from the results of all experiments:

- The highest moisture content was found to be in WCL-2 which is 19.83% as the seam is watery in nature.
- WCL-10 and NECL-1,2,3,4,5,6 have the highest GCV (higher rank coal) which shows that it has low susceptibility towards spontaneous heating.
- WCL-2 and WCL-6 have low GCV value which shows that they are lower rank coals and have higher susceptibility than other coals.
- DTA results show that wcl-2 is the highest susceptible sample but the transition temperature is also high.
- NECL-5 is the least susceptible with a reasonably high transition temperature.
- The calorific value of WCL-2 is found to be less so it has high susceptibility towards spontaneous heating.
- WCL-2 has -E grade and its proximate analysis, EMF and Flammability temperature has moderate impact for spontaneity.
- Calorific value of WCL-7 is found to be medium which shows that it has moderately susceptible to spontaneous heating.
- WCL-3 has -C grade coal which shows poorly susceptible in nature.
- An experimental result shows that NECL-5 is poorly susceptible and WCL-9 is moderately susceptible to spontaneous heating.
- NECL-5 shows poor impact towards spontaneous combustion of coal.
- WCL-2 has low calorific value and low transition temperature which shows highly susceptible.

- An experimental result shows that WCL-3 is moderately susceptible and WCL-8 is poorly susceptible to spontaneous heating.
- Results of Flammability temperature and Calorific value of WCL-4 shows that it is moderately susceptible to spontaneous heating.

CONCLUSIONS:

The following conclusions are drawn from the analysis of sixteen coal samples collected from WCL and NECL:

1. Different graphs plotted between various parameters of experimental results show that
    - The moisture content of coal decreases with increase in transition temperature.
    - The calorific value of coal increases with increase in transition temperature.
2. Observations and experimental results shows that the coal samples collected from the field are classified into the following category.
    - Highly susceptible to spontaneous heating: WCL-2,1,6.
    - Moderately susceptible to spontaneous heating: WCL-3,4,5,9 .
    - Poorly susceptible to spontaneous heating: WCL-10, NECL-1,2,3,4,5,6 .

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APPENDIX

APPENDIX 1 –WET OXIDATION CURVES
APPENDIX 2 –OLPINSKI INDEX CURVES
APPENDIX 3 –DTA-TG CURVES

APPENDIX 1

WET OXIDATION CURVES

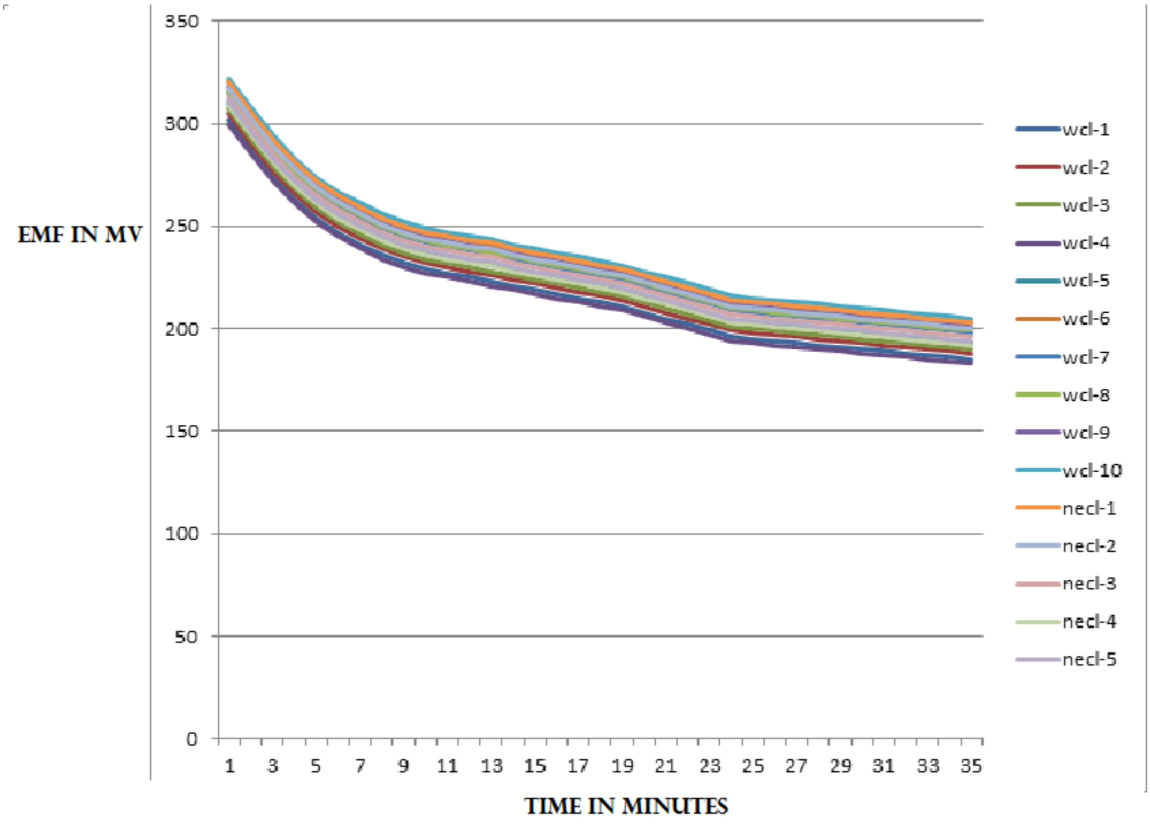

Fig A1 Wet oxidation potential curve for the samples

APPENDIX 2

OLPINSKI INDEX CURVES

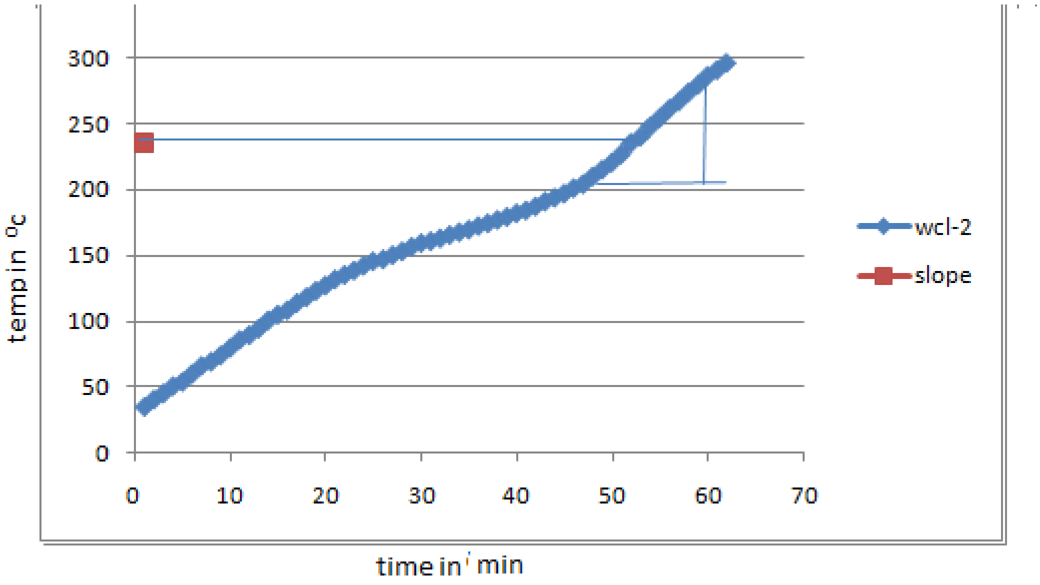

Fig A2 OLIPINSKI INDEX curve of wcl-2

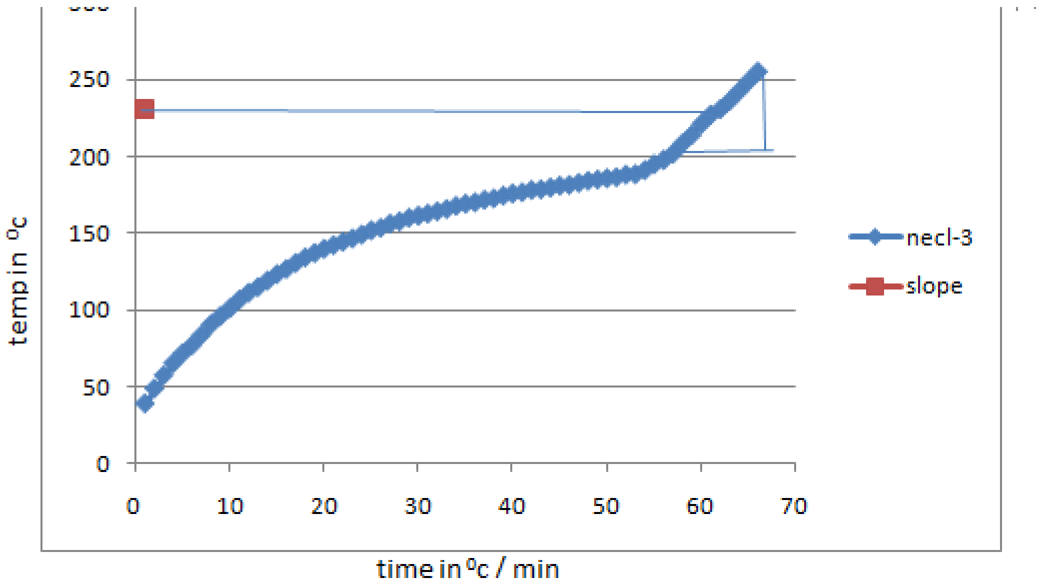

Fig A3 OLIPINSKI INDEX curve of NECL-3

APPENDIX 3

DTA-TG CURVES

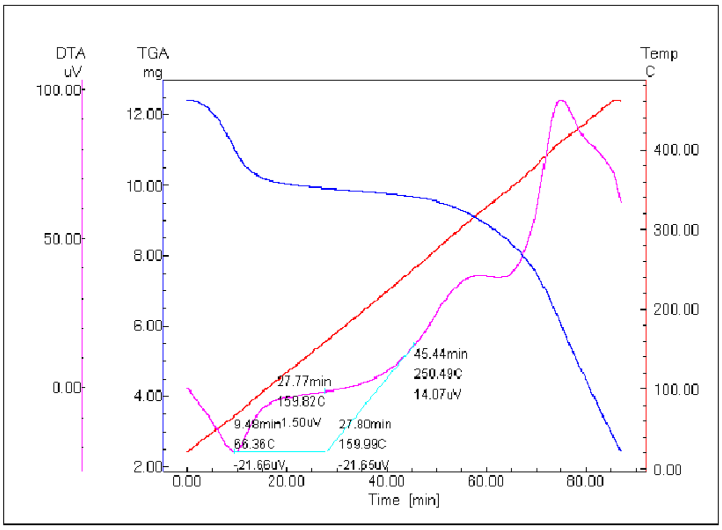

Fig A4 DTA–TG curve of wcl-1

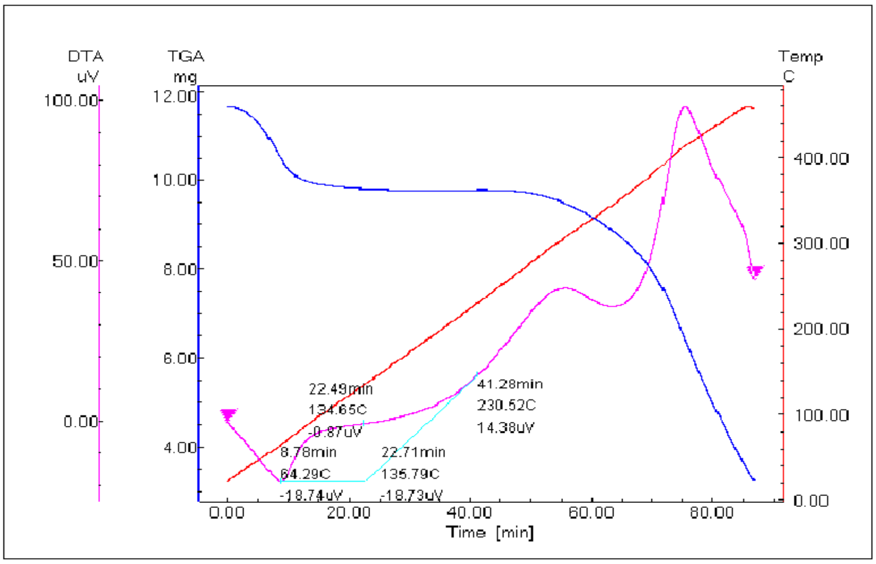

Fig A5 DTA – TG curve of wcl-2

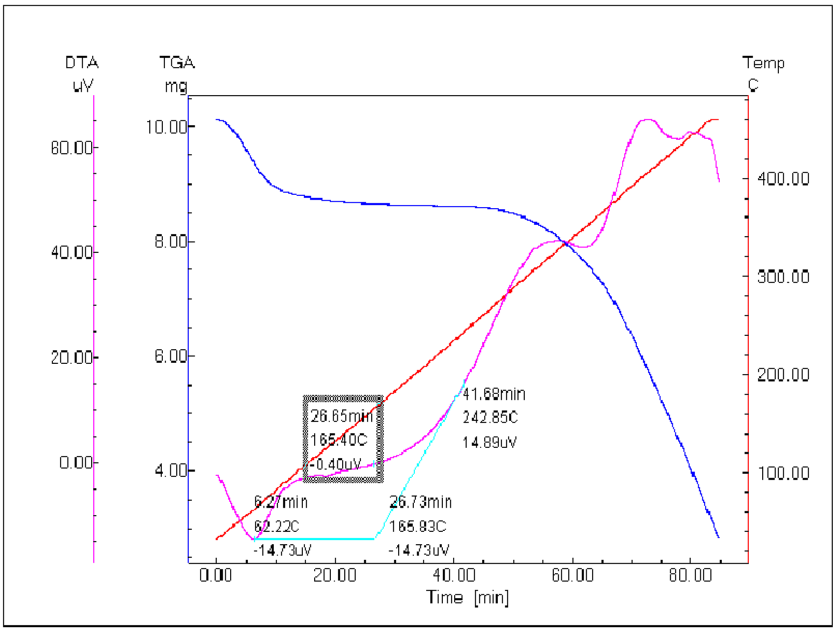

Fig A6 DTA – TG curve of wcl-3

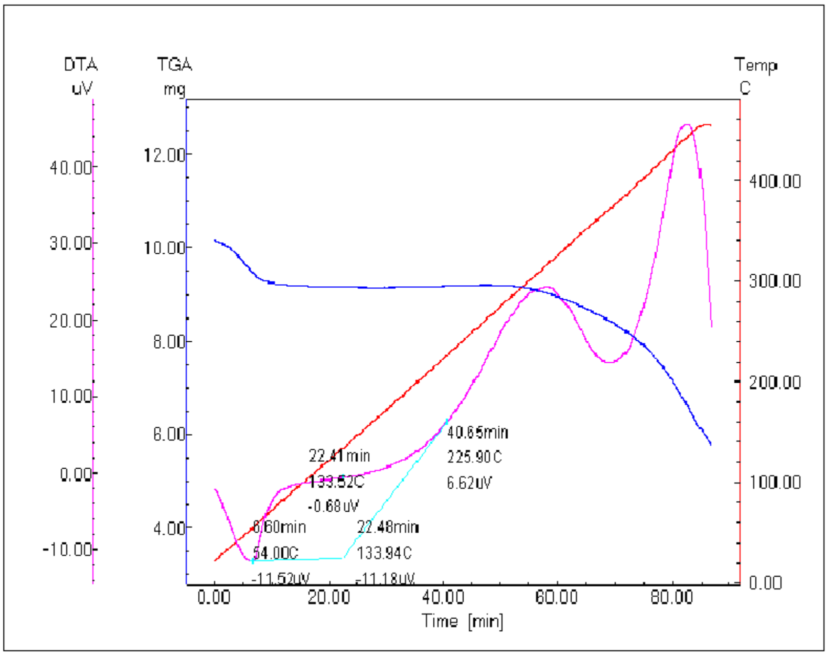

Fig A7 DTA – TG curve of wcl-4

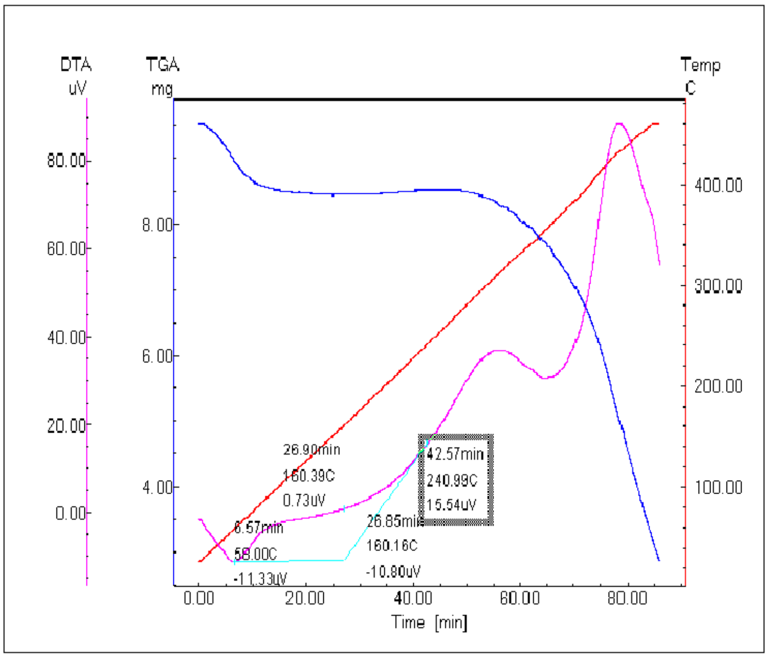

Fig A8 DTA – TG curve of wcl-5

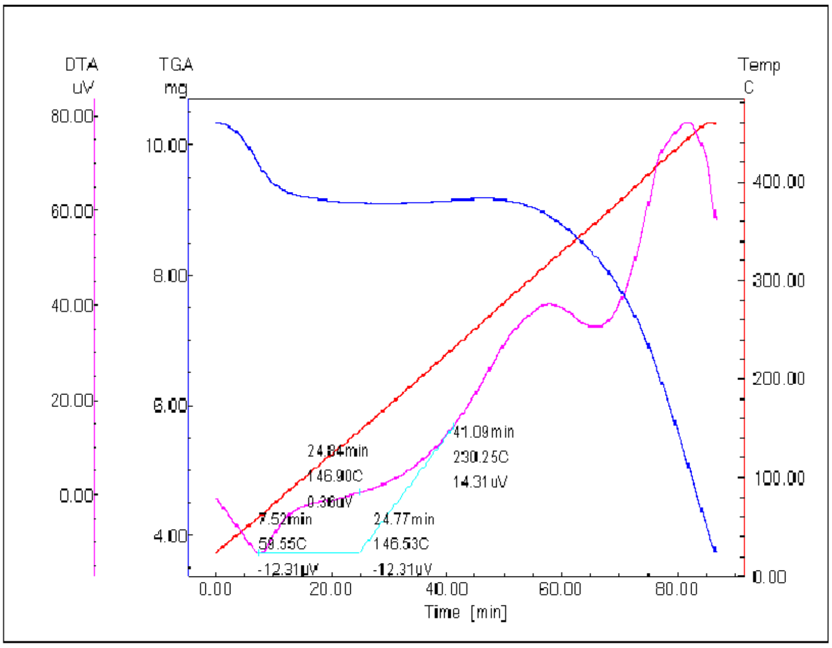

Fig A9 DTA – TG curve of wcl-6

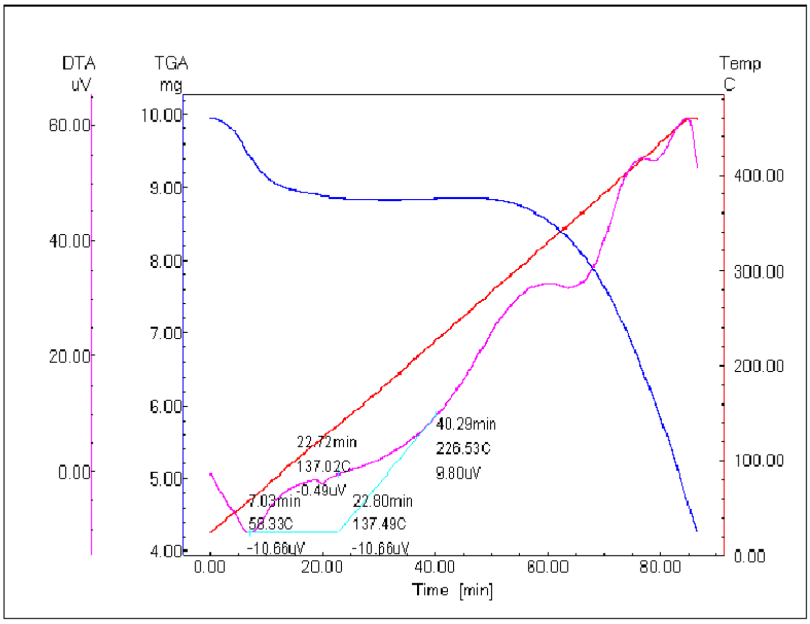

Fig A10 DTA – TG curve of WCL-7

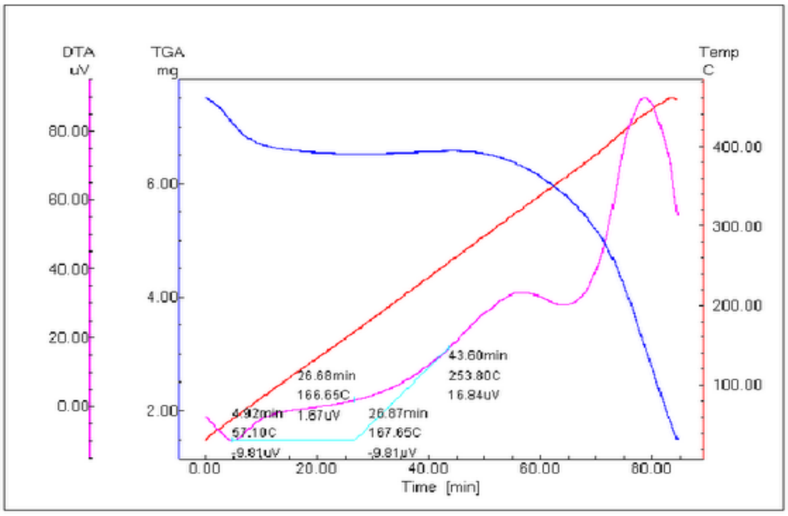

Fig A11 DTA – TG curve of wcl-8

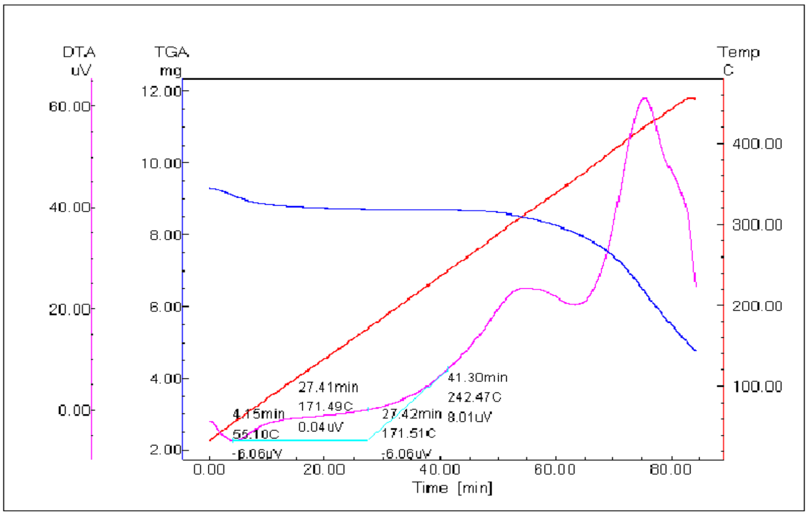

Fig A12 DTA – TG curve of wcl-9

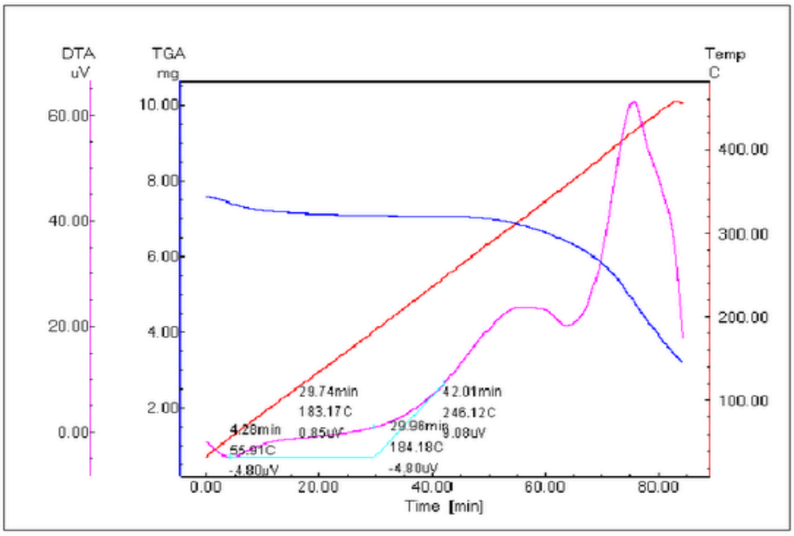

Fig A13 DTA – TG curve of wcl-10

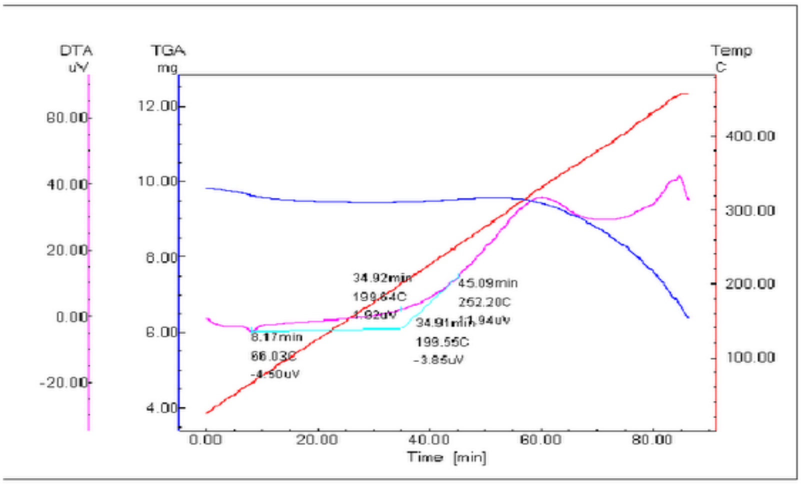

Fig A14 DTA – TG curve of necl-1

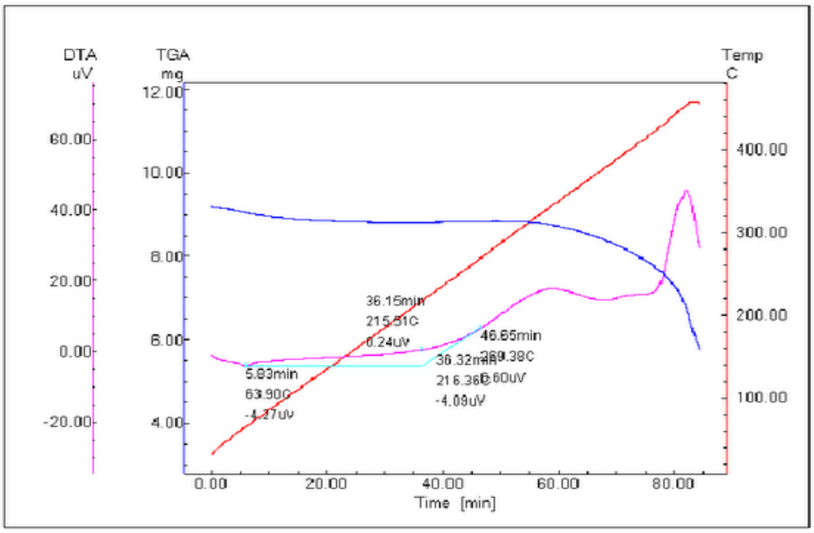

Fig A15 DTA – TG curve of necl-2

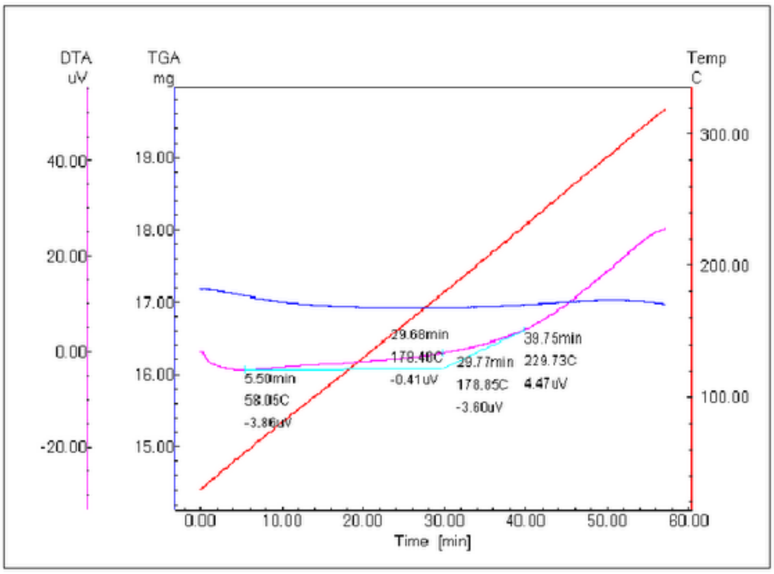

Fig A16 DTA–TG curve of necl-3

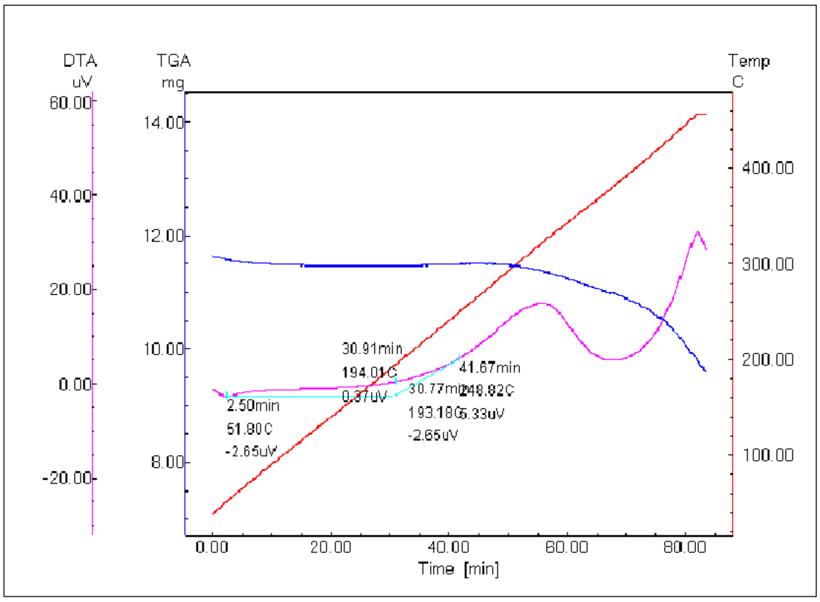

Fig A17 DTA – TG curve of necl-4

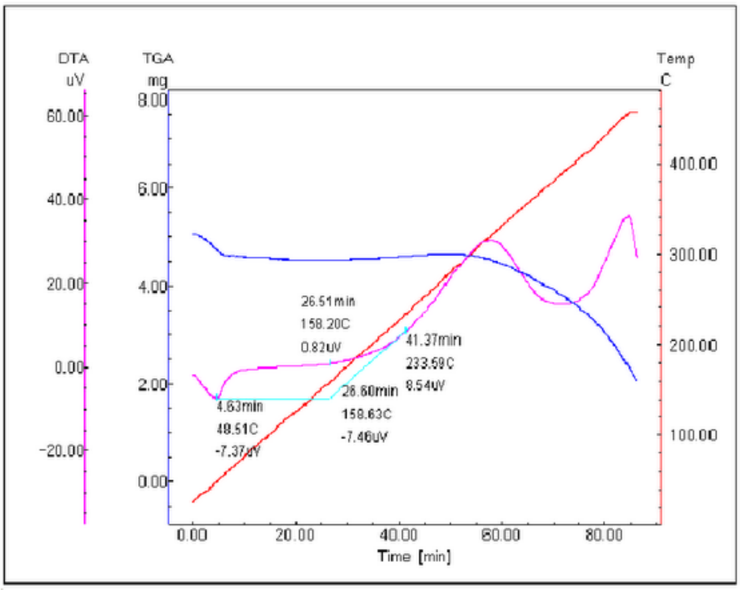

Fig A18 DTA – TG curve of necl-5

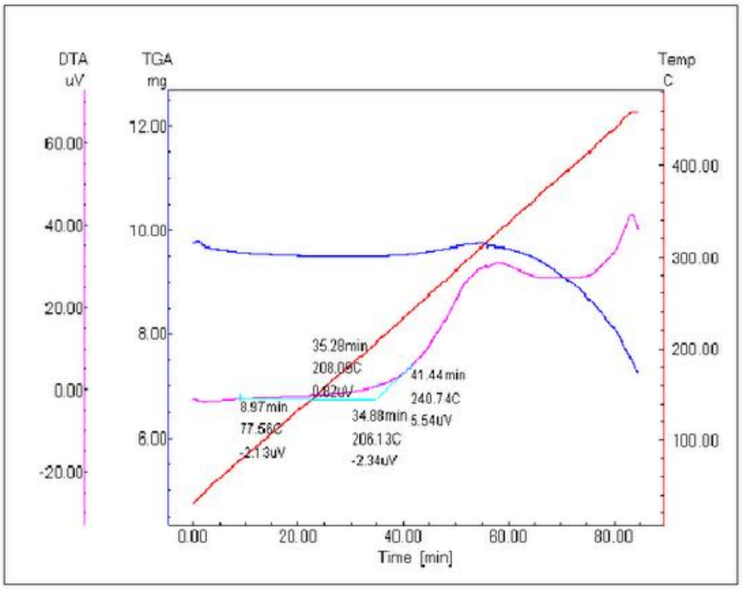

Fig A19 DTA – TG curve of necl-6