APPLICATION OF CHEMICAL INHIBITORS ON SPONTANEOUS HEATING OF SOME INDIAN COAL

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

BACHELOR OF TECHNOLOGY

IN

MINING ENGINEERING

BY

SOURABH KUMAR KACHARIYA

110MN0508

DEPARTMENT OF MINING ENGINEERING

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UNDER THE GUIDANCE OF

PROF. D. S. NIMAJE

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CERTIFICATE

This is to certify that the thesis entitled "**APPLICATION OF CHEMICAL INHIBITORS ON SPONTANEOUS HEATING OF SOME INDIAN COAL**" submitted by Sourabh Kumar Kachariya (Roll No. 110MN0508) in partial fulfillment of the requirements for the award of Bachelor of Technology degree in Mining Engineering at the 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 this thesis has not formed the basis for the award of any Degree or Diploma or similar title of any University or Institution.

Date: 9th May, 2014

Prof. D.S. Nimaje
Assistant Professor
Dept. of Mining Engineering
National Institute of Technology
Rourkela – 769008

CONTENT

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ABSTRACT

The Spontaneous combustion is a resultant of oxidation reaction that generally happens without an exterior heat source applied. The course alters the internal heat profile of the material, thus leading to an increase in temperature. Thus, the auto oxidation of generally leads to accumulation of heat energy in the coal, which if not decelerated lead to accidents like mine fire. The proper prediction, assessment of the spontaneous heating is very important, and serves as a very vital role in the whole mining industry. The need for prediction, assessment and suppression of the spontaneous heating of coal is important for the efficient working and better production of the mine. Thus the suppression of spontaneous plays an important role in welfare of the mine and workers. For the suppression of the spontaneous combustion, the inhibitors can be applied on surface of the coal. The complex nature of the coal makes the selection of the chemical inhibitor a difficult task. Selecting a particular inhibitor from the set of chemical available, to perform the task of retardation of the spontaneous heating tendency, requires a tedious set of experiments to be done.

In the present task, ten samples were collected from different coalfields of Indian like MCL (Mahanadi coalfield Limited) and CCL (Central coalfield Limited), to perform a set of experiments to find the nature of chemical inhibitor on the susceptibility of coal toward spontaneous heating. The rationality of the experimental approach was validated by measuring several performance metrics of the collected samples with and without a chemical inhibitor, including flammability experiment. Therefore the fundamental properties as well as spontaneous heating susceptibility indices of the coal samples were concluded by subsequent experimental techniques like proximate analysis, Gross calorific value and Flammability temperature

These set of experimental techniques helped to point out that the chemical inhibitor selected by means of the proposed approach efficiently slows the oxidation of coal, thus signifying the rationality of the selection technique. After the experiments carried out along with the chemical inhibitors like NaCl, Na_2CO_3, $CaCO_3$, $CaCl_2$ and Dolerite, NaCl and $CaCO_3$ was found to be the very efficient in decreasing the susceptibility of the coal toward spontaneous heating.

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Chapter 1

INTRODUCTION

INTRODUCTION

1.1 BACKGROUND

Coal has turn out to be a significant part of the modern economy of the world. For its major contribution in the direction of the energy sector, make it a very significant natural resource. In the present scenario India is 3rd ranked in the production of coal with an output of 605.8 million tonnes, sharing about 7.7 % of world production [22]. Mine fire accidents in the Indian coalfields are usually initiated by spontaneous combustion of coal notwithstanding various precautionary measures being taken. A coal mine fire is a severe hazard to the Indian coal mining industry. In India every year many mine fire happenings take place in the surface plus underground because of spontaneous combustion. This threat has been prevailing in India for a number of years now. Investigation of the reasons of the coal mine fires disclose that they initiate either from an open fire over the exterior mining agencies or initiate due to erratic nature of coal.

The main feature of a starting of a mine fire in India is, since the coal seams are thicker and there is an inclination of spontaneous heating in the course of the depillaring operation. The difficulty of mining of thick seam and the standing coal pillars is a grave danger when coal has high moisture, high volatile matter and low ash content which is further responsible to spontaneous combustion. It is unfeasible to be capable of mining all the coal by caving method. Pillars standing for extended time period are accountable to depreciate and falling may occur in future.

The coal mine fire is a chief matter of concern for the global coal mining industry for decades. It has demonstrated to be a chief problem globally, resulting in the disastrous accident taking the life of many people associated with the mining industry, exclusively in coal rich nations such as India and China. These catastrophic mine fires have severe financial, social and environmental impacts. They not only burden the economy but also endanger precious life. The coal mine fire have a severe health and safety hazard besides disturbing the environment by discharging toxic fumes, harming and destroying the machines, ventilation system, schedule production and even causes the subsidence of surface structures such as railway line, buildings, roads, pipelines structures, bridges ,electric lines and most importantly residential areas.

1.2 CONCEPT OF SPONTANEOUS HEATING

Due to the spontaneous heating susceptibility nature of the coal, its auto oxidation process have become complex physico-chemical process in which simultaneous and immediate reactions takes place which becomes a difficult task to control, resulting to the release of heat energy and eventually resulting in the mine fire. The spontaneous combustion of coal fluctuates over a varied range and it is significant to evaluate the degree of proneness for taking precautionary procedures in contradiction of the occurrence of fires to evade the fatalities experienced by the organization (Pal et al.2012). The rate of coal oxidation gives the extent of liability of coal towards spontaneous heating. The spontaneous combustion of coal fluctuates over a varied range and it is significant to evaluate their degree of proneness for taking precautionary measures against the happening of fires to evade the losses suffered by the organization. The rate of oxidation of coal provides the degree of susceptibility of coal towards spontaneous heating.

Though it a chemically reactive substance. It reacts with the oxygen present in the atmosphere and generates the heat energy. The spontaneous combustion of coal occurs when heat, which is produced by the low-temperature oxidation of the coal, is not adequately dissipated. The reason behind the self-ignition of coal is for of heat buildup. When coal is oxidized by oxygen in air and produces weak heat, if the heat production rate is larger than dissipated heat rate, then the coal bed gets heated up, so the temperature rises progressively, and then, the coal self-ignites. The procedure and phenomenon are known as the spontaneous combustion of coal. This results in a net temperature increase in the coal mass that can lead to a fire. This generation of heat energy can lead to accidents like mine fire, subsidence etc. It is not only harmful to working environment but also create a major production hitch. It creates both working and health hazard, which need to be minimized.

1.3 CONCEPT OF ASSESSMENT AND INHIBITION

The appropriate prediction, assessment of the spontaneous heating is very important, and serves as a very vital role in the whole mining industry. The need for prediction, assessment and suppression of the spontaneous heating of coal is important for the efficient working and better production of the mine. Thus the suppression of spontaneous plays an important role in welfare of the mine and workers. The knowledge in checking spontaneous combustion of coal is to avoid

the four conditions not exist at the same time. These four conditions are cracked coal, oxidation, and long time period and heat accumulation. The hindrance approaches can be divided two classes: firstly by physical method and secondly by chemical method (Wei Lu et al., 2009). The physical inhibition method uses the physical principles to retard the spontaneous combustion of coal, generally isolating the oxygen and letting heat lost faster. However the physical method is not always the appropriate approach. Sometimes due to air leak through fissure can lead to spontaneous heating. Using chemicals to inhibit the nature of their spontaneous heating is a significant approach.

For the suppression of the spontaneous combustion the inhibitors can be applied on surface of the coal. The complex nature of the coal makes the selection of the chemical inhibitor a difficult task. Now days, the chemical inhibitors are extensively used to avoid or extinguish coal mine fires and have been successfully applied for these purposes. Presently, a widespread range of inorganic salts like $NaCl$, $CaCO_3$, Na_2CO_3 and $CaCl_2$ have been well-thought-out for use in this role. These inhibitors, though, slow down coal oxidation simply by generating a barrier to oxygen and by the adsorption of water. Consequently, these compounds naturally show low efficiency and small active lifetimes. In recent times, other various chemical substances that have been used to check coal self-oxidation have been found to both reduces the degree of creation of reactive species or to obstruct the free radical reactions related with ignition.

To verify the liability of inhibition of the spontaneous heating if coal by chemical inhibitors various experimental techniques have been adopted by the researchers across the globe. Some of these includes Differential thermal analysis (Nimaje et al., 2010), Crossing point temperature method (Didari et al., 2000), Flammability temperature method (Nimaje et al., 2010), Wet oxidation potential method. These experimental techniques are drawn to find out the competence of the inhibitors on the retardation of spontaneous combustion. Numerous methods have been developed over the years to evaluate the rate of proneness of coal toward spontaneous heating. This tendency to self-heating of coal furthermore decides the total incubation period of coal seams, which accordingly determines the size of the panel to be designed, which is a very imperative safety measure in the planning of the mine. It is thus commanding that the planners of a mine decide beforehand the spontaneous heating susceptibility of the seam chosen to be mined

so that it determines whether the extraction of the coal seam should be done before the incubation period, or take the precautionary measures to challenge the hazard.

1.4 OBJECTIVES

The main objective of the project was to choose the most effective chemical inhibitors which retard the spontaneous heating susceptibility of the coal and correlate its experimental outcomes with Flammability temperature and Gross calorific value.

To achieve the objective of the project, the following methodology was adopted:-

- ❖ Literature review: All past research work carried out by researchers, academicians, scientist etc. related to present topic was reviewed to gain some knowledge.
- ❖ Sample collection: Ten samples were collected from different coalfields of India like MCL and CCL
- ❖ Experimentation : The experimentation part was completed in three steps
    - ✓ Proximate analysis: To determine the parameters of proximate analysis like M, VM and Ash of the collected coal samples.
    - ✓ Calorific value determination: To determine the gross calorific value of the collected coal
    - ✓ Flammability temperature: To determine the susceptibility of coal toward spontaneous heating of the collected coal samples.
- ❖ Analysis: Statistical analysis was carried out among the inhibitors concentration and the Flammability temperature and find out the best correlation.

Chapter 2

LITERATURE REVIEW

LITERATURE REVIEW

2.1 SPONTANEOUS HEATING MECHANISM

The coal oxidation is a heat releasing process in nature. The environment of the interaction amid coal and oxygen at very much lower temperatures is just a physical process that is adsorption and alters into a Chemisorption form beginning from a particular ambient temperature. When the coal is opened to air it absorbs the oxygen on the exposed exterior than it reacts with it. About some portion of the unprotected surface absorbs oxygen at a quicker rate than others and the whole oxidation procedure results in the creation of gases and heat energy. Primarily CO, CO_2, water vapor along with the evolution of heat while the chemical reaction is the result of the oxidation process. Recently exposed surfaces of coal put away oxygen at a comparatively greater rate. It then falls very leisurely over time without taking much difficultly if caused. The heat is permitted to accumulate in the atmosphere. Usually, self-ignition of the coal is thought to happen when the thermal equilibrium amid the amount of heat dissipated to the ambient air and the amount of heat generated becomes unbalanced. Thus the much higher rate of heat production than the heat dissipated, results in the rise of the temperature of the coal, resulting in the coal mine fire.

The degree of oxidation at ambient temperature determines portion of the proneness of coal toward auto-oxidation. This low temperature oxidation of coal is not an unusual chemical procedure but a complex phenomenon that usually is comprised of several instantaneous chemical courses which effect equally in erosive material elimination and structural modification of the organic matter. A huge number of steady chemical chain reactions occur due to numerous carbons' oxidation states and a diversity of strong carbon oxygen complex is made. The obvious compositional, elemental as well as structural alteration discloses that the oxygen's reaction with solid coal is a time reliant dynamic method (Xilin et al. 1997) .Noticeable deviations in coal molecular structure and composition rises from persistent sequence of the events whose constituents disclose a complex inter dependent relationship. Therefore the reaction atmosphere is assorted intrinsically since two bulk stages, solid and gas is present and extrinsically as many structural variations carried by the reaction, impacts the overall coal reactivity. Coal becomes heated up on absorbing oxygen, whose disintegration occurrence can be expressed in the manner

that, the oxidation is very sluggish below 50^0C and hastens above it, but then again above 80^0C, a time period of stable state is retained, perhaps due to the elimination of moisture from coal. The elimination of oxides of carbon happens from 120^0C. The contact of oxygen with coal quickens swiftly up to 180^0C and then the thermal disintegration starts in the middle of 180^0C to 220^0C. Self-persistent course of combustion instigates in amid 220^0C to 275^0C with very sudden increase of temperature till the ignition point is achieved.

Active Combustion Leading to Ignition ($>275^0$)

Self Sustained Process of Combustion (275)

Thermal Decomposition (220^0C)

Evolution of oxides of carbon (180^0C)

Steady State Oxidation due to Moisture Removal (120^0C)

Comparitively Accelerated Oxidation (80^0C)

Very Slow Oxidation (upto 50^0C)

Coal + Oxygen
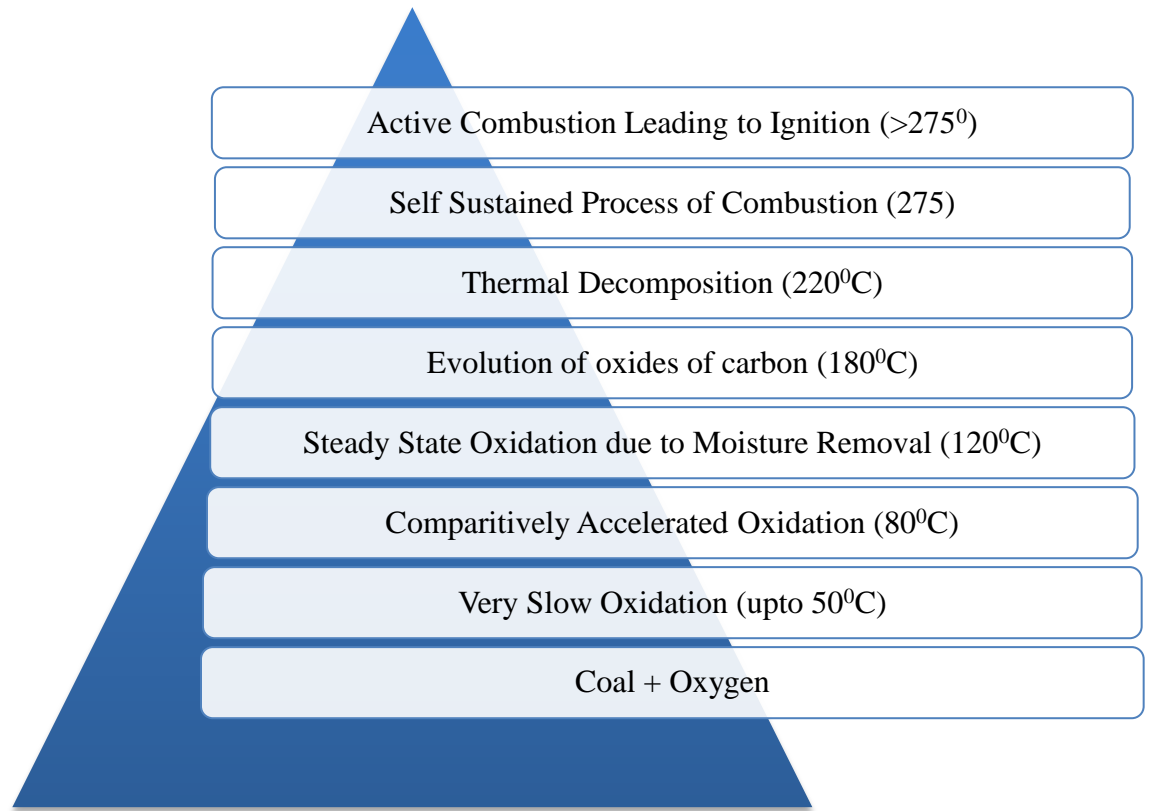
Fig 2.1 Stages in Spontaneous Heating of Coal

2.2 FACTORS AFFECTING SPONTANEOUS HEATING

The foremost cause for the complications in understanding the whole mechanism of spontaneous combustion is the existence of numerous internal and external parameters affecting the commencement and development of the phenomenon. These aspects have been studied by various researchers (Kroger et al., 1962; Guney, 1968; Chamberlain et al., 1973; Feng et al., 1973; Beier, 1973; Kim, 1977; Banerjee1982; Didari, 1988). The key factors which have major effects on the course are summarized hereafter.

2.2.1 INTRINSIC FACTORS (Kroger et al., 1962)– These factors are mostly associated to nature of coal

- ❖ Pyrites – The pyrite content rises the affinity of spontaneous heating increases.
- ❖ Inherent moisture – Alterations in moisture content such as drying or wetting of coal have major effects.
- ❖ Particle size and surface area – As particle size reduces the exposed surface area increases and the liability toward spontaneous heating also increases.
- ❖ Rank and Petrographic components – Lower rank coals are more susceptible to spontaneous heating than higher rank coal.
- ❖ Chemical constituents – Ash generally decreases accountability for spontaneous heating but then again definite parts of ash such as lime and soda have escalating effect whereas alumina and silica have hindering effects.
- ❖ Mineral matter – Few chemicals stimulate an others inhibit spontaneous heating.

2.2.2 EXTRINSIC FACTORS (Kroger et al., 1962) – These are the factors which are mostly associated to atmospheric, mining and geological parameters

- ❖ Temperature – Higher immediate temperature leads to rise in oxidation procedure and finally to spontaneous heating of coal.
- ❖ Extraneous moisture – Vaporization of exterior moisture leads to discharge of heat of wetting, which helps in the temperature rise and increases spontaneous heating susceptibility.
- ❖ Oxygen concentration –More the oxygen concentration in the atmosphere, more rapid will be the oxidation process.
- ❖ Coal seam and surrounding strata – Occurrence of faults that gives the passage of air and oxygen to react with the coal, which generally increases the rate of heating.
- ❖ Method of working, ventilation and air flow rate – The type of mining methods such as bord and pillar mining that leaves behind some pillars have higher spontaneous heating chances than longwall methods. Air flow rate panels heating to a large extent.
- ❖ Timbering, roadways, bacteria and barometric pressure – Presence of substance that can decompose like timbers in the mines leads to the hazard of catching fire, which deliver the adequate heat mandatory for spontaneous heating of coal.

2.2.3 MINING FACTORS (Morris et al., 1986)

i) Mining Methods

ii) Rate of Advance

iii) Pillar Conditions

iv) Roof Conditions

v) Crushing

vi) Packing

vii) Effect of Timber

viii) Roadways

ix) Leakage

x) Multi Seam Workings

xi) Coal Losses

xii) Main Roads

xiii) Worked-out areas

xiv) Heat from Machines

xv) Stowing

xvi) Ventilations Pressure

xvii) Barometric Pressure

xviii) Change in Humidity

2.2.4 GEOLOGICAL FACTORS (Morris et al., 1986)

i) Seam thickness

ii) Seam gradient

iii) Caving characteristics

iv) Faulting

v) Coal Outbursts

vi) Friability

vii) Depth of cover

viii) Geothermal Gradient

2.2.5 SEAM FACTORS (Morris et al., 1988)

i) Rank

ii) Petrographic Composition

iii) Temperature

iv) Available air

v) Particle Size/Surface Area

vi) Moisture

vii) Sulphur

viii) Ash/Mineral Matter

ix) The effect of previous oxidation or heating

x) Physical Properties

xi) Heating due to earth movement

xii) Bacteria

xiii) Pyrite Content

xiv) Thermal Conductivity

2.3 ROLE OF INHIBITORS IN SPONTANEOUS COMBUSTION

The need for prediction, assessment and suppression of the spontaneous heating of coal is important for the efficient working and better production of the mine. Thus the suppression of spontaneous plays an important role in welfare of the mine and workers. This can be done the application of the chemical agents to retard the spontaneous heating tendency.

In the context to the given project, inhibitors are the chemical liquids or salts that help in the retardation of the spontaneous heating tendency of the coal. They aid in reducing the spontaneous combustion in the presence of atmospheric oxygen. Intended for the suppression of the spontaneous combustion the inhibitors can be applied on surface of the coal. The complex nature of the coal makes the choice of the chemical inhibitor a challenging task. This tendency to self-heating of coal furthermore decides the total incubation period of coal seams, which accordingly determines the size of the panel to be designed, which is a very imperative safety measure in the planning of the mine.

Recently, the chemical inhibitors are broadly used to evade or quench coal mine fires and have been positively applied for these purposes. Currently, an extensive range of inorganic salts have been well-thought-out for use in this role. These inhibitors however, slow down coal oxidation just by causing a barrier to oxygen and by the adsorption of water. Subsequently, these compounds certainly illustrate low efficiency and small active lifetimes (Wei lu et al. 2009). Lately, other a number of chemical substances that have been used to check coal self-oxidation have been found to both moderates the degree of creation of reactive species or to hinder the free radical reactions related with ignition.

The effect of addition of the chemical inhibitors were experimentally found by the undergoing the flammability temperature test of the coal samples. The samples were undergone, the flammability temperature test without and with the chemical additives/inhibitor at different concentration. The chemical additives that shifts the flammability temperature to maximum related to its normal flammability temperature, was found to be better inhibitor, related to retarding the spontaneous heating tendency of the coal. The inhibitor that increases the FT to maximum with respect to initial Flammability Temperature serves as a better inhibitor.

2.4 NATIONAL AND INTERNATIONAL STATUS

Ghosh et al. (1985): Ghosh made an effort to develop a process to identify degree of liability of coal toward the spontaneous combustion of coal. It was found out that if pyrite was existing in a coal, in finely divided form, then the proneness of coals for spontaneous combustion upsurges besides the temperature of a coal bed rises if water was added to it, which be likely to point out that water spraying or else even flooding could not be deliberated as an effective step to regulate the spontaneous combustion of coal. Furthermore, it was also recommended that if coal is ice-cold (to −193°C) the micro pores and micro cracks in the coal are probably tapered. The oxygen is less expected to move in the coal over these micro pores and micro cracks and hereafter likelihoods of spontaneous combustion due to auto - oxidation is reduced.

Smith, Alex C et al. (1988): United States Bureau of Mines, conducted a test to assess the ten additives/inhibitors toward the self-heating tendency of coal. The high spontaneous heating capacity bituminous coal samples were tested to these aqueous additives. The additive that pushes the most minimum self-heating temperature was found to be a better inhibitor. The comparative alteration in the SHT or the time required to reach the sample temperature of 150^0C determined the efficiency of the inhibitors that is the coal with and without the additives. Various additives like sodium chloride, ammonium chloride, sodium acetate were found to be found to be effective. DSC experiments were conducted to verify the effectives of the inhibitor.

Gouws et al. (1990): An adiabatic calorimeter was designed to assist the spontaneous combustion affinity of coal to be recognized. Several indicators of self-heating possibilities were found, for example total temperature rise, primary rate of heating, minimum self-heating temperature, and kinetic constants were examined. Consequences gained from the adiabatic tests were associated with the outcomes of crossing-point temperature (CPT) determinations and differential thermal analysis (DTA) tests for the same coals, with an opinion to expressing a mathematically reliable spontaneous combustion liability index. The paper focused on the chief constituents of the adiabatic calorimeter.

Dong Xilin et al. (1997): The work was centered on identification of an active inhibitor to check the self-heating and spontaneous ignition tendency of coal, from the consequence of a number of retardants on the bituminous coal was scrutinized experimentally in a pre-programmed controlled temperature oven. The minimum instigation energy of coal reacted with inhibitors has been assessed in the temperature range of 60^0C to 220^0C through the Frank-Kamenetskii model and the rate of temperature rise. Many aspects persuading the inhibition effect are measured. From the investigational results, a kinetic explanation of the hindrance mechanism was stated concerning mutually radical reaction and active center theories. It was found that there were probably two rules for the explanation of oxidation of a bituminous coal in the temperature range studied, through a chemically influenced rule and other with a combination of pore-diffusion ability and chemically measured rule.

Sujanti et al. (1998): A laboratory analysis was conducted to find out the consequence of inorganic matter on the spontaneous combustion activities of coal. The total of 14 samples were arranged and mixed with the set of 11 inhibitors to find out there tendency toward spontaneous heating. All of the samples were then conducted experiment in an isothermal reactor to acquire its critical ambient temperature beyond which spontaneous heating generally occurred. Potassium chloride and sodium chloride were noted to be the most active inhibitors, tailed by magnesium acetate, and calcium chloride in the effectiveness process.

Watanabe et al. (2001): The examination of the effect of the inherent added inorganic matter was done on the low temperature oxidation of coal. The overall efficiency of the inhibitors on suppressing the spontaneous heating was also found. Of the various inhibitors used the effectiveness was found in this manner respectively, NaCl, $CaCl_2$ and $MgCl_2$ while some of them were found to escalate the oxidation process, like $Cu(Ac)_2$, KAc and NaAc.

Panigrahi et al. (2005): Detail laboratory experimentation was done to assess the suitability of the inhibitors to retard the spontaneous combustion features of coal. The experimental investigation showed that 5% aqueous solution of some of these inhibitors will demonstrate an acceptable results in hindering the spontaneous combustion characteristics of the given coal samples.

Beamish et al. (2008): Beamish and associates conducted test on a huge number of the Australian and New Zealand coal sample. They conducted an adiabatic test on the coal sample to determine the self -heating rate of the samples. A third order polynomial was found to the correlation between the spontaneous combustion of the sample and rank of the coal. It was found that steaming coals had higher self-heating rates than coking coals. They also tried to find out the influence of mineral matter on the spontaneous combustion tendency.

Wei lu et al. (2009): The study was based on the concept that different active structures need different activation energy to follow the spontaneous combustion process. The focus on the detail study of the mechanism of the spontaneous combustion of coal was carried out. They developed a theory to initially inhibit the coal sample by deactivating the coal structures with lower activation energy toward the oxidation. Thus the coal will not self-ignite at lower activation energy or at lower temperature.it was found that chemical inhibition of the coal sample did not change the environment change, so the process was irreversible. The affinity of coal to again re-ignite due to oxidation also decreased.

Nimaje et al. (2010): The thermal study on spontaneous combustion of the coal was conducted. It was found that out of the various experimental methods developed, the role of the thermal studies was significant and prevailing in evaluating the spontaneous heating liability of the coal. A detail synopsis was made on thermal studies done by numerous researchers throughout the world for finding out the spontaneous heating liability of the coal and shown that it had a lot of importance on experimental procedures, which is essential for developing suitable approaches and efficient plans before hand to inhibit happening and spread of fire.

Shui-jun et al. (2011): The study was carried out to find out the effect of organic and inorganic additive/inhibitors toward the spontaneous combustion characters of the coal. A personally furnished small-sized experimentation platform was created with an advanced gas analyzer PG-250A, which was used to determine the alteration in concentration of CO released by the three types of coals of dissimilar in the process of self-oxidation at much a low temperature like $150^{o}C$ was examined constantly earlier and afterward mixing the different kind Ammonia-free Gel, $MgCl_2$ and antioxidant.

Guangheng Wang et al. (2011): An investigation was carried out for the time evolution of the coal structure at low temperature at nearly 120^0C for the time period of 14 days. The characterization of the coal sample was done with the help of FTIR. It was found that the groups like carboxyl and ether group are main feature for increasing the oxidation of the coal. It was found the aromatic structures had also positive effect on the spontaneous oxidation of the coal.

Wang Deming et al. (2013): It was tough job to select a particular efficient inhibitor to retard the spontaneous combustion of the coal due to the presence of the complex structures. The analysis of the complex coal structure was done with the help of FTIR (Fourier Transformation Infrared spectrum). Elucidation of the active functional group was undertaken to develop an effective method for determination of an efficient chemical inhibitor. The justification of the approach was checked using the CPT, oxygen consumption, CO emission rates. The FTIR analysis was used to monitor the distribution and changing the concentration of active functional groups. The active groups with lower activation energy were eliminated by chemical inhibitor to eradicate the future oxidation.

Beamish et al. (2013): Few reactive coals from Australia and US were used to enumerate the consequence of the effect of adding the anti-oxidant agent; a moist coal adiabatic oven test was undergone. For the particular dose of the inhibitor applied to the coal sample, there was a substantial reduction in the self-oxidation of the coal. For bituminous coal there was an extension by a factor, while it was double for the highly volatile bituminous coal. The result made out of the experimentation was similar with the site experience on the application of the anti-oxidant on the spontaneous coal.

Chapter 3

EXPERIMENTATION

EXPERIMENTATION

To examine the properties of various parameters of coal such as intrinsic properties and spontaneous combustion properties, that has impact on the spontaneous heating tendency of coal. For this the following experiments are looked-for to be done for studying the intrinsic properties of coal. Some of them are:-

- ❖ Proximate analysis
- ❖ Ultimate analysis
- ❖ Petrographic analysis
- ❖ Calorific value

While to study the liability of coal toward the spontaneous heating, the following experiments are needed to be carried out:

- ❖ Wet oxidation potential
- ❖ Flammability temperature
- ❖ Crossing point temperature
- ❖ Olpinski index
- ❖ Critical air blast
- ❖ Differential thermal analysis
- ❖ Differential scanning calorimetry

3.1 SAMPLE COLLECTION AND PREPARATION

Sample collection is a vital process of the project. It includes the collection of the sample in a designated manner. It is the method in which the physical and chemical properties of the mineral or ore can be determined with the anticipated exactness. It is the course of gathering the small portion of a whole such coal, which represents such the consistence of that portion, which characterizes that of a whole seam.

There are different methods of sampling are:

- ❖ Channel sampling
- ❖ Chip sampling
- ❖ Grab sampling
- ❖ Bulk sampling
- ❖ Drill hole sampling

The chip sampling is carried for the hard ores, wherever it is tough to make through the channels. It can be done in instance of unvarying ores and wherever the rock structures are not dependent of the values. The sample collection is a tedious process. The sample is gathered by breaking of the small and equal sized chips, from the face at points likewise spread out in both vertical and horizontal direction.

The grab sampling is applied for the broken ore that are present in the stope or near the face of the bench and ore transported. Nevertheless, it is very unpredictable as the approximation of the volume of broken ore will be imprecise. The process of grab sampling of the tubs or ships is though more depictions since samples are collected from parts of regular volume.

The bulk sampling is carried for the condition, where the traditional sampling method breaks behind. Bulk samples eradicate the consequence of uneven dissemination of significance or minor. For the project work, the samples have been collected by channel sampling which is the most common method followed.

3.1.1 CHANNEL SAMPLING (IS 436 PART I/SECTION I - 1964)

The section of seam to be sampled shall be exposed from the roof to the floor. The seam 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, freshly 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.
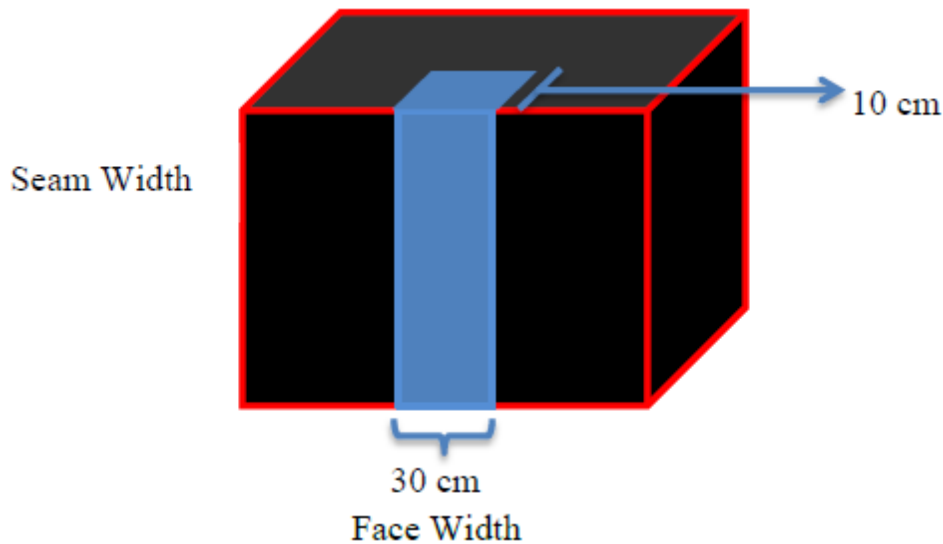

Fig 3.1 Channel Sampling (Bharath, 2010)

3.1.2 SAMPLE PREPARATION (IS 436 PART 1/SECTION 1-1964 AND IS 436 PART II-1965)

The samples were collected from the coal field, through channel sampling, which were crushed into very small particle size, in the laboratory in accordance with the experimental necessities. The entire crushed sample is then separated to prerequisite sizes by the help of sieves then it is put to be stored in air tight polythene packets. The crushed sample is sieved to -72 mesh and -200 mesh respectively for different experiments. These sealed packets are then put in storage in an air tight plastic container for extended experimental use.

3.2 DETERMINATION OF INTRINSIC PROPERTIES OF COAL

3.2.1 PROXIMATE ANALYSIS (IS 1350 PART I -1984)

The sole purpose of coal proximate analysis is to ascertain the intrinsic parameters of coal on as received basis like, fixed carbon (FC), volatile matters (VM), moisture content (M), and ash of the coal sample. The measurement is done on weight percent (wt. %) and the calculation is completed in a number of different basis (as-received) – puts all variables into deliberation and uses the total weight as the source of measurement as given below :-

❖ ad (air-dried) – It neglects the presence of moistures other than inherent moisture.

❖ db (dry-basis) – It just leaves out all moistures, including surface moisture, inherent moisture, and other moistures

❖ daf (dry, ash free) – In this all moisture and ash constituent in coal is neglected.

❖ dmmf (dry, mineral-matter-free) – It ditches out the presence of moisture and mineral matters in coal

3.2.1.1 MOISTURE CONTENT

Procedure:

❖ 1 g of – 72 mesh (BSS) coal sample was taken in a glass crucible.

❖ Weight of the coal sample along with the glass crucible was taken

❖ It was put in a furnace at 110^0 C and left for 90 minutes.

❖ Finally the sample was removed from furnace after 90 minutes and then weight of the glass crucible was taken again.

❖ The moisture content of the coal sample was calculated by using the following formula

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

Where,

M = moisture content, %

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

3.2.1.2 ASH CONTENT

Procedure:

- ❖ 1g of -72 mesh (BSS) coal sample was taken in a silica crucible
- ❖ The weight of the crucible with coal is taken
- ❖ The samples is kept on a muffle furnace at 450°C for 30 minutes and then additionally it is heated for 1 hour with temperature increasing from 450 to 850°C.
- ❖ The silica crucible is removed and then it is allowed to cool in a desiccator for 15 minutes and weight is taken for the crucible, again.
- ❖ Ash content is calculated by the formula:-

$$ASH = \frac{Z - X}{Y - X} \times 100$$

Where,

X = Mass of crucible, g

Y = Mass of crucible and sample, g

Z = Mass of crucible and ash, g

3.2.1.3 VOLATILE MATTER

Procedure:

- ❖ 1 g of -72 mesh (BSS) coal sample was taken in a crucible and the lid was put on.
- ❖ The crucible is put in the furnace, which is maintained at 925°C for 7 minutes exactly. Crucible is taken out and weighted again.
- ❖ The volatile matter content calculation is done by using the relation

$$VM = \frac{Z - X}{Y - X} \times 100$$

Where,

X = Mass of empty crucible and lid, g

Y = Mass of crucible plus lid and sample before heating, g

Z = Mass of crucible plus lid and sample after heating, g

3.2.1.4 FIXED CARBON

Calculation of the fixed carbon is done by subtracting the sum of all the above parameters and is given as,

$$FC = 100 - (M + VM + Ash)$$

Where,

M = Moisture content

VM = Volatile matter content

Ash = Ash content

3.3 METHODS FOR DETERMINING SPONTANEOUS HEATING SUSCEPTIBILITY OF COAL

3.3.1 FLAMMABILITY TEMPERATURE METHOD (Nimaje et al., 2010)

This method is used to determine the spontaneous susceptibility of the coal. The whole setup is designed for finding out the flammability temperature of coal. The setup has the following parameters:-

- ❖ Tabular furnace of internal diameter 50mm and length 300mm, opening at both ends
- ❖ A dust dispersing unit
- ❖ A solenoid valve a reservoir for air
- ❖ A mercury manometer
- ❖ A drying tower and an aspirator bulb.

The Coal dust sample of 200mg is kept in the glass helical dust disperser. Through which air from the air reservoir is allowed to flow over the disperser and on backup situation it is allowed to flow from the divergent mount. It creates a well dispersed dust-air mixture inside the furnace. Flammability temperature is the least temperature at which this dust-air mixture catches fire, which is showed by the presence of flame approaching out from the bottom of the tubular furnace. The procedure for conducting this experiment include following steps:-

- ❖ 200 mg of coal sample of -200 mesh size (BSS) was poured in a glass helical tube for the raw coal test, while for inhibitor mixed coal sample a set of doped samples are prepared

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by adding some amount of inhibitor to coal, by weight concentration it should be of 5%, 10%, 15%, 20% and so on if needed.

❖ The mercury column difference of 8 cm is maintained by aspirator bulb, to maintain the pressure of 80mm of hg and then the tap is turned off.

❖ At preferred temperature, the solenoid valve is switched on, which lets the air to pass through it very quickly.

❖ After that we find out the status of coal sample through the 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.

❖ The flammability temperature of the coal sample is found out by above method

❖ The experimentation part is repeated for another round of samples with inhibitor mixed with desired ratio.

❖ All the readings are noted down.

❖ Then finally the minimum temperature at which the dust-air mixture ignite is resembled to the flammability temperature.
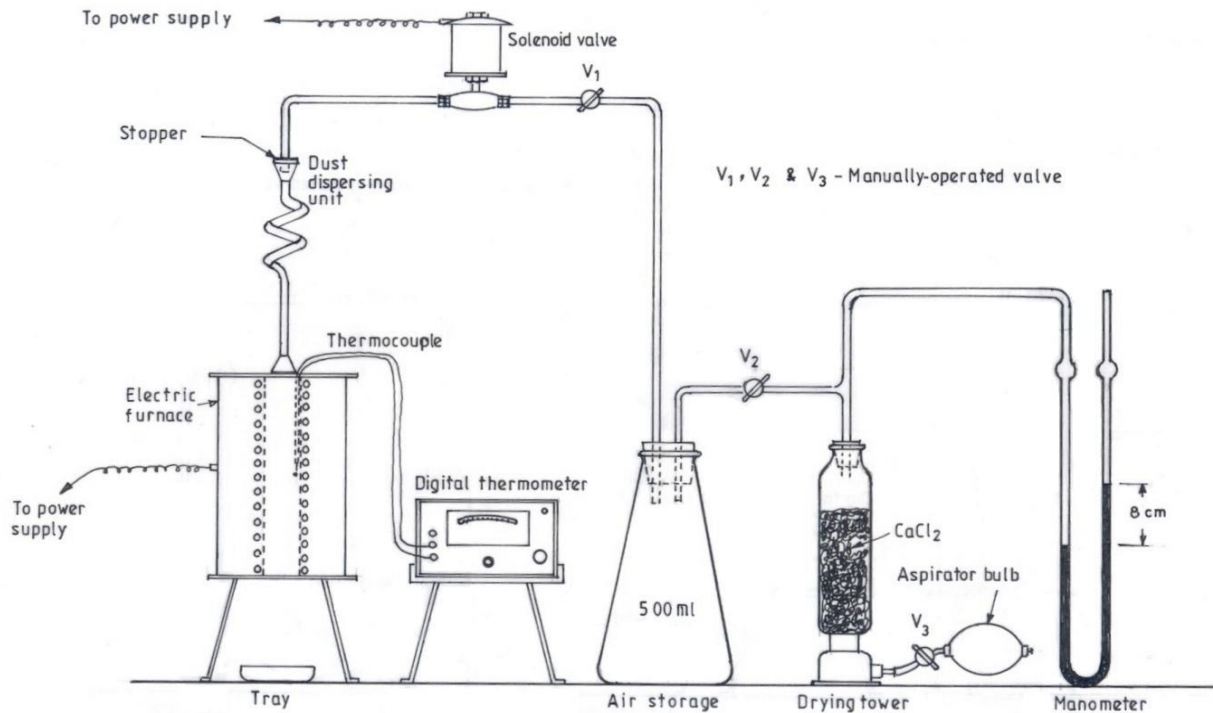

Fig 3.2 Schematic Diagram of Flammability Temperature Apparatus (Nimaje et al., 2010)

3.4 METHOD FOR DETERMINING OF GROSS CALORIFIC VALUE OF COAL

3.4.1 GROSS CALOFIC VALUE

Calorific value is the amount of energy released by the coal, by burning the unit of material. It is trapped in the form of the potential energy, which can be converted into heat energy. This value is needed for the comparison of the grade of the coal or other materials. Gradation of the material is done by the amount of heat energy produced by the unit mass of the material. For determination of calorific value of coal, bomb calorimeter is usually used.

The Bomb calorimeter comprises of a resolute cylindrical chamber recognized as bomb, which is made up of stainless steel. The chamber in which bomb is kept is built-in with an air tight cover which can be made to screw on the chamber. The cover on the calorimeter has three slots, of which two are for sparking while the other one for the entry of oxygen. Subsequently driving the oxygen inside the chamber, the opening can also be obstructed by screwing in the third terminal. The Schematic layout of bomb calorimeter is shown below
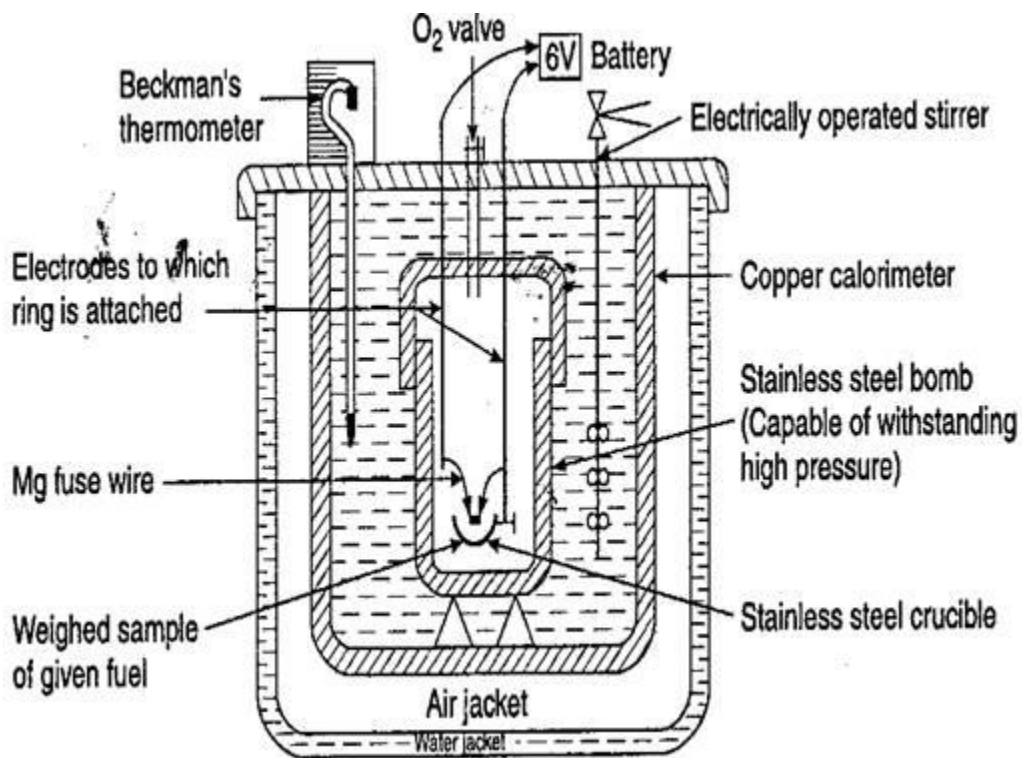

Fig 3.3 Schematic layout of Bomb Calorimeter [21]

Two bend rods are linked to the two terminals, which had a slot for wire. Here is the facility for placing the crucible holding the pellet connected to the fuse wire through a cotton thread. The entire set-up is positioned in a larger vessel comprising a well-known amount of water in it.

Procedure

The gross calorific value of the coal samples is measured using the following procedure:-

- ❖ About 1g coal was taken in a crucible and then measured in the digital balance
- ❖ The weight data of the respective coal sample is imported to the bomb calorimeter by means of start pre-weight button in addition to it is stored together with the name of sample.
- ❖ Thread of nichrome wire was cut and attached to the slot provided in two bent rods below the cover such that the wire is in physical contact with the coal.
- ❖ The crucible along with the coal is put on the circular groove made by the attachment of the two bent rods.
- ❖ The complete arrangement was cautiously screwed over the bomb
- ❖ The oxygen line was connected over the valve on the cover to provide the oxygen.
- ❖ Oxygen was filled in the bomb by pressing the oxygen fill button.
- ❖ Afterwards the bomb was cautiously positioned inside the water jacket.
- ❖ The bomb is positioned such that is does not come in immediate contact with the stirrer.
- ❖ The leads are attached to the two terminals provided on the cover.
- ❖ The lid of machine is shut and the Start button is pressed to start the procedure.
- ❖ Subsequently the machine will ignite the coal and show the Gross Calorific Value on screen.

The calorific value of coal is calculated by:

Calorific value = $(T_2 - T_1)$ * Water equivalent / Weight of the pellet

Where,

T_1 – Initial temperature, T_2 – Final temperature

The following formula designed by CFRI (Central Fuel Research Institute):

If M < 2% then Useful heat value (UHV) =91.7F+75.6(V-0.1A)-60M

If M > 2% then Useful heat value (UHV) =85.6[100-(1.1A+M)-60M]

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Where, F=Fixed Carbon, V=Volatile Matter, Ash=Ash content, M=Moisture

As per the Gazette Notification No. 22021/1/2008-CRC-II, Date 30.12.2011 issued by Government of India to switch over from UHV based gradation system to GCV based system and in pursuance of the Colliery Control Order 2000[23].

Table 3.1 Grading of Non-Coking Coal

GRADE	GROSS CALORIFIC VALUE(Kcal/kg)
G1	Exceeding 7000
G2	Exceeding 6700 and not exceeding 7000
G3	Exceeding 6400 and not exceeding 6700
G4	Exceeding 6100 and not exceeding 6400
G5	Exceeding 5800 and not exceeding 6100
G6	Exceeding 5500 and not exceeding 5800
G7	Exceeding 5200 and not exceeding 5500
G8	Exceeding 4900 and not exceeding 5200
G9	Exceeding 4600 and not exceeding 4900
G10	Exceeding 4300 and not exceeding 4600
G11	Exceeding 4000 and not exceeding 4300
G12	Exceeding 3700 and not exceeding 4000
G13	Exceeding 3400 and not exceeding 3700
G14	Exceeding 3100 and not exceeding 3400
G15	Exceeding 2800 and not exceeding 3100
G16	Exceeding 2500 and not exceeding 2800
G17	Exceeding 2200 and not exceeding 2500

Table 3.2 Grading of Coking Coal

GRADE	ASH CONTENT
STEEL GRADE – I	< 15 %
STEEL GRADE – II	15 – 18 %
WASHERY GRADE – I	18 – 21 %
WASHERY GRADE – II	21 – 24 %
WASHERY GRADE – III	24 – 28 %
WASHERY GRADE – IV	28 – 35%
SEMI COKING – I	< 19 %(A+M)
SEMI COKING – II	19 – 24 %(A+M)
HARD COKE BY PRODUCT PREMIUM	< 25%
ORDINARY	25 – 30%
BEEHIVE PREMIUM	< 27 %
BEEHIVE SUPERIOR	27 – 31 %
BEEHIVE ORDINARY	32 – 36%

Chapter 4

<u>RESULTS</u>

RESULTS

EXPERIMENTAL SPECIFICATIONS

1. Proximate analysis

 A. Determination of moisture

- ❖ Amount of coal: 1 g coal
- ❖ Size of coal: - 212 micron (-72 mesh BSS)
- ❖ Heating time: 1.5 hours at $108 \pm 2°$ C

B. Determination of volatile matter

- ❖ Amount of coal: 1 g of coal
- ❖ Size of coal: - 212 micron (-72 mesh BSS)
- ❖ Heating time: 7 minutes at $925 \pm 10°$ C

C. Determination of ash

- ❖ Amount of coal: 1 g of coal sample
- ❖ Size of coal: - 212 micron (-72 mesh BSS)
- ❖ Heating time: 30 minutes at 450°C and 60 minutes at 850°C

2. Flammability Temperature

- ❖ Amount of coal: 200 mg of coal sample
- ❖ Size of coal: - 72 micron (-200 mesh BSS)
- ❖ System: Coal + Air
- ❖ Pressure of air: 8 cm of Hg

3. Gross Calorific value

- ❖ Amount of coal: 1 g of coal
- ❖ Size of coal: - 212 micron (-72 mesh BSS)

LIST OF COAL SAMPLES

Sample collection is a vital process of the project. It includes the collection of the sample in a designated manner. It is the course of gathering the small portion of a whole such coal, which represents such the consistence of that portion, which characterizes that of a whole seam. The method used for the gathering of the sample was channel sampling. The samples were collected from the coal field, given in the table 4.1 through channel sampling, which were crushed into very small particle size, in the laboratory in accordance with the experimental necessities.

Table 4.1 List of the Coal Samples

Sl.No	Sample ID	Name of Organization
1	MCL 1	
2	MCL 2	
3	MCL 3	MCL (Mahanadi coalfields Limited)
4	MCL 4	
5	MCL 5	
6	MCL 6	
7	CCL 1	
8	CCL 2	CCL (Central Coalfield Limited)
9	CCL 3	
10	CCL 4	

PROXIMATE ANALYSIS PARAMETERS OF COAL

The proximate analysis is a part of determination of intrinsic properties of the coal. It is a substantial part of the process of experimentation carried out to determine any property of the coal. The sole purpose of coal proximate analysis is to ascertain the intrinsic parameters of coal like, fixed carbon (FC), volatile matters (VM), moisture content (M), and ash of the coal sample. The measurement is done on weight percent (wt. %) and the calculation is completed in a number of different basis. The proximate analysis of coal sample is given in table 4.2.

Table 4.2 Proximate analysis of coal samples

Sl.No	Sample ID	M%	VM %	Ash%	FC%
1	MCL 1	8.14	12.46	36	43.4
2	MCL 2	2.80	26.63	21.66	48.91
3	MCL 3	5.57	33.43	18.45	42.55
4	MCL 4	8.65	23.85	31.6	35.9
5	MCL 5	6.20	25.68	28.39	39.73
6	MCL 6	7.04	24.16	21.45	47.35
7	CCL 1	6.58	23.23	49.39	20.8
8	CCL 2	7.99	32.86	46.51	12.64
9	CCL 3	5.11	26.98	16.04	51.87
10	CCL 4	3.86	28.93	36.10	31.11

GROSS CALORIFIC VALUE

Calorific value is the amount of energy released by the coal, by burning the unit of material. It is trapped in the form of the potential energy, which can be converted into heat energy. Gradation of the material is done by the amount of heat energy produced by the unit mass of the material. For determination of calorific value of coal, automatic bomb calorimeter is used. The Bomb calorimeter comprises of a resolute cylindrical chamber recognized as bomb, which is made up of stainless steel. The chamber in which bomb is kept is built-in with an air tight cover which can be made to screw on the chamber. The GCV of all the collected coal samples are listed in Table 4.3.

Table 4.3 Gross Calorific Value of Coal samples

Sl.No	Sample ID	Gross Calorific Value(kcal/kg)	Grades
1	MCL 1	3517.99	G13
2	MCL 2	5923.73	G13
3	MCL 3	6259.81	G4
4	MCL 4	4968.26	G8
5	MCL 5	3758.78	G12
6	MCL 6	4370.11	G10
7	CCL 1	5699.76	G6
8	CCL 2	7303.76	G1
9	CCL 3	4325.81	G10
10	CCL 4	4732.54	G9

FLAMMABILITY TEMPERATURE OF COAL

This method is used to determine the spontaneous susceptibility of the coal. The whole setup is designed for finding out the flammability temperature of coal. The flammability of the raw coal is given in table 4.4. The Coal dust sample is kept in the glass helical dust disperser, through which air from the air reservoir is allowed to flow over the disperser and on backup situation it is allowed to flow from the divergent mount. For the given experiment only the raw coal is subjected to flammability temperature.

Table 4.4 Flammability Temperature of Raw Coal

Sl.No	Sample ID	Flammability Temperature(^{0}C)
1	MCL 1	552
2	MCL 2	561
3	MCL 3	542
4	MCL 4	571
5	MCL 5	511
6	MCL 6	549
7	CCL 1	549
8	CCL 2	558
9	CCL 3	536
10	CCL 4	528

FLAMMABILITY TEMPERATURE OF COAL WITH SODIUM CHLORIDE (NaCl)

The flammability temperature of the coal sample with the different concentration with NaCl is given in the table below in the table 4.5. The maximum increase in the flammability temperature was shown up to 15% by weight ratio.

Table 4.5 Flammability Temperature of Coal sample with NaCl

Sl.No	Sample ID	Flammability Temperature(^{0}C)	NaCl			
			5%	10%	15%	20%
1	MCL 1	552	561	567	573	-
2	MCL 2	561	567	574	580	-
3	MCL 3	542	549	554	561	540
4	MCL 4	571	577	585	589	-
5	MCL 5	511	518	524	531	-
6	MCL 6	549	558	563	570	-
7	CCL 1	549	557	564	569	-
8	CCL 2	558	569	574	579	-
9	CCL 3	536	544	551	555	537
10	CCL 4	528	536	543	549	-

FLAMMABILITY TEMPERATURE OF COAL WITH SODIUM CARBONATE (Na_2CO_3)

The flammability temperature of the coal sample with the different concentration with Na_2CO_3 is given in the table below in the table 4.6. The maximum increase in the flammability temperature was shown up to 15% by weight ratio. The Na_2CO_3 showed a certain increase in the flammability temperature.

Table 4.6 Flammability Temperature of Coal sample with Na_2CO_3

Sl.No	Sample ID	Flammability Temperature(^{0}C)	Na_2CO_3			
			5%	10%	15%	20%
1	MCL 1	552	558	562	568	-
2	MCL 2	561	568	572	575	-
3	MCL 3	542	549	555	558	-
4	MCL 4	571	576	581	584	571
5	MCL 5	511	518	522	528	-
6	MCL 6	549	556	561	567	-
7	CCL 1	549	554	560	562	-
8	CCL 2	558	565	570	574	-
9	CCL 3	536	542	548	538	-
10	CCL 4	528	534	540	544	-

FLAMMABILITY TEMPERATURE OF COAL WITH CALCIUM CARBONATE (CaCO₃)

The flammability temperature of the coal sample with the different concentration with $CaCO_3$ is given in the table below in the table 4.7. The maximum increase in the flammability temperature was shown up to 15% by weight ratio. The $CaCO_3$ showed a significant escalation in the flammability temperature.

Table 4.7 Flammability Temperature of Coal sample with CaCO₃

Sl.No	Sample ID	Flammability Temperature(^{0}C)	CaCO₃			
			5%	10%	15%	20%
1	MCL 1	552	559	565	572	-
2	MCL 2	561	568	574	580	-
3	MCL 3	542	548	554	560	-
4	MCL 4	571	577	583	587	573
5	MCL 5	511	519	524	530	-
6	MCL 6	549	557	561	570	-
7	CCL 1	549	558	563	568	-
8	CCL 2	558	567	573	578	-
9	CCL 3	536	544	549	555	-
10	CCL 4	528	535	544	548	

FLAMMABILITY TEMPERATURE OF COAL WITH CALCIUM CHLORIDE (CaCl$_2$)

The flammability temperature of the coal sample with the different concentration with CaCl$_2$ is given in the table below in the table 4.8. The maximum increase in the flammability temperature was shown up to 10% by weight ratio. But after the 15% it showed an unpredictable behavior.

Table 4.8 Flammability Temperature of Coal sample with CaCl$_2$

Sl.No	Sample ID	Flammability Temperature(^{0}C)	CaCl$_2$			
			5%	10%	15%	20%
1	MCL 1	552	556	562	564	-
2	MCL 2	561	566	570	550	-
3	MCL 3	542	548	554	-	-
4	MCL 4	571	575	580	-	-
5	MCL 5	511	517	521	524	-
6	MCL 6	549	555	560	547	-
7	CCL 1	549	553	558	542	-
8	CCL 2	558	563	567	569	-
9	CCL 3	536	541	547	-	-
10	CCL 4	528	533	538	542	-

FLAMMABILITY TEMPERATURE OF COAL WITH STONE DUST (DOLERITE)

The flammability temperature of the coal sample with the different concentration of the stone dust of the Dolerite is given in the table below in the table 4.9. The maximum increase in the flammability temperature was shown up to 10% by weight ratio. Had an negligible increase in flammability temperature after the concentration was increased to 15%.

Table 4.9 Flammability Temperature of Coal sample with Dolerite

Sl.No	Sample ID	Flammability Temperature(^{0}C)	Dolerite			
			5%	10%	15%	20%
1	MCL 1	552	556	559	-	-
2	MCL 2	561	565	568	570	-
3	MCL 3	542	546	549	551	-
4	MCL 4	571	574	578	-	-
5	MCL 5	511	515	517	519	-
6	MCL 6	549	556	558	-	-
7	CCL 1	549	553	558	-	-
8	CCL 2	558	562	567	-	-
9	CCL 3	536	540	543	547	-
10	CCL 4	528	533	536	-	-

CHAPTER 5
STATISTICAL ANALYSIS

STATISTICAL ANALYSIS

Flammability Temperature v/s GCV
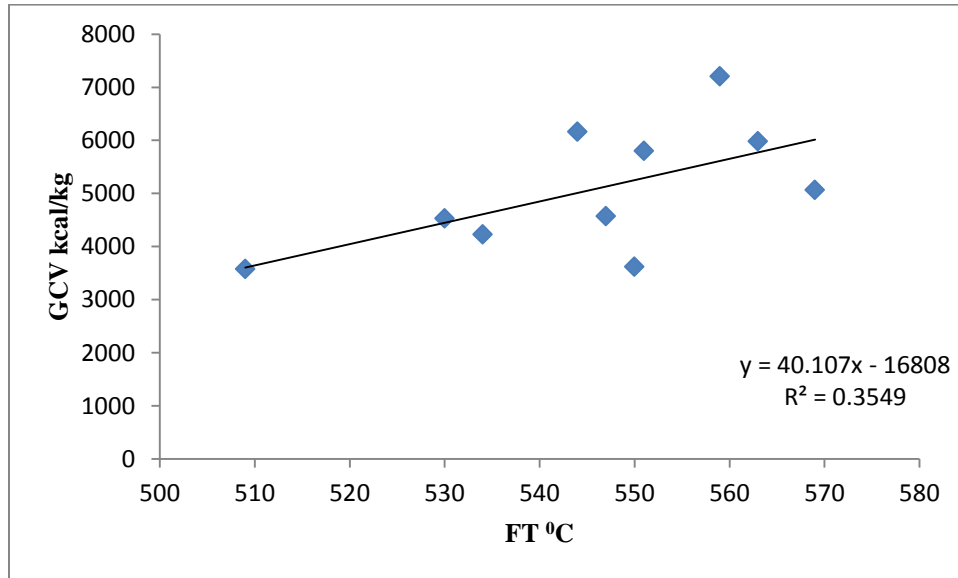
Fig 5.1 Correlation plot between FT and GCV

Flammability Temperature v/s Moisture Content
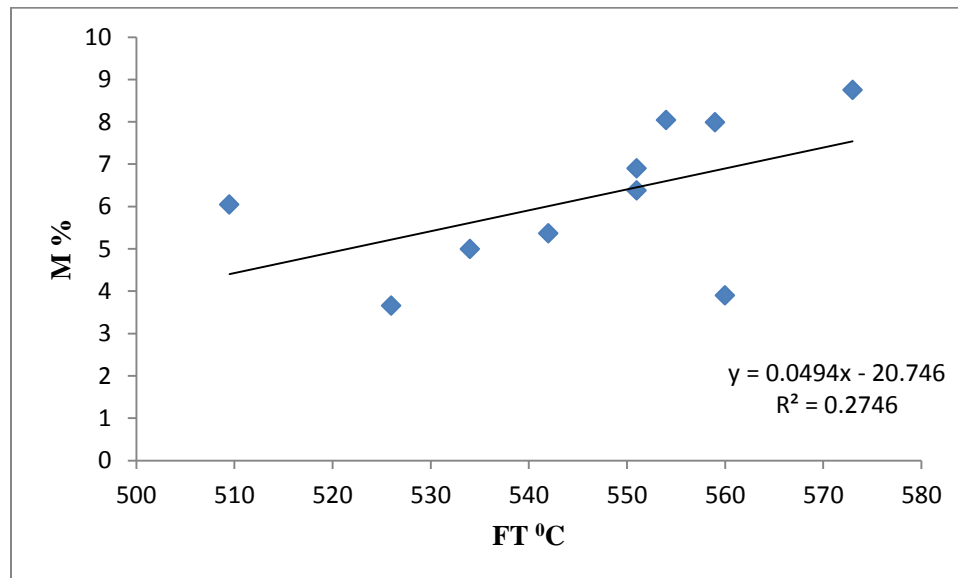
Fig 5.2 Correlation plot between FT and Moisture Content
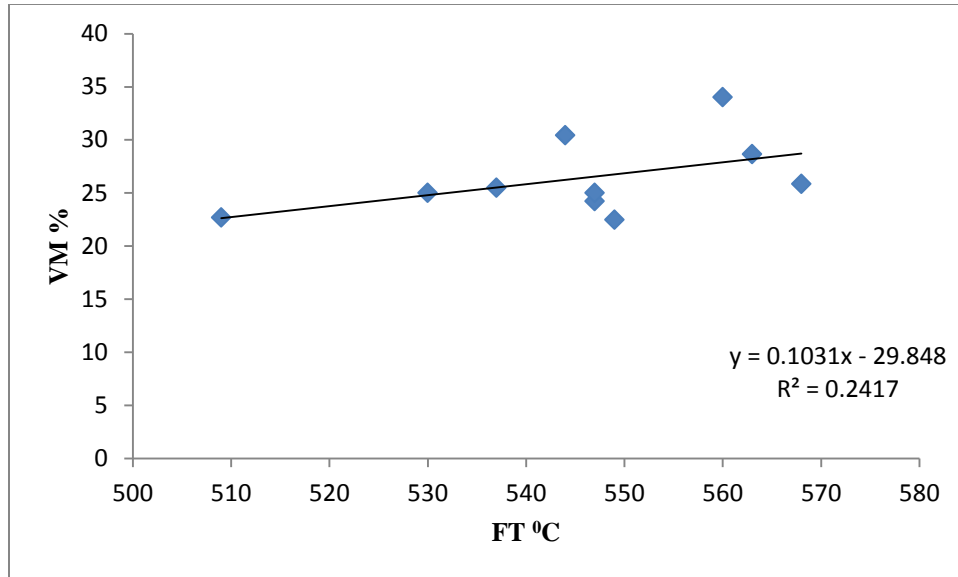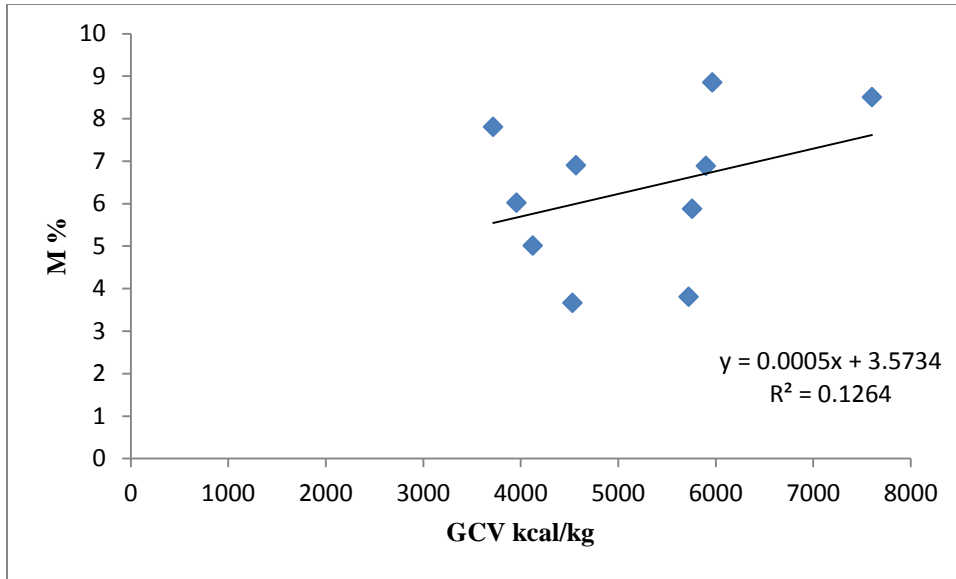
Flammability Temperature v/s VM

y = 0.1031x - 29.848
R² = 0.2417

Fig 5.3 Correlation plot between FT and VM

Flammability Temperature v/s Ash content

y = 0.2535x - 107.46
R² = 0.17
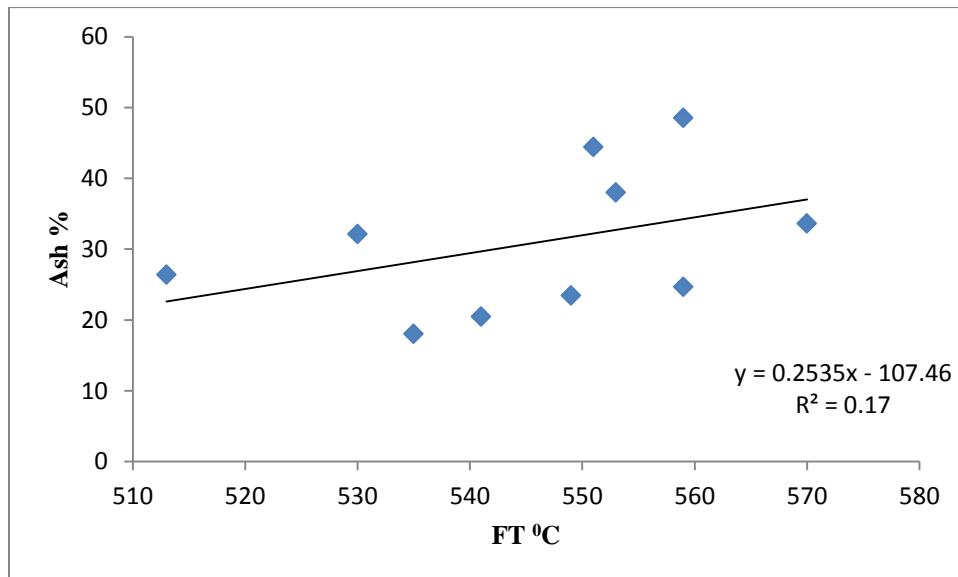
Fig 5.4 Correlation plot between FT and Ash content

GCV V/S Moisture Content

y = 0.0005x + 3.5734
R² = 0.1264

Fig 5.5 Correlation plot between GCV and Moisture content

GCV V/S VM

y = 0.0042x + 4.6908
R² = 0.6609
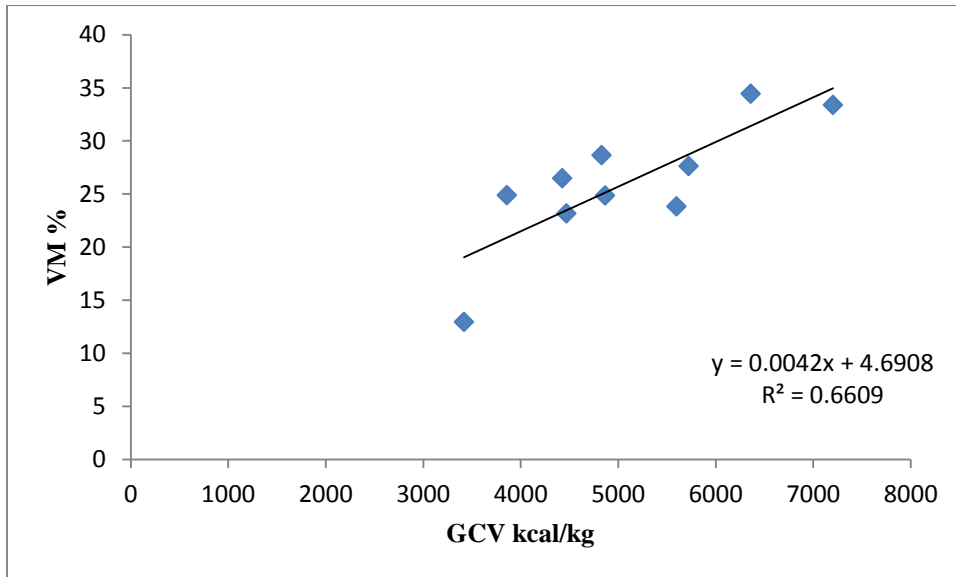
Fig 5.6 Correlation plot between GCV and VM

GCV V/S Ash Content
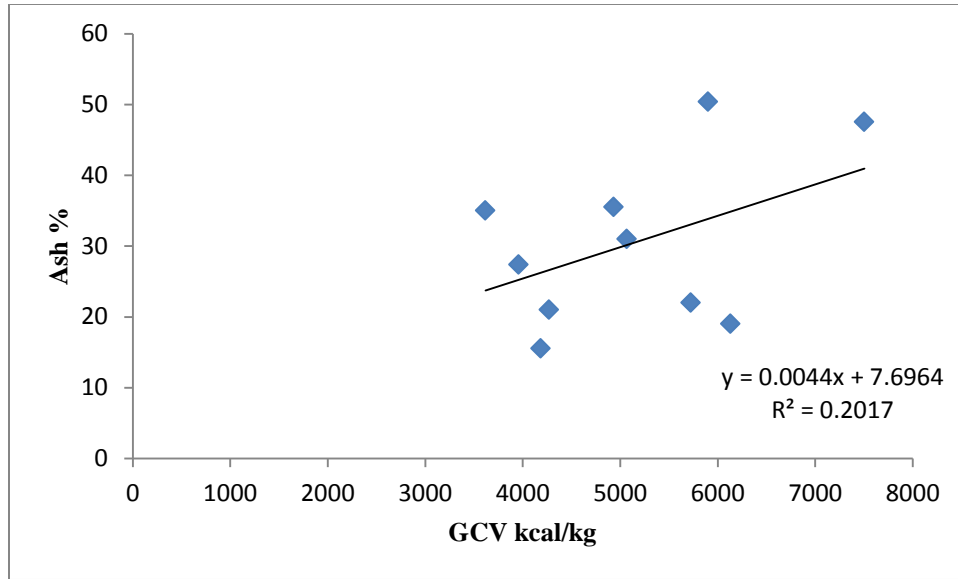
Fig 5.7 Correlation plot between GCV and Ash content

With the aim of establishing the effects of various intrinsic properties on the spontaneous oxidation liability of coal samples, the statistical correlation studies were performed. The coefficients of correlation between the intrinsic properties and susceptibility indices were found out taking intrinsic properties, viz. moisture, volatile matter, ash and gross calorific value as independent variable and the susceptibility indices determined like Flammability temperature method as dependent variable. It is shown in the table 5.1. Further the correlation was also carried out the proximate analysis parameters and the gross calorific value, as shown in the table 5.2.

Table 5.1 Correlation between flammability temperature and proximate analysis parameters

Sl.No	Independent Variable	Empirical relation	R^2
1	M	FT = 0.0494M – 20.746	0.27
2	VM	FT = 0.1031VM – 29.848	0.24
3	Ash	FT =0.2535Ash – 107.46	0.17
4	GCV	FT = 40.107GCV – 16808	0.35

Table 5.2 Correlation between GCV value and proximate analysis parameters

Sl.No	Independent Variable	Empirical relation	R^2
1	M	$GCV = 0.0005M - 3.5734$	0.12
2	VM	$GCV = 0.0042VM + 4.6908$	0.66
3	Ash	$GCV = 0.0044Ash + 7.6964$	0.20
4	FT	$FT = 40.107GCV - 16808$	0.35

Chapter 6

DISCUSSION AND CONCLUSION

DISCUSSION AND CONCLUSION

6.1 DISCUSSION

The outcomes of the proximate analysis, gross calorific value and flammability temperature method are tabularized and their respective graphs depicting the regression values are plotted in order to compare the relative efficiency of the various inhibitors in process to upsurge the flammability temperature, a measure to spontaneous heating susceptibility of coal and thereby decreasing its liability towards spontaneous oxidation of coal. Following are the concluded proclamations acquired from the graph analysis.

- ❖ Sample MCL 2 has low moisture content, but is high in volatile matter content.
- ❖ Sample MCL 5 has high moisture content, but its ash content is also comparatively high.
- ❖ Sample MCL 4 has the highest moisture content (8.65), and moderate volatile matter.
- ❖ The flammability temperature of the Central Coalfield Limited coal samples varies from 528^0C to 558^0C.
- ❖ The flammability temperature of the Mahanadi Coalfield Limited coal samples varies from 511^0C to 571^0C.
- ❖ Though the sample CCL 1 and MCL 6 have different moisture content, ash content, volatile matter content, they come up with approximate range of flammability temperature.
- ❖ Out of the five inhibitors used the NaCL and $CaCO_3$ performed better than the Na_2CO_3, $CaCl_2$ and dolerite stone dust, in inhibiting the spontaneous heating tendency of the coal samples.
- ❖ There was a considerable upsurge in flammability temperature by adding the inhibitors up to 15% (by wt.) in compared to 10% or 5% (by wt.) of the inhibitors.
- ❖ While adding the inhibitors in MCL coal samples, positive outcome was achieved for the 5%, 10% and 15% (by wt.) concentration of NaCl, $CaCO_3$ and Na_2CO_3. On the other hand, for a few samples, a fall in the temperature was noticed after adding in excess of 10% (by wt.) in case of Dolerite stone dust and $CaCl_2$.
- ❖ Meanwhile the dolerite the stone dust showed low tendency to inhibit the coal and was only consistent up to 10% concentration by weight.
- ❖ Despite the fact that the $CaCl_2$ performed well up to 10% concentration by weight, but it showed inconsistent behavior by increasing the concentration up to 15% by weight.

6.2 CONCLUSION

From the detailed experimentation it was concluded that the inhibitor like NaCl and $CaCO_3$, gave complete justice to its role of inhibiting the spontaneous combustion of the coal sample. They had shown their best retardation tendency up to the concentration of 15% by weight. These two inhibitors are not even just a very economical inhibitor, which certainly holds no hazard to health of human or environment somehow and even have a tendency to upsurge the flammability temperature of coal to a definite level. These two inhibitors are even easily available for the commercial purpose.

From the statistical analysis of the flammability temperature of the coal sample and proximate analysis parameters of the coal sample, it was concluded that flammability temperature has a positive inclination toward the moisture content and volatile matter. The correlation coefficient between the flammability temperature and volatile matter was found to be 0.26. Thus, the correlation of intrinsic properties with the flammability temperature showed that properties like moisture and volatile matter have a better correlation than other.

6.3 SCOPE OF FUTURE WORK

The application of inhibitors in the retardation of the susceptibility of the coal sample has a significant scope for future work. More number of coking and non-coking coal samples should be tried with the specified inhibiting agents and also sandstone and other rock dust should be tried to find out effect on the flammability of coal. Further, the use of some more chemical inhibitors in the field of inhibition of the self-oxidation of the coal can also be done in near future.

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APPENDIX -A

COMPARISON OF FLAMMABILITY TEMPERATURE OF COAL WITH DIFFERENT CONCENTRATION OF INHIBITORS
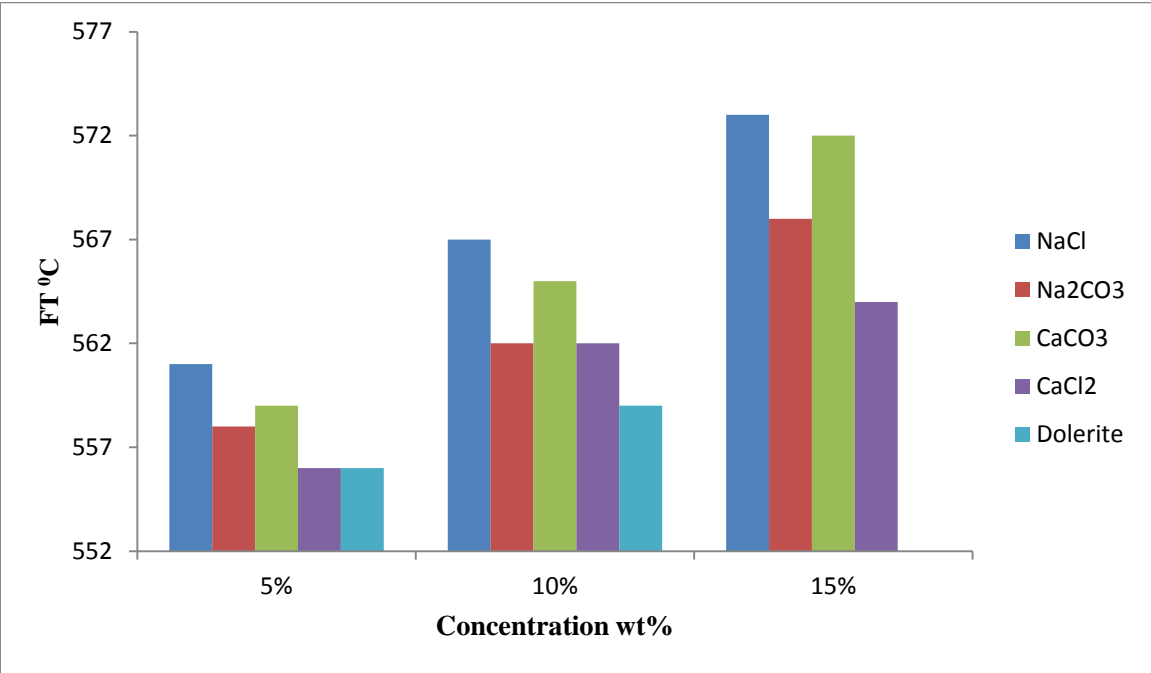

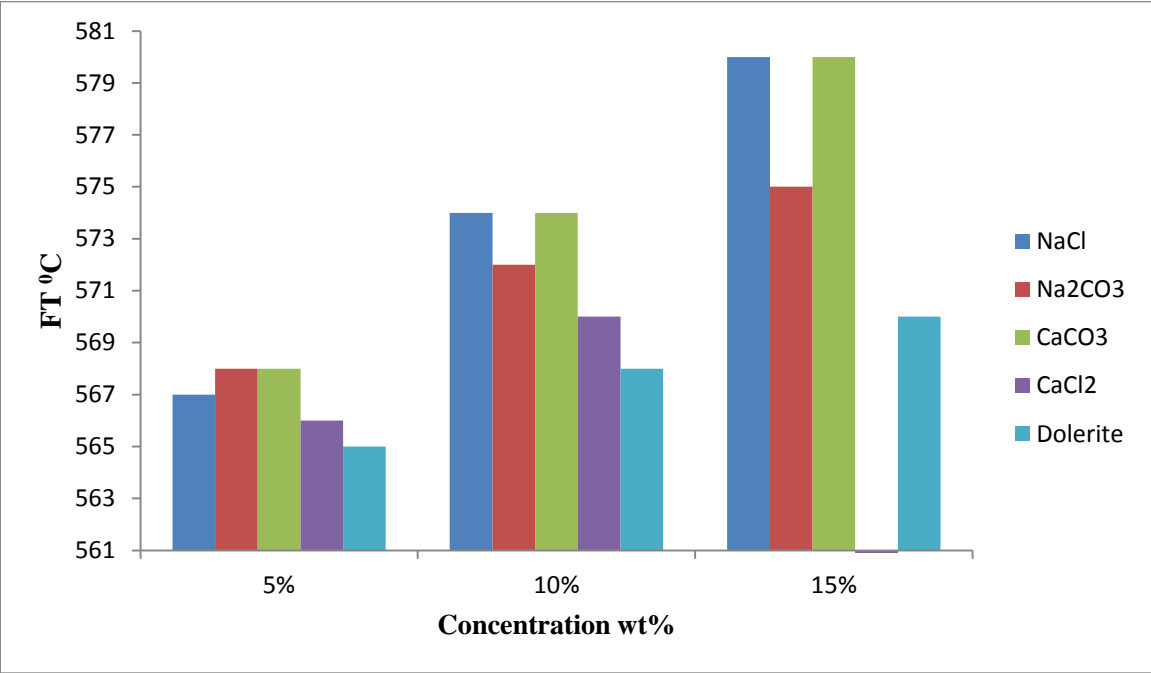**Fig A1.Effect of Different Inhibitors on MCL 1**

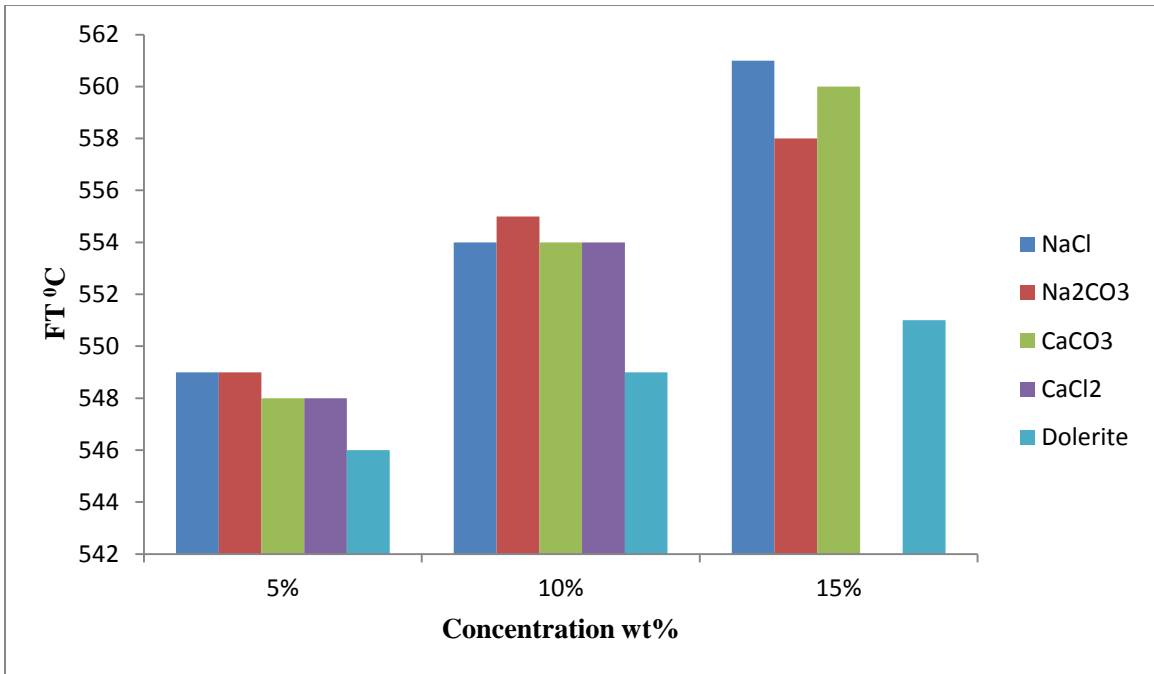**Fig A2.Effect of Different Inhibitors on MCL 2**

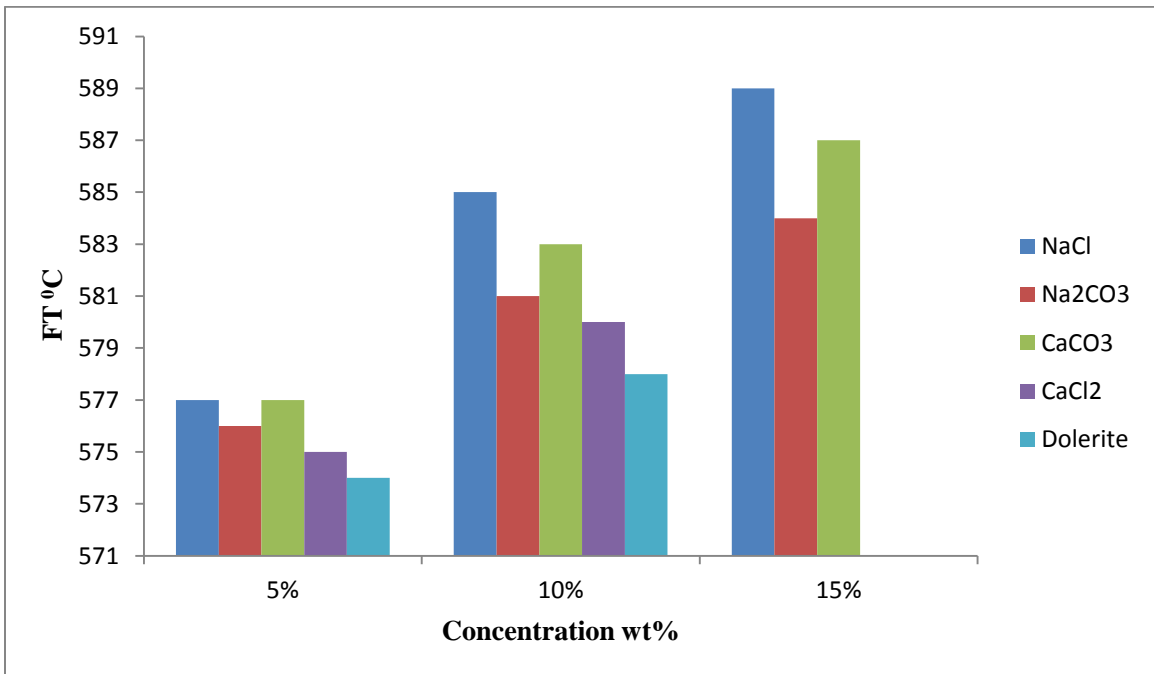**Fig A3.Effect of Different Inhibitors on MCL 3**

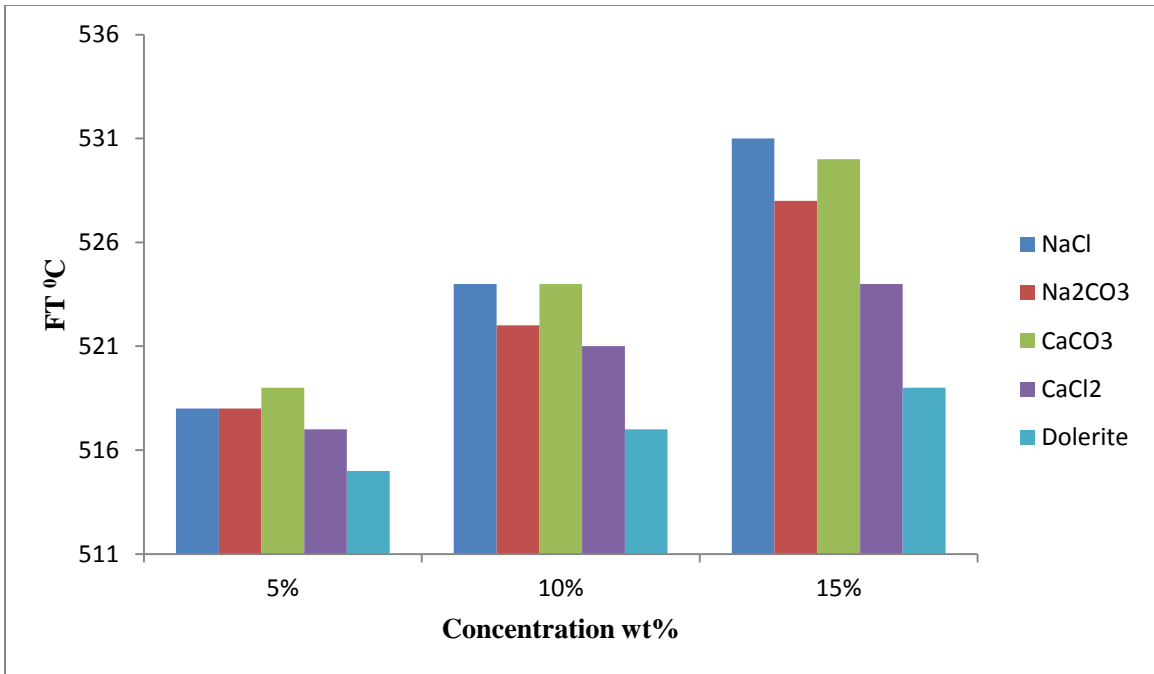**Fig A4.Effect of Different Inhibitors on MCL 4**
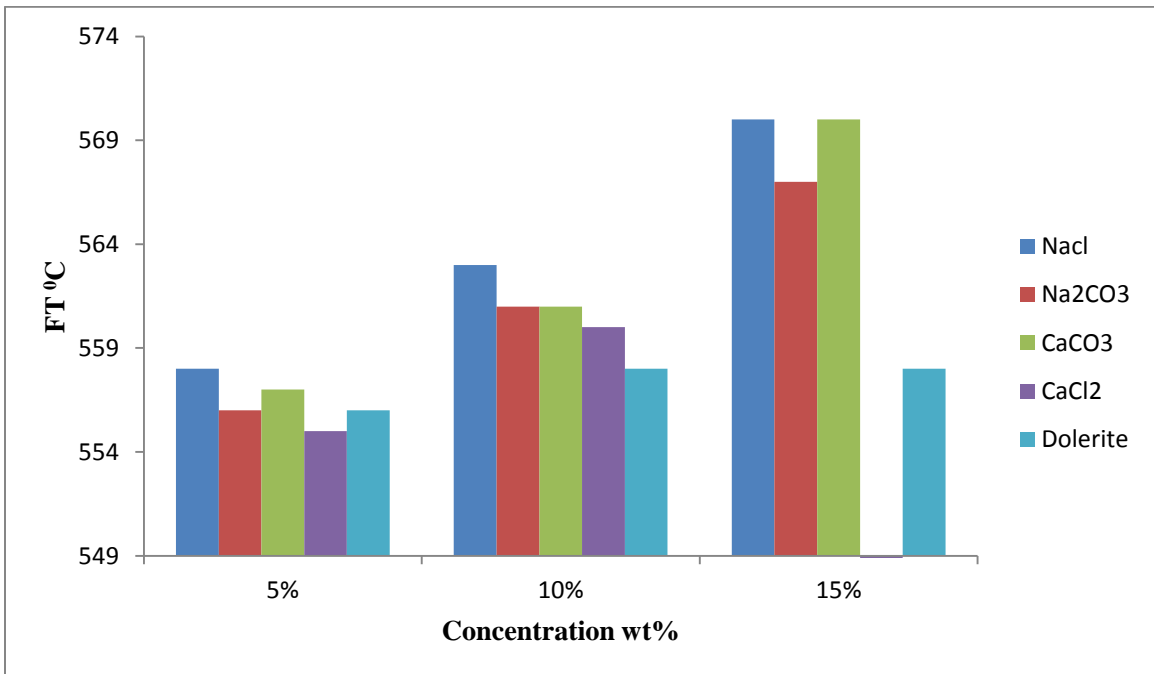
Fig A5.Effect of Different Inhibitors on MCL 5
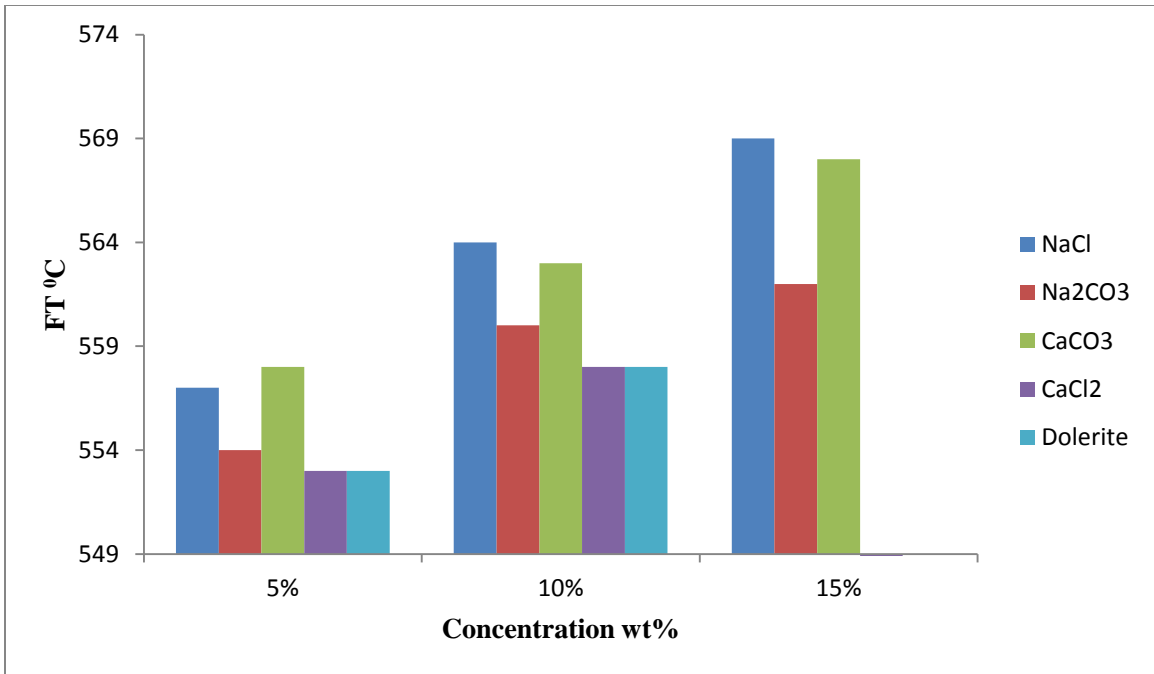

Fig A6.Effect of Different Inhibitors on MCL 6
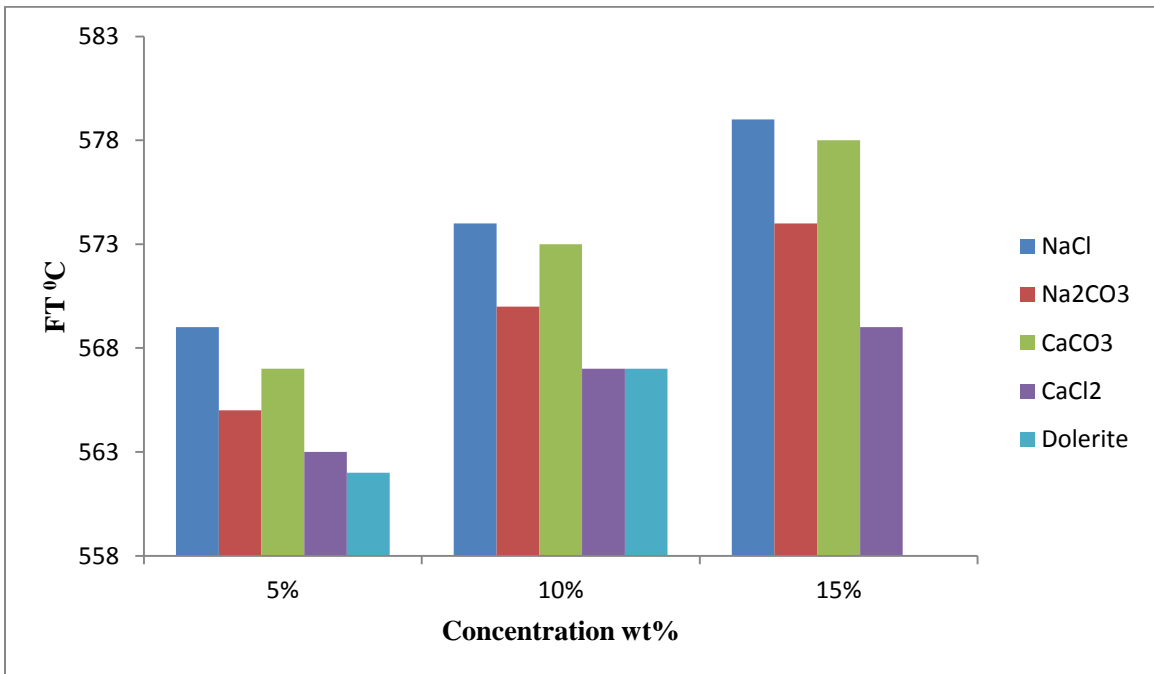
Fig A7.Effect of Different Inhibitors on CCL 1

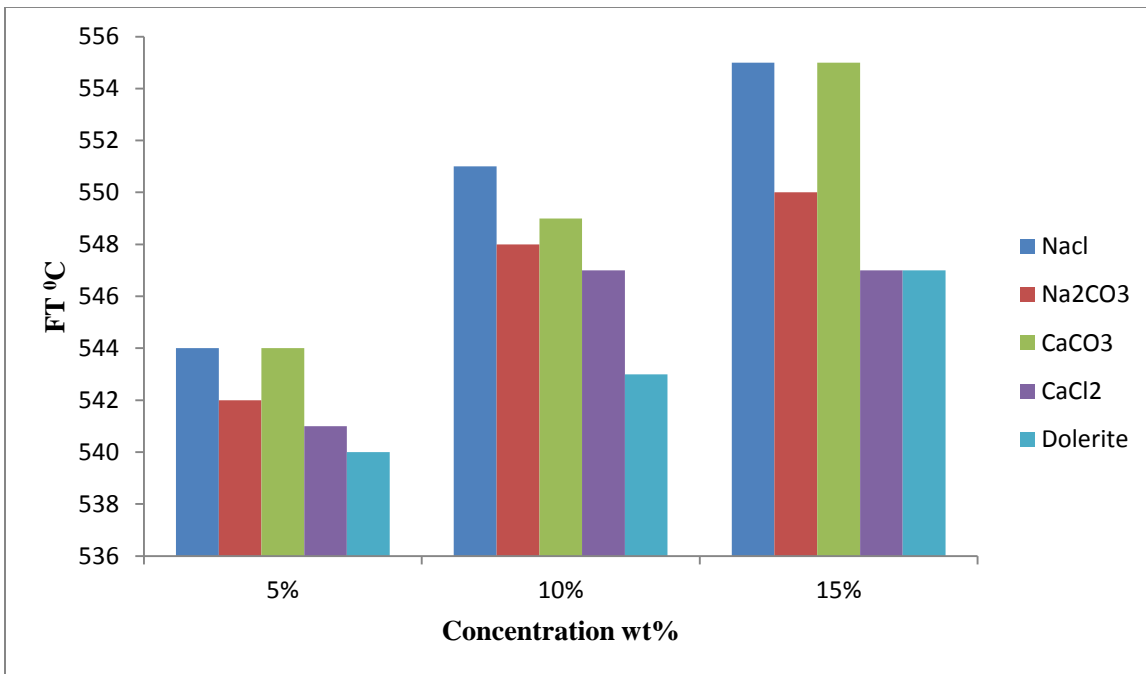**Fig A8.Effect of Different Inhibitors on CCL 2**
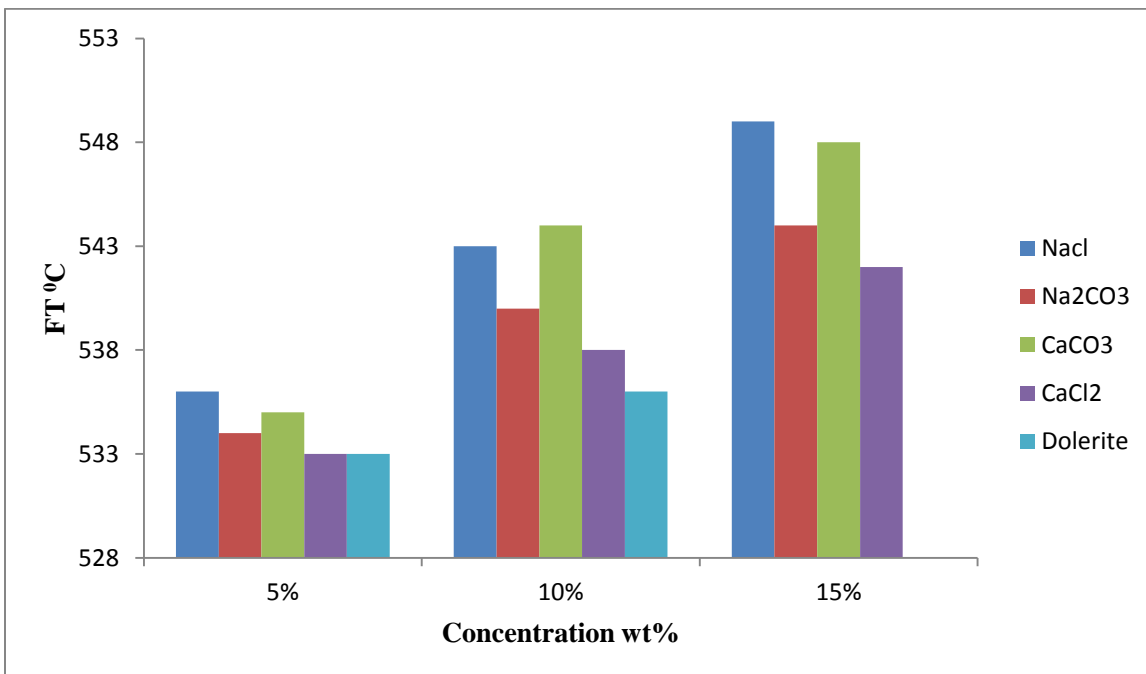
Fig A9.Effect of Different Inhibitors on CCL 3

Fig A10.Effect of Different Inhibitors on CCL 4