APPLICATION OF GENETIC ALGORITHM FOR THE ASSESSMENT OF SPONTANEOUS HEATING SUSCEPTIBILITY OF COAL

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

BACHELOR OF TECHNOLOGY
IN
MINING ENGINEERING

BY

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DEPARTMENT OF MINING ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY
ROURKELA - 769008
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UNDER THE GUIDANCE OF

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C E R T I F I C A T E

This is to certify that the thesis entitled **"Application of Genetic Algorithm for the Assessment of Spontaneous Heating Susceptibility of Coal"** submitted by **Sri Mihir Kumar Swain** 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 the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

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ACKNOWLEDGEMENT

I wish to express my profound gratitude and indebtedness to Dr. H. B. Sahu, Associate Professor, Department of Mining Engineering, NIT, Rourkela for introducing the present topic and for their inspiring guidance, constructive criticism and valuable suggestion throughout this project work.

I express my sincere thanks to Prof. S. S. Mahapatra, Professor, Mechanical Engineering Department for helping me with the formulation of the software.

I express my sincere thanks to Er. Vishal Agarwal, Management Trainee, Jhanjra, underground Mine, ECL; and Er S. K. Singh, Safety Officer, SECL; for their help during the collection of coal amples for this project work.

I am also thankful to Mr. B. K. Bhoi, Mr B. N. Naik, and Mr. B. K.. Pradhan and other staff members of Department of Mining Engineering for their assistance and help in carrying out different experiments in the laboratories.

Last but not the least, my sincere thanks to all our friends who have patiently extended all sorts of help for accomplishing this undertaking.

Date: **Mihir Kumar Swain**

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ABSTRACT

INTRODUCTION

When coal is exposed to air, oxygen is absorbed and some portions of the coal substance with production of some gases (mainly CO, CO_2), water vapour with the evolution of some amount of heat. This oxidation takes place even at ambient temperatures and humidity. 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”. Mine fire is major hazard in coal mining industry worldwide. The first step to take proper preventive measure is the assessment of liability of coal seams towards self heating. Various expert systems are being adopted these days to predict the self heating properties of coal. In the present work a new soft computing approach, viz. genetic algorithm has been applied for categorization of coal samples, depending upon their spontaneous heating susceptibility.

EXPERIMENTAL INVESTIGATION

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 BCCL, two samples from Central Coal field Limited and one each from Western coal field Limited and NCL. The samples were collected following channel sampling procedure. Some of the samples were well known for their high and low susceptibility in Indian coalfields. The proximate constituents were determined in laboratory using the standard experimental procedure. The crossing point temperature of these coal samples was determined at a heating rate of 1^0C/ minute with an air flow rate of 80 cc/min. The onset temperature from DTA thermograms of these coal samples was determined by intersection between two tangents drawn at the inflexion point of the endothermic region and another tangent was drawn at rising portion of curve of stage III. The wet oxidation potential of the coal samples were determined using $KMnO_4$ solution.

Table 1 Proximate constituents, CPT, onset temperatures and wet oxidation potential difference of coal samples

Sample no.	Moisture (%)	VM (%)	Ash (%)	CPT (^{0}C)	T_c (^{0}C)	WOPD (mV)
1	4.974	31.949	23.913	159	171.07	112
2	9.955	30.395	12.6	171	129.49	112
3	5.785	27.35	18.6	163	123.4	114
4	5.894	30.706	26.25	167	143.41	119
5	7.669	30.921	10.8	162	138.36	101
6	9.164	26.586	16.241	185	123.12	113
7	6.488	28.262	10.395	165	162.56	109
8	3.96	26.134	23.3	173	163.63	80
9	2.932	30.883	12.037	163	186.8	99.9
10	1.948	33.052	17.527	156	184.15	108
11	2.345	29.641	15.725	165	189.56	103
12	4.48	25.01	44.02	169	155.93	102
13	2.4	23.27	52.3	174	147.29	104
14	14.5	31.97	12.35	155	158.46	51.2
15	8.97	29.49	22.88	147	153.34	47.5
16	9.59	28.93	7.68	149	124.82	54.1
17	11.13	25.19	38.46	149	171.87	99.3
18	1	17.36	15.73	180	188.98	26.6
19	1.9	33.08	16	155	128.38	63.9

20	0.6	22.32	10.73	160	169.66	41.8
21	8.43	24.43	9.6	152	162.3	87.8
22	1.8	36.13	14.27	150	129.33	106.6
23	10	32.27	18	144	132.94	143.1
24	10.52	29.47	11.91	152.5	136.87	121.8
25	7.67	29.83	18.88	155	145.33	123.8
26	14.39	29.31	12.76	150	128	161
27	9.68	29.8	18.12	138	122.67	206

APPLICATION OF GENETIC ALGORITHM

A genetic algorithm (GA) inspired by Darwin's theory of evolution is a search technique used in computing to find exact or approximate solutions to optimization and search problems. Genetic algorithms are a particular class of evolutionary algorithms (EA) that use techniques inspired by evolutionary biology such as inheritance, mutation, selection, and crossover. Genetic algorithms are. In the present work coal seams are classified by using genetic algorithm to determine their spontaneous heating susceptibility, taking Euclidean distance as fitness function. For this purpose a program was written in C++. The program was run using four variables:

1. Moisture
2. Volatile matter
3. Ash
4. One of the following susceptibility indices at a time.
    - Crossing point temperatures
    - Onset temperatures
    - Wet oxidation potential values

It was observed that the results were consistent, when four clusters were obtained, so four clusters were obtained in all cases.

DISCUSSION AND CONCLUSION

The genetic algorithm takes into account the intrinsic parameters determined by proximate analysis, which is regular affair in the field as it is required to determine the grade of coals. It was observed that the categorization matched with the field results fairly accurately. It is hoped that the output of the work will benefit the practicing mining engineers and researchers to a greater extent in categorizing coal samples, depending upon their spontaneous heating susceptibility and accordingly they can plan the mining activities and adopt advance precautionary measures to deal with fire problems in mines.

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Chapter 1

INTRODUCTION

OBJECTIVE

1. INTRODUCTION

When coal is exposed to air, oxygen is absorbed and some portions of the coal substance with production of some gases (mainly CO, CO_2), water vapour with the evolution of some amount of heat. This oxidation takes place even at ambient temperatures and humidity. It is a slow process and the heat evolved is carried away by air. However, if the rate of dissipation of heat is less than that is evolved, the temperature of the coal rises, ultimately leading ot fire. This process of self heating of coal or other carbonaceous material resulting eventually in its ignition is termed as "spontaneous heating" or "auto oxidation".

Therefore, to a certain extent, all coals are liable to spontaneous combustion, when exposed to favorable environment, liberating heat. This, if allowed to accumulate. Would enhance the rate and lead to fires, known as endogenous fires. The incidences of fires in coal mines are mostly due to spontaneous combustion of coal, though endogenous fires cause some incidences. Mine fire is a major hazard in coal mines worldwide. It contributes to problems such as loss of coal reserves due to burning, creates environmental pollution and adversely affects the safety and economic aspects of mining.

All type of coals have not the same propensity for spontaneous combustion. Various coals responds differently to self heating when exposed to similar atmospheric conditions. It, therefore, becomes imperative to categorize coals based o their susceptibility to spontaneous heating for deciding the safety measures. In the past, this differential behaviour of coal has been attributed to the intrinsic as well as extrinsic properties of coal. A number of approaches have been made by different researchers for categorizing coals based on their intrinsic properties such as volatile matter, fixed carbon, ash, superficial moisture, total moisture, total iron, non-pyretic iron, total sulphur contents of coal. A few researchers tried to make use of petrographical classification or rank correlation, but have not been found to be enough for practically utility in distinguishing the reliability of coal to spontaneous heating. Also, some approaches have been made by researchers for categorizing coal based on the studies on the effect of coal oxygen interaction. A number of approaches have been developed over the years to assess the proneness of coal to spontaneous heating. This propensity to self heating of coal also decide the incubation period of coal seams, which decide the size of the panel to be formed, which is a important safety measure im mine planning. It is therefore imperative thet planners of a mine determine in advance the spontaneous heating susceptibility of the seam/seams to be mined so that either the coal is extracted before the incubation period, or advance precautionary measures are planned to tackle this menace.

Evolutionary Algorithms can be divided into three main areas of research: Genetic Algorithms (GA) (from which both Genetic Programming (which some researchers argue is a fourth main area) and Learning Classifier Systems are based), Evolution Strategies (ES) and Evolutionary Programming. Genetic Programming began as a general model for adaptive process but has since become effective at optimization while Evolution Strategies was designed from the beginning for variable optimization.

The origins of Evolution Computing can be traced to early work by Computer Scientists in the 1950s and 1960s with the idea that evolutionary processes could be applied to engineering problems of optimization. This led to three major independent implementations of Evolutionary Computing of which two are Evolution Strategies and Genetic Algorithms.

Genetic Algorithms were initially developed by Bremermann in 1958 but popularized by Holland who applied GA to formally study adaptation in nature for the purpose of applying the mechanisms into computer science. This work lead to the development of the Schema starting in 1968 which was explained in detail in his 1975 book Adaptation in Natural and Artificial Systems.

1.1 OBJECTIVE

Keeping this in view the objectives of the project work has been formulated as:

- Collection of coal samples from different mines
- Determination of intrinsic properties of the collected coal samples by proximate analysis
- Determination of spontaneous heating susceptibility of the coal samples by
    - crossing point temperature
    - differential thermal analyzer, and
    - wet oxidation potential method
- Application of genetic algorithm for categorization of coal samples, depending upon their spontaneous heating susceptibility.

Chapter 2

LITERATURE REVIEW

2. LITERATURE REVIEW

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

Banerjee (1985) determined the crossing point temperature (CPT) for a number of Indian coal samples following the crossing points temperature method. He observed that coals with crossing point temperatures between 120^0C and 140^0C could be considered to be highly susceptibility to spontaneous heating and those above 160^0C are poorly susceptible. The moderately susceptible ones showed values in between the above mentioned.

Nandy et al. (1972) noted the variation in crossing point temperature values with the volatile matter, oxygen percentage and the moisture content of coal he found that CPT normally decreases with increase in each of these constituents of coals. But beyond 35% VM, 9% oxygen, or 4 to 6% moisture content there is not much change in CPT values.

Feng, Chakravorty and Cochrane (1973) developed a composite liability index using the results of crossing point temperature experiments, called FCC index. This is calculated using the following equation:

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

They selected the lower limit for the heating rate at 110^0C in order to insure that all the moisture had evaporated from the sample. The upper limit of 220^0C was chosen as there would have been little evolution of volatile matter below this temperature.

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

$$\text{Liability index} = \frac{\text{heating rate at the crossing point}}{\text{time to reach the crossing point}} \times \frac{\text{time to reach the inflection point}}{\text{average heating rate between the inflection and crossing point}} \times 10$$

They state that the of their index increases with self heating liability.

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

Banerjee and chakravarty (1967) have suggested differential temperature analysis (DTA) for the study of spontaneous combustion of coal, particularly in classifying coals with respect to their susceptibility to self heating. A standard experimental procedure for carrying out DTA studies had been prescribed by them. Calcined alumina is recommended as inert reference material for DTA experiments. A heating rate of 5^0C/min was advised for such studies. Typical temperatures obtained from various coals are included in this study to explain self heating phenomenon.

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

Panigrahi, Ojha, Saxena and Kejriwal (1997) conducted experiments for the determination of Russian U-index, 10 samples from Jharia coalfields have been analyzed 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.

Chattoraj and Roy (2007) applied Genetic Algorithm (GA) to the optimization of gain of microstrip antenna, fabricated on ferrite substrate, biased externally by a steady magnetic field The fitness function for the GA program was developed using cavity method for the analysis of microstrip antenna. The computed results were compared with the results obtained using GA optimizer of MATLAB. The gain of a ferrite microstrip antenna is a sensitive function of bias magnetic field and saturation magnetization of ferrite. They developed a Genetic Algorithm code for magnetized ferrite microstrip antenna using C++ language where fitness function was obtained using cavity model for magnetized circular FMSA. The different parameters being varied are steady bias magnetic field, saturation magnetization, dielectric constant and height of the ferrite substrate. They compared the optimized results with the results obtained using GA optimizer of MATLAB.

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

Sandra and Ivan (2007) applied genetic algorithm in median filtering. Images are often corrupted by impulse noise due to errors generate in noisy sensors or communication channels. Two types of impulse noise can be defined: 1) fixed-valued and 2) random-valued. In many applications it is very important to remove noise in the images before some subsequent processing such as edge detection, object recognition and image segmentation. They proposed an adptive filtering using genetic algorithm. In the simulations over various images, the proposed partition based median (PBM) filter using genetic algorithm in training have demonstrated better results in noise suppressing then competitive filters based on median filtering in terms of SNR(dB) as well as the perceived image quality.

Ali, Emary and El-Kareem (2009) applied genetic algorithm in solving linear equation systems. There are several algorithms for solving linear system of equations. Iteration algorithms are recommended for the large linear systems with sparse matrix. But in the case of general n x m matrices, the classic iterative algorithms are not applicable with a few exceptions. So, in this paper, they have used genetic algorithms to find the solution of a system of linear equations since it is difficult to describe the solution set of a linear system with infinitely many solutions. To avoid the disadvantages of solving large system of linear equations such as rounding errors, inverting large matrixes, the genetic algorithms are introduced. The obtained results indicate that a GA is effective and represents an efficient approach to solve the systems of linear equations. When they used G.A. in solving linear system, they saw that the solution was almost equal to the analytical one.

Chapter 3

SPONTANEOUS HEATING OF COAL

PROBLEMS ASSOCIATED WITH SPONTANEOUS HEATING OF COAL

MECHANISM

DIFFERENT INDICES USED TO MEASURE SPONTANEOUS HEATING

3. SPONTANEOUS HEATING

Spontaneous combustion is a type of combustion which occurs without an external ignition source. Coal can interact with oxygen of air in ambient temperature liberating heat which if allowed to accumulate would enhance the rate and ultimately lead to fires known as spontaneous heating of coal. Spontaneous heating would be facilitated in conditions where large mass of coal is involved and ventilation is neither too little to restrict coal-oxygen interaction nor too big to dissipate away all the heat generated from above. Under such conditions, a part of coal mass may heat up to the stage of ignition after the lapse of a certain time period.

3.1 PROBLEMS ASSOCIATED WITH SPONTANEOUS HEATING OF COAL

Mine fires may engulf a large area and spread further if they are not immediately attended to. Associated hazards are also encountered, may be gas poisoning from the liberation of carbon monoxide and explosions if he fires come in contact with adequate concentration of fire damp.

These fires may create hinderance to normal production or pose a threat to surface structures or adjacent property and may create pollution problems.

Fire in surface stacks is easier to deal with than underground fires. Due to this, several million tons of coals are lost every year.

3.2 MECHANISM

Although many factors affect heat producing reactions, the oxidation of carbonaceous matter in coal at ambient temperatures is the major cause for the initiation of spontaneous combustion. The oxidation of coal, like all oxidation reactions, is exothermic in character.

Physical adsorption of oxygen

$$\text{Coal + oxygen} \rightarrow \text{coal-oxygen complex} \rightarrow \text{oxidized coal+ } CO, CO_2, H_2O$$

The main causes of spontaneous heating are the sorption and oxidation properties of coal substance itself at low temperatures. Freshly exposed coal has at ambient atmospheric temperatures, affinity for oxygen of the air in contact with it. At first, the oxygen is adsorbed by purely physical process, depending on the temperature, which rapidly gives place to a chemical chain reaction resulting in the oxidation of certain constituents of coal with the production of a small quantity of heat.

3.3 DIFFERENT INDICES USED TO MEASURE SPONTANEOUS HEATING

Liability index with chemical method

It is the difference in puff or explosion temperature of coal in fully reduced and fully oxidized states. It is based on the fact that the ignition point of coal is lowered due to oxidation. By measuring the ignition temperature of coal in as-mined/ as-received state (T), fully oxidized state (T_0) and fully reduced state (T_R), the degree of oxidation and liability index are calculated from the lowering of ignition temperatures.

Degree of oxidation= $\frac{TR-T}{TR-T0} \times 100$

Liability index $\Delta T_R = T_R - T_0$

Liability index	Types of heat
$\Delta T_R < 10$	no danger of self-heating
$10 < \Delta T_R < 25$	less liable to self- heating
$\Delta T_R > 25$	very liable to self-heating

C/H ratio

Ghosh and Banerjee introduced C/H ratio to assess the intensity character of the fire, along with the rate of oxygen consumption that indicates extensivity character of it. Considering coal to be a fuel of the type $C_xH_yO_z$ they showed the method of calculation to be as.

$$[3(CO_2+CO+CH_4+2C_2H_4)]/ [0.2648N_2-O_2-CO_2-0.5CO+0.5H_2+CH_4+C_2H_4]$$

C/H ratio	Types of fire
up to maximum 3	superficial heating
Above 5	active fire
From around 20	blazing fire

Jones and Trickett ratio

This ratio $\{[CO_2] + 0.75[CO]-0.25[H_2]\}/\Delta O_2$ serves as an indicator of the type of fuel involved in any fire or explosion. Jones and Trickett developed this ratio for determining whether methane or coal dust has been involved in a mining explosion.

Type of fuel	values
For methane	0.4 to 0.5
For coal, oil or conveyor belt	0.5 to 1
For timber	0.9 to 1.6

Young's ratio

Carbon dioxide produced as percentage of oxygen absorbed is considered as Young's ratio or CO_2/O_2 deficiency ratio.

Young's ratio	Types heating
$Y<25$	superficial heating
$Y>50$	high intensity fire

Graham's ratio

Graham's ratio = (CO_2 produced)/ (O_2 deficiency) *100

Graham's ratio	Result of heating
0.4 Or less	normal value
0.5	necessity for a thorough check-up
1	existence of heating
2	serious heating approaches active fire
3 and above	active fire with certainty
Greater than 7	blazing fire

Chapter 4

EXPERIMENTAL INVESTIGATION

SAMPLE COLLECTION AND PREPARATION

PROXIMATE ANALYSIS

CROSSING POINT TEMPERATURE

DIFFERENTIAL THERMAL ANALYSIS

WET OXIDATION POTENTIAL METHOD

4. EXPERIMENTAL INVESTIGATION

4.1 SAMPLE COLLECTION AND PREPARATION

Sampling is the process by which physical and chemical characteristics of a mineral or ore are ascertained 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 determined by proximate and ultimate analysis such as fixed carbon, volatile matter, ash, caking index and calorific value etc. the physical nature of the ore is sometimes necessary to be determined 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 collected 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.

4.2 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.

4.2.1 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 inherent 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 100^0C. 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 related 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 ±2^oC. 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.

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

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

4.2.2 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 decomposition of the various components of coal. Some of the constituents 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 determination of volatile matter a special volatile 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 800^oC for an hour in the muffle furnace and then cooled to 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 muffle furnace maintained at 925°C with the lid covering the crucible. The heating was carried out exactly for seven minutes, after which the crucible was removed, cooled in air and then in a desiccator and weighed again.

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

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

4.2.3 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: extraneous 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 mixed up during mining and handling 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 insignificant as far as the total quantity of ash is concerned. But Indian coals suffer from the major disadvantage, that the mineral matter content is not only high, but of intimately associated type, due to its drift origin.

Ash is quantitatively and qualitatively different from the mineral matter originally present in coal, because of the various changes 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 conditions determine the extent to which the weight change takes place and it is essential that standardized procedures should be closely followed to ensure reproducibility.

Experimental Procedure

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

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

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)

Table 4.1 proximate analysis of coal samples

Sample no	Proximate Analysis		
	Moisture,M (%)	Volatile Matter, VM (%)	Ash Content(A) %
1	4.974	31.949	23.913
2	9.955	30.395	12.6
3	5.785	27.35	18.6
4	5.894	30.706	26.25
5	7.669	30.921	10.8
6	9.164	26.586	16.241
7	6.488	28.262	10.395
8	3.96	26.134	23.3
9	2.932	30.883	12.037
10	1.948	33.052	17.527
11	2.345	29.641	15.725

12	4.48	25.01	44.02
13	2.4	23.27	52.3
14	14.5	31.97	12.35
15	8.97	29.49	22.88
16	9.59	28.93	7.68
17	11.13	25.19	38.46
18	1	17.36	15.73
19	1.9	33.08	16
20	0.6	22.32	10.73
21	8.43	24.43	9.6
22	1.8	36.13	14.27
23	10	32.27	18
24	10.52	29.47	11.91
25	7.67	29.83	18.88
26	14.39	29.31	12.76
27	9.68	29.8	18.12

CROSSING POINT TEMPERATURE

It is the temperature at which the temperature of coal coincides with that of the heating furnace or bath in ^{0}C. 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 setup

The setup for the determination of crossing point temperature (CPT) of coal consists of following:

- Vertical tubular furnace having heating capacity of 3kw. The furnace is provided with a temperature controller and a printer.
- Glass reaction tube is of 26mm internal diameter and 150mm in length. The reaction tube has spiraling glass tube of 6mm internal diameter around it which is connected to the bottom (inside) of the reaction tube for air inlet and a small out-let tube at the top acts as air/gas outlet.

- Flow meter and pressure flow control valves.
- Purifying and dehumidifying trains for air or nitrogen.
- A potassium hydroxide bubbler to remove carbon dioxide in the incoming air.
- A sulphuric acid bubbler to remove moisture in air.
- A drying tower containing granular calcium chlorides to remove moisture from air.

Fig 4.1 Experimental setup of crossing point temperatures

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 density 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 entrapped 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 1^0C 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.

Table 4.2 crossing point temperatures of coal samples

Sample No.	CPT(^{0}C)
1	159
2	171
3	163
4	167
5	162
6	185
7	165
8	173
9	163
10	156
11	165
12	169
13	174
14	155
15	147
16	149
17	149
18	180
19	155
20	160
21	152
22	150
23	144
24	152.5
25	155
26	150
27	138

4.4 DIFFERENTIAL THERMAL ANALYSIS

Thermal analysis is technique 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 changes in a block which is heated at a linear heating rate.

The experiment was carried out by a Differential Thermal Analyser (Figure 4.2). The standardized parameters suggested by Banerjee and Chakravorty (1967) were followed while performing the experiments.

The crucible for sample and reference was put in position on the ceramic post. 6-10 mg of -212μ size coal sample was weighed and put into the sample holder. Oxidizing atmosphere was maintained by keeping the coal sample exposed to air. Alpha alumina powder was used as the reference material. The tubular furnace was then lowered. The software was programmed to run until 450^0C at a rate of 5^0C per minute. After the heating is terminated, thermogram is obtained for the sample. A few sample thermograms have been presented in figures 4.3 to 4.10

Fig 4.2: Experimental set up of differential thermal analysis

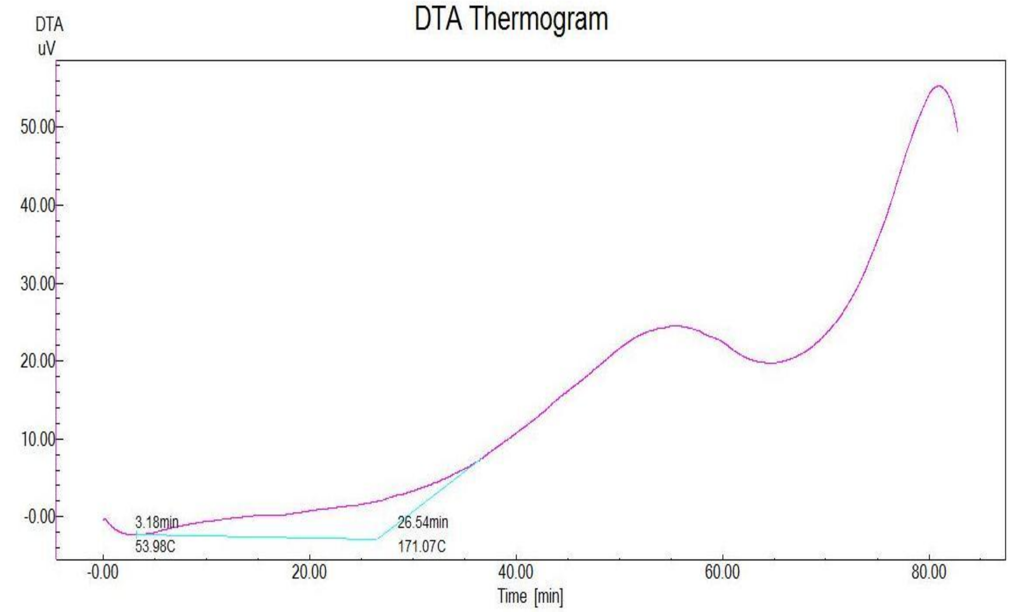


Fig 4.3: DTA thermogram of sample no. 1

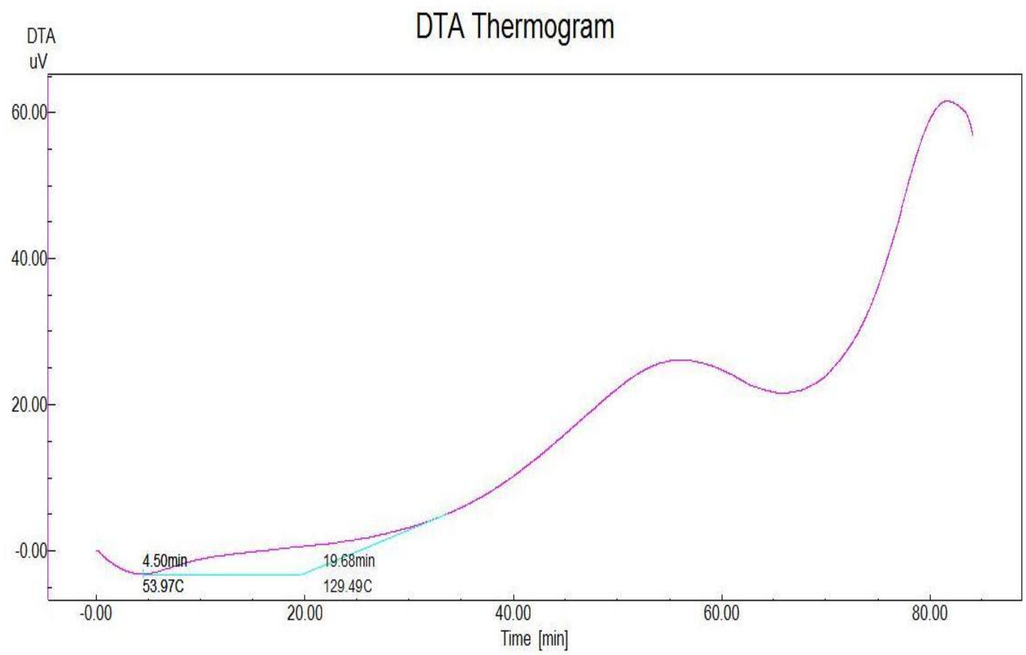


Fig 4.4: DTA thermogram of sample no. 2

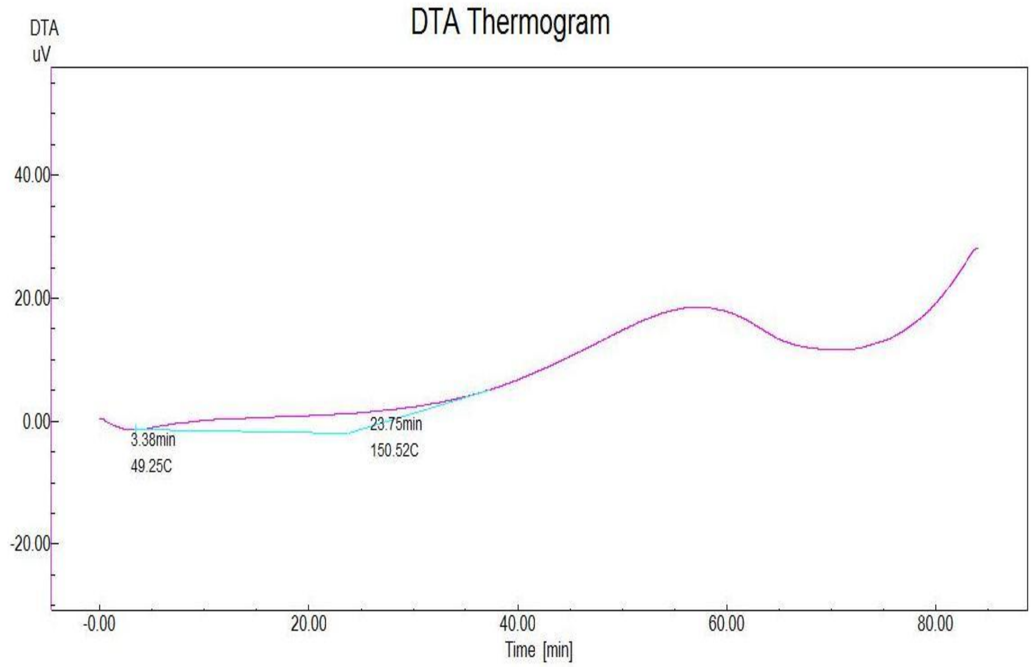


Fig 4.5: DTA thermogram of sample no. 3

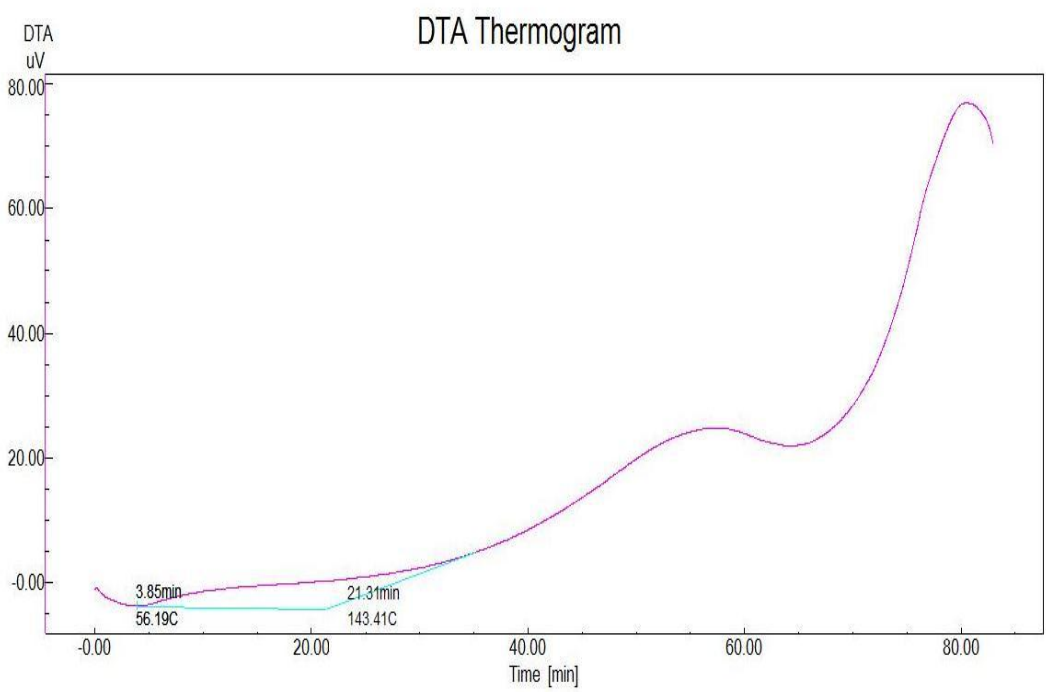


Fig 4.6: DTA thermogram of sample no. 4

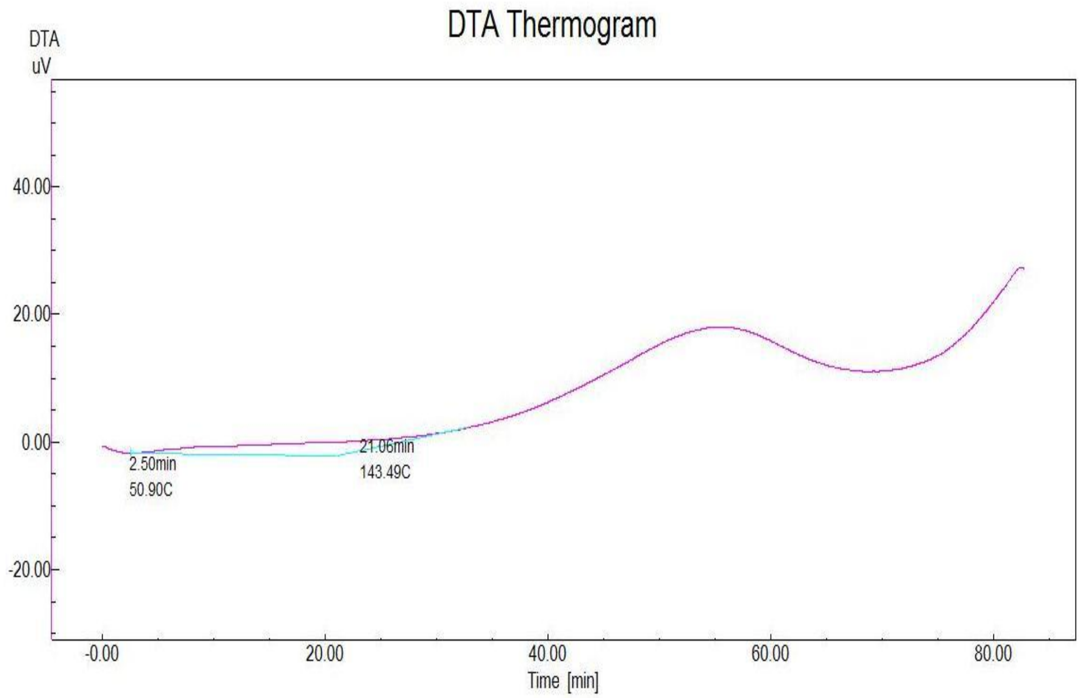


Fig 4.7: DTA thermogram of sample no. 5

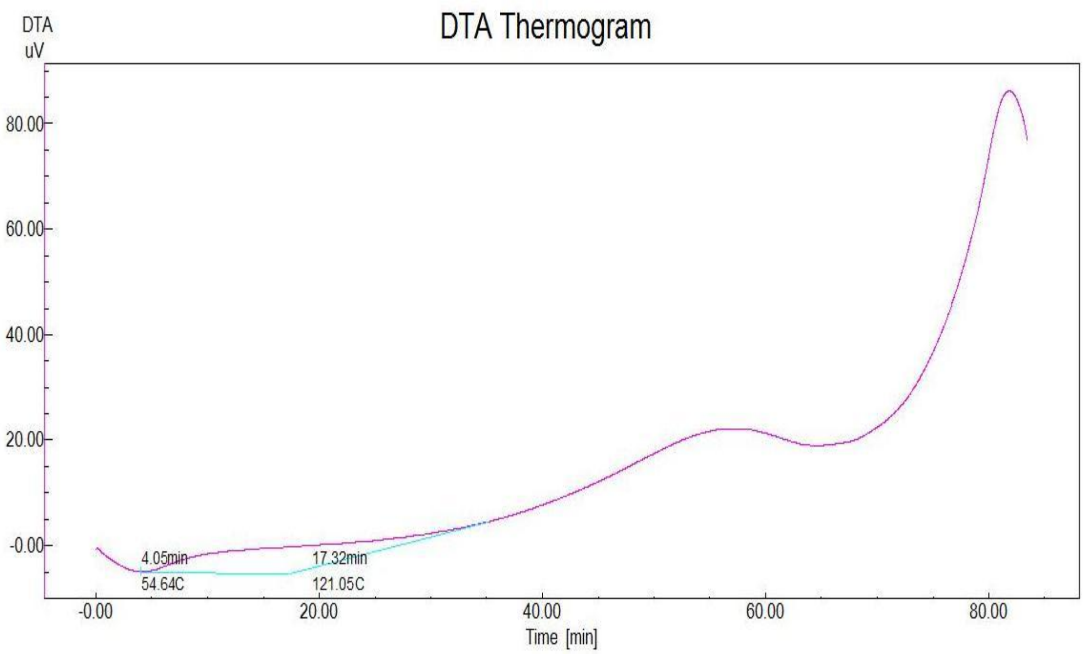
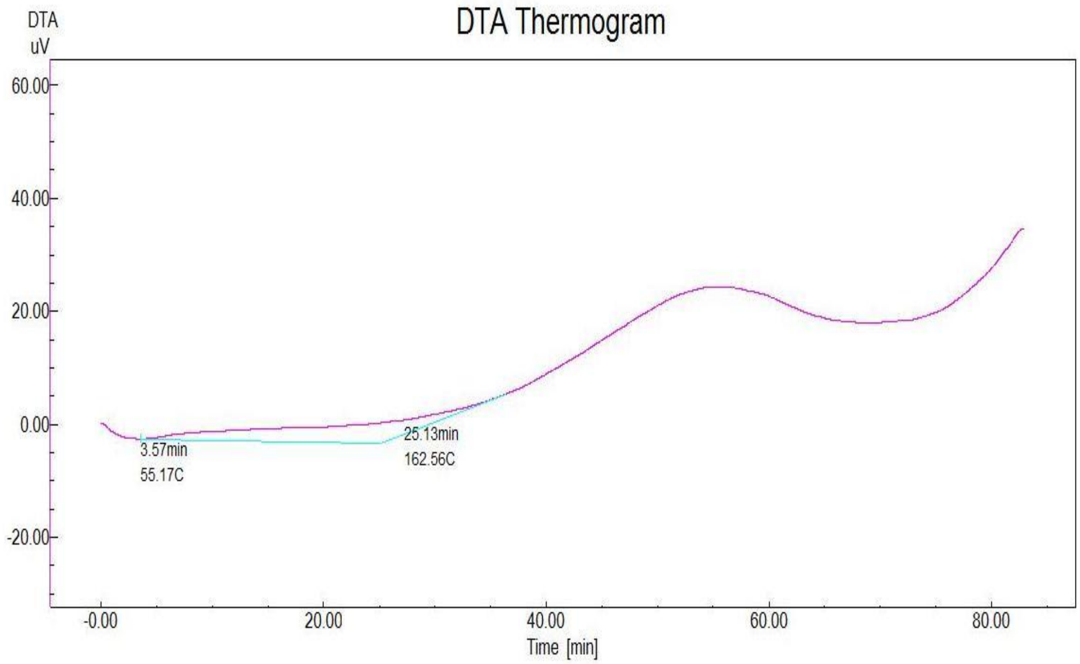


Fig 4.8: DTA thermogram of sample no. 6



DTA

Fig 4.9: DTA thermogram of sample no. 7

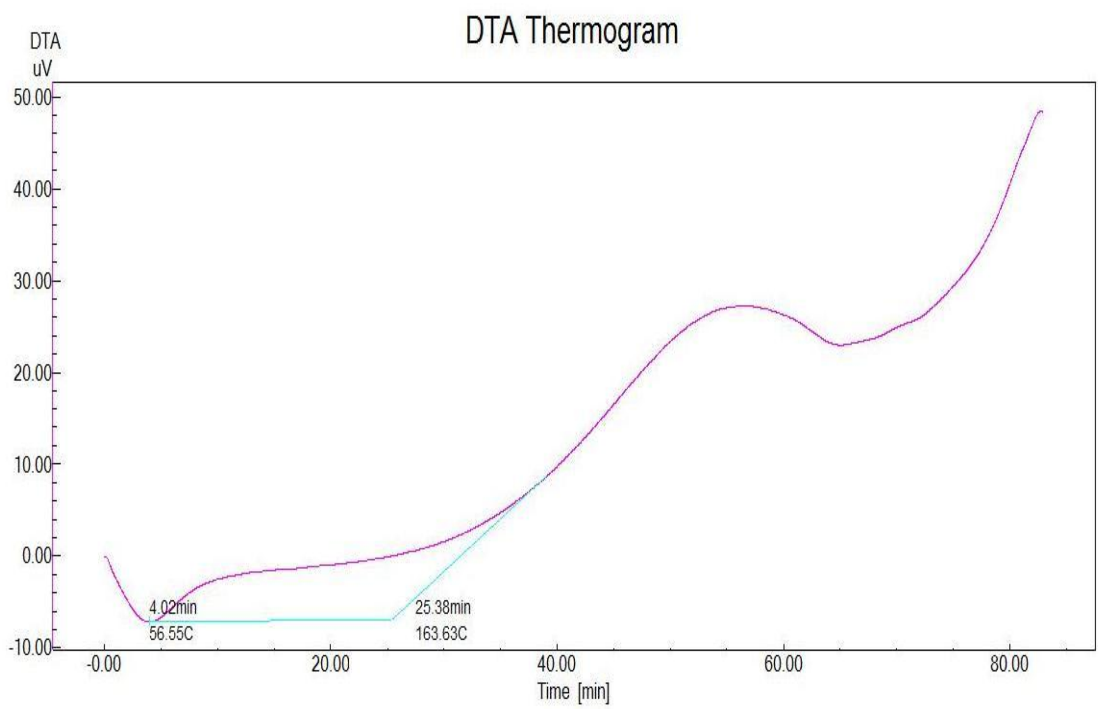


Fig 4.10: DTA thermogram of sample no. 8

It has been shown by Banerjee and Chakravorty (1967) that a thermogram of coal can be divided into three segments or stages. 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 significant, but the rate of heat release is not steady all through, as it changes with temperature. A steep rise in heat evolution 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 regarded as a reliable indicator of the self heating risk, because it may be equally high for low rank coals. However, the temperature of transition or characteristic temperature or onset temperature is considered to be significant. It is considered that in lower temperatures, the coal is more susceptible towards spontaneous heating. Therefore, all the thermograms were analysed for the following details.

1. Onset temperature or characteristic temperature (T_c)

   The onset temperature or characteristic temperature was determined by the following procedure:

   - A tangent was drawn at the inflexion point of the endothermic region and another tangent was drawn at the rising portion of the curve of stage III.
   - The intersection between the two tangents gave the characteristic temperature.

The onset temperature (Tc) of all the coal samples were determined by following the above procedure and have been presented in table 4.3

Table 4.3 Onset temperature of coal samples

Sample No.	T_c(^{0}C)
1	171.07
2	129.49
3	123.4
4	143.41
5	138.36
6	123.12
7	162.56
8	163.63
9	186.8

10	184.15
11	189.56
12	155.93
13	147.29
14	158.46
15	153.34
16	124.82
17	171.87
18	188.98
19	128.38
20	169.66
21	162.3
22	129.33
23	132.94
24	136.87
25	145.33
26	128
27	122.67

4.5 WET OXIDATION POTENTIAL

The coal molecule may be considered as consisting of two parts : the aliphatic or hydroaromatic 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 faster. 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 aliphatics.

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 manganate ion by the following reaction:

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

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

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

Where

R = Universal gas constant

T = Temperature

F = Faraday's constant

When coal is added to alkaline permanganate, oxidation takes place and the concentration of manganate ion in solution increases relative to permanganate and there will be resultant change in the potential till all the oxidation possible in coal molecule is complete. Therefore, addition of coal to alkaline permanganate solution results in a change of potential of carbon electrode dipped in the solution. The electrode can be represented as carbon/MnO_2^-, MnO_2^{2-}.

Apparatus Required:

- Beaker
- Saturated calomel electrode
- Carbon electrode
- Millivoltmeter
- Magnetic stirrer
- 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. A few sample curves are as presented in Figures 4.11 to 4.12. Different samples require different time duration for attaining a nearly constant potential difference (ΔE). Therefore, the duration of experiment in each case is different. In order to compare the oxidation rate of different samples a constant time frame is chosen based on the analysis of the plots. In the present 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 comparative study and the results are as presented in Table 4.4.

Table 4.4 Wet oxidation potential difference of coal samples

Sample numbers	Wet oxidation potential difference (mV)
1	112
2	112
3	114
4	119
5	101
6	113
7	109
8	80
9	99.9
10	108
11	103
12	102
13	104

14	51.2
15	47.5
16	54.1
17	99.3
18	26.6
19	63.9
20	41.8
21	87.8
22	106.6
23	143.1
24	121.8
25	123.8
26	161
27	206

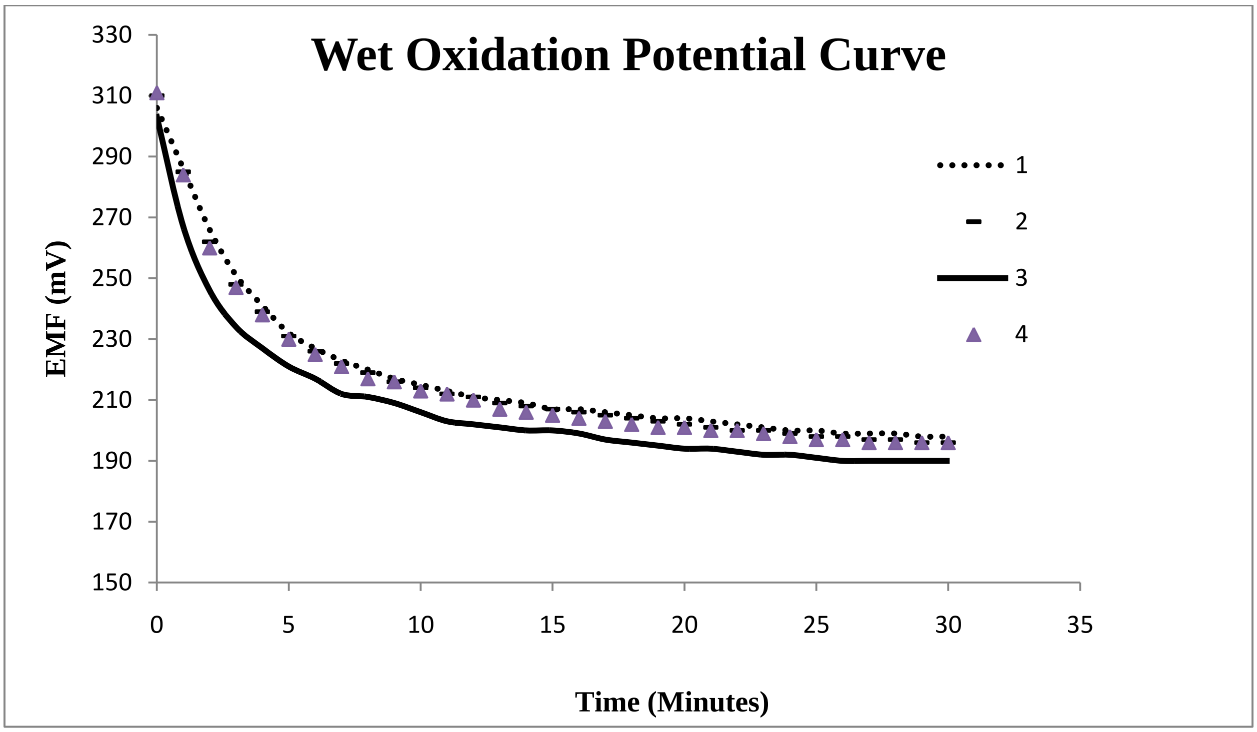


Fig 4.11 wet oxidation potential curve of sample nos. 1, 2, 3 and 4

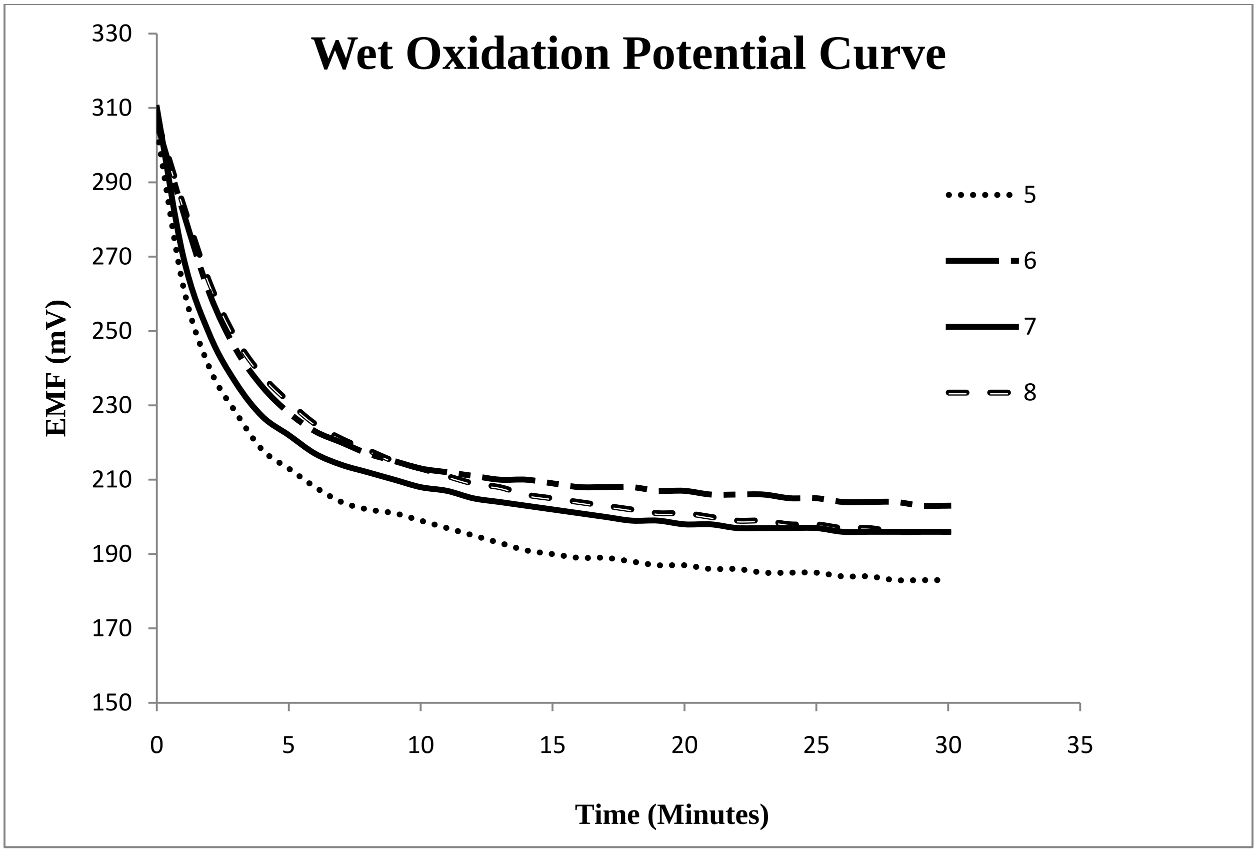


Fig 4.12 wet oxidation potential curve of sample nos. 5, 6, 7 and 8

Chapter 4

APPLICATION OF GENETIC ALGORITHM FOR THE ASSESSMENT OF SPONTANEOUS HEATING SUSCEPTIBILITY OF COAL

GENETIC ALGORITHM

OUTLINE OF THE BASIC GENETIC ALGORITHM

METHODOLOGY

COMPARISONS OF GAs WITH OTHER METHODS

APPLICATION OF GENETIC ALGORITHM FOR ASSESSMENT OF SPONTANEOUS HEATING SUSCEPTIBILITY OF COAL

5. APPLICATION OF GENETIC ALGORITHM FOR THE ASSESSMENT OF SPONTANEOUS HEATING SUSCEPTIBILITY OF COAL

5.1 GENETIC ALGORITHM

A genetic algorithm (GA) is a search technique used in computing to find exact or approximate solutions to optimization and search problems. Genetic algorithms are categorized as global search heuristics. Genetic algorithms are a particular class of evolutionary algorithms (EA) that use techniques inspired by evolutionary biology such as inheritance, mutation, selection, and crossover. Genetic algorithms are inspired by Darwin's theory about evolution. Solution to a problem solved by genetic algorithms is evolved. Algorithm is started with a set of solutions (represented by chromosomes) called population. Solutions from one population are taken and used to form a new population. This is motivated by a hope, that the new population will be better than the old one. Populations are selected to form new solutions (offspring) according to their fitness, the more suitable they are the more chances they have to reproduce. This is repeated until some condition (for example number of populations or improvement of the best solution) is satisfied.

5.2 OUTLINE OF THE BASIC GENETIC ALGORITHM

1. **[Start]** Generate random population of *n* chromosomes (suitable solutions for the problem)
2. **[Fitness]** Evaluate the fitness *f(x)* of each chromosome *x* in the population
3. **[New population]** Create a new population by repeating following steps until the new population is complete
4. **[Selection]** Select two parent chromosomes from a population according to their fitness (the better fitness, the bigger chance to be selected)
5. **[Crossover]** With a crossover probability cross over the parents to form a new offspring (children). If no crossover was performed, offspring is an exact copy of parents.
6. **[Mutation]** With a mutation probability mutate new offspring at each locus (position in chromosome).
7. **[Accepting]** Place new offspring in a new population

8. **[Replace]** Use new generated population for a further run of algorithm
9. **[Test]** If the end condition is satisfied, **stop**, and return the best solution in current population
10. **[Loop]** Go to step **2**

5.3 METHODOLOGY

Coding

Before a GA can be run, a suitable coding (or representation) for the problem must be devised. We also require a fitness function, which assigns a figure of merit to each coded solution. During the run, parents must be selected for reproduction, and recombined to generate offspring. It is assumed that a potential solution to a problem may be represented as a set of parameters (for example, the parameters that optimize a neural network). These parameters (known as genes) are joined together to form a string of values (often referred to as a chromosome. For example, if our problem is to maximize a function of three variables, F(x; y; z), we might represent each variable by a 10-bit binary number (suitably scaled). Our chromosome would therefore contain three genes, and consist of 30 binary digits. The set of parameters represented by a particular chromosome is referred to as a genotype. The genotype contains the information required to construct an organism which is referred to as the phenotype. For example, in a bridge design task, the set of parameters specifying a particular design is the genotype, while the finished construction is the phenotype. The fitness of an individual depends on the performance of the phenotype. This can be inferred from the genotype, i.e. it can be computed from the chromosome, using the fitness function. For a bit string encoding of length L; the size of the search space is 2L and forms a hypercube. The genetic algorithm samples the corners of this L-dimensional hypercube. Generally, most test functions are at least 30 bits in length; anything much smaller represents a space which can be enumerated. Obviously, the expression 2L grows exponentially. As long as the number of “good solutions” to a problem is sparse with respect to the size of the search space, then random search or search by enumeration of a large search space is not a practical form of problem solving. On the other hand, any search other than random search imposes some bias in terms of how it looks for better solutions and where it looks in the search space. A genetic algorithm belongs to the class of methods known as "weak methods" because it makes relatively few assumptions about the problem that is being solved. The chromosome should in some way contain information about solution which it represents. The most used way of encoding is a binary string. The chromosome then could look like this:

Chromosome 1	1101100100110110
Chromosome 2	1101111000011110

Fitness function

A fitness function must be devised for each problem to be solved. Given a particular chromosome, the fitness function returns a single numerical "fitness," or "figure of merit," which is supposed to be proportional to the "utility" or "ability" of the individual which that chromosome represents. For many problems, particularly function optimisation, the fitness function should simply measure the value of the function.

Reproduction

Good individuals will probably be selected several times in a generation, poor ones may not be at all. Having selected two parents, their chromosomes are recombined, typically using the mechanisms of Crossover and mutation.

Crossover

Crossover is a genetic operator that combines two chromosomes (parents) to produce a new chromosome (off spring). Crossover selects genes from parent chromosomes and creates a new offspring. The simplest way how to do this is to choose randomly some crossover point and everything before this point point copy from a first parent and then everything after a crossover point copy from the second parent. Crossover can then look like this (| is the crossover point):

Chromosome 1	11011 | 00100110110
Chromosome 2	11011 | 11000011110
Off spring 1	11011 | 11000011110
Off spring 2	11011 | 00100110110

Mutation

Mutation is a genetic operator that alters one or more gene values in a chromosome from its initial state. This can result in entirely new gene values being added to the gene pool. With these new gene values, the genetic algorithm may be able to arrive at better solution than was previously possible. Mutation is an important part of the genetic search as help helps to prevent the population from stagnating at any local optima. Mutation occurs during evolution according to a user-definable mutation probability. This is to prevent falling all solutions in population into a local optimum of solved problem. Mutation changes randomly the new offspring. For binary encoding we can switch a few randomly chosen bits from 1 to 0 or from 0 to 1. Mutation can then be following:

Original offspring 1	110**1**111000011110
Original offspring 2	110110**0**100110110
Mutated offspring 1	110**0**111000011110
Mutated offspring 2	110110**1**100110110

Convergence

The fitness of the best and the average individual in each generation increases towards a global optimum. Convergence is the progression towards increasing uniformity. A gene is said to have converged when 95% of the population share the same value. The population is said to have converged when all of the genes have converged. As the population converges, the average fitness will approach that of the best individual. A GA will always be subject to stochastic errors. One such problem is that of genetic drift. Even in the absence of any selection pressure (i.e. a constant fitness function), members of the population will still converge to some point in the solution space. This happens simply because of the accumulation of stochastic errors. If, by chance, a gene becomes predominant in the population, then it is just as likely to become more predominant in the next generation as it is to become less predominant. If an increase in predominance is sustained over several successive generations, and the population is finite, then a gene can spread to all members of the population. Once o gene has converged in this way, it is fixed; crossover cannot introduce new gene values. This produces a ratchet effect, so that as generations go by, each gene eventually becomes fixed. The rate of genetic drift therefore provides a lower bound on the rate at which a GA can converge towards the correct solution. That is, if the GA is to exploit gradient information in the fitness function, the fitness function must provide a slope sufficiently large to counteract any genetic drift. The rate of genetic drift can be reduced by increasing the mutation rate. However, if the mutation rate is too high, the search becomes effectively random, so once again gradient information in the fitness function is not exploited.

5.4 COMPARISONS OF GAs WITH OTHER METHODS

Neural nets

Both GAs and neural nets are adaptive, learn, can deal with highly nonlinear models and noisy data and are robust, "weak" random search methods. They do not need gradient information or smooth functions. In both cases their flexibility is also a drawback, since they have to be carefully structured and coded and are fairly application-specific. For practical purposes they appear to work best in combination: neural nets can be used as the prime modelling tool, with GAs used to optimise the network parameters.

Random Search

The brute force approach for difficult functions is a random, or an enumerated search. Points in the search Space is selected randomly or in some systematic way, and their fitness evaluated. This is a very unintelligent strategy, and is rarely used by itself.

Gradient methods

A number of different methods for optimizing well-behaved continuous functions have been developed which rely on using information about the gradient of the function to guide the direction of search. If the derivative of the function cannot be computed, because it is discontinuous, for example, these methods often fail. Such methods are generally referred to as hillclimbing. They can perform well on functions with only one peak (unimodal functions). But on functions with many peaks, (multimodal functions), they suffer from the problem that the first peak found will be climbed, and this may not be the highest peak. Having reached the top of a local maximum, no further progress can be made.

Iterated Search

Random search and gradient search may be combined to give an iterated hillclimbing search. Once one peak has been located, the hillclimb is started again, but with another, randomly chosen, starting point. This technique has the advantage of simplicity, and can perform well if the function does not have too many local maxima. However, since each random trial is carried out in isolation, no overall picture of the "shape" of the domain is obtained. As the random search progresses, it continues to allocate its trials evenly over the search space. This means that it will still evaluate just as many points in regions found to be of low fitness as in regions found to be of high fitness. A GA, by comparison, starts with an initial random population, and allocates increasing trials to regions of the search space found to have high fitness. This is a disadvantage if the maximum is in a small region, surrounded on all sides by regions of low fitness. This kind of function is difficult to optimize by any method, and here the simplicity of the iterated search usually wins.

Simulated annealing

This is essentially a modified version of hill climbing. Starting from a random point in the search space, a random move is made. If this move takes us to a higher point, it is accepted. If it takes us to a lower point, it is accepted only with probability p(t), where t is time. The function p(t) begins close to 1, but gradually reduces towards zero, the analogy being with the cooling of a solid. Initially therefore, any moves are accepted, but as the "temperature" reduces, the probability of accepting a negative move is lowered. Negative moves are essential sometimes if local maxima are to be escaped, but obviously too many negative moves will simply lead us away from the maximum. Like the random search, however, simulated annealing only deals with one candidate solution at a time, and so does not build up an overall picture of the search space. No information is saved from previous moves to guide the selection of new moves.

5.4 APPLICATION OF GENETIC ALGORITHM FOR ASSESSMENT OF SPONTANEOUS HEATING SUSCEPTIBILITY OF COAL

Algorithm

1. Random population of 25 chromosomes was generated.
2. The fitness function f(x) of each chromosome in the population was evaluated.

   F(x) = $\sqrt{\sum(Xi - Yi)2}$
3. A new population was created by repeating following steps until the new population is complete.

4. Two chromosomes from a population were selected according to their fitness.
5. With a crossover probability a new offspring was formed.
6. With a mutation probability new offspring was mutated at each locus.
7. New offspring was placed in a new group.
8. After a run of algorithm new groups of samples were generated

Procedure

Coal seams are classified by using genetic algorithm to determine their spontaneous heating susceptibility. For this purpose a program was written in C++. The program was run using four variables, which are

6. Moisture
7. Volatile matter
8. Ash
9. One of the following susceptibility indices at a time.
    - Crossing point temperatures
    - Onset temperatures
    - Wet oxidation potential values

All results of 27 coal samples were normalized by dividing maximum value in column and then stored in a text file. The program was run to obtain different clusters. However, it was observed that sample numbers in different were consistent when four clusters were obtained, therefore four clusters were taken in all cases. The results of clustering taking the constituents of proximate analysis and one of the susceptibility indices at a time, viz. CPT, T_c obtained from DTA thermogram and wet oxidation potential difference are as presented in tables 4.5 to 4.7.

Table 4.5 Clustering of samples using M, VM, A and CPT as variables

Cluster no.	Number of samples	Sample numbers
1	16	1,2,3,4,5,6,7,12,15,17,21,23,24,25,26,27
2	2	14, 16
3	8	8,9,10,11,18,19,20,22
4	1	13

Table 4.6 Clustering of samples using M, VM, A and DTA as variables

Cluster no.	Number of samples	Sample numbers
1	14	2,3,4,5,6,7,12,15,17,21,23, 24,25,27
2	3	14,16, 26
3	1	13
4	9	1,8,9,10,11,18,19,20

Table 4.7 Clustering of samples using M, VM, A and Wet oxidation potential difference as variables

Cluster no.	Number of samples	Sample numbers
1	16	1,2,3,4,5,6,7,12,15,16,17,21,23,24,25,27
2	1	13
3	8	8,9,10,11,18,19,20,22
4	2	14,26

Chapter 6

DISCUSSION AND CONCLUSION

DISCUSSION

CONCLUSION

6. DISCUSSION AND CONCLUSION

6.1 DISCUSSION

The proximate analysis of all the 27 samples which were carried out following the Indian Standard procedure. It may be observed from table 4.1 that the sample MCL 3 has the highest moisture content (14.5%) and sample no.20 has the lowest(0.6%). It was also found that sample no. 22 and sample SECL 9 have the highest volatile matter content (36.13% and 33.052%) respectively, where as sample no. 18 has the lowest volatile matter content (17%). It has been observed in the past that coals with high volatile-matter content ignite easily and are highly reactive in combustion applications. The ash content of the samples varied to a large extent form 7.68 for sample MCL 5 to 52.3% for sample MCL 2.

It may be observed from table 4.3 that the onset temperature of the coal samples varied from 123.4 (sample no. 3) to 189.56(sample no. 11). Lower is the transition temperature higher is the spontaneous heating susceptibility of coal seams. Sample no. 3 has the lowest onset temperature. So it may be considered to be very highly susceptible. This sample belongs to the SECL and it is corroborated from the fact that it is known to be a fiery seam in the field. Panigrahi and Sahu (2004) have found that the coal seams having onset temperature in the range of 122^0C to 140^0C are highly susceptible to heating. Therefore, sample no. 2,3,5,6,16,19,22,23,24,26 and 27 could be considered as very highly susceptible to heating. They have also found that the seams having onset temperature between 140^0C to 170^0C to be moderately susceptible and above 170^0C to be poorly susceptible to spontaneous heating. Therefore, sample nos.4,7,8,12,13,14,15,20 and 21 can be considered as moderately susceptible and sample no. 1,9,10,11,17 and 18 as poorly susceptible to heating.

It may be observed from table 4.3 that the crossing point temperature of the coal samples varied from 147 (sample no. 15) to 185(sample no. 6). Lower is the crossing point temperature, higher is the spontaneous heating susceptibility of coal seams. Sample no. 15 has the lowest crossing point temperature. So it may be considered to be very highly susceptible. This sample belongs to the MCL. Coal seams having crossing point temperature in the range of 120^0C to 140^0C are highly susceptible to heating. Therefore, sample no. 27 could be considered as very highly susceptible to heating. Crossing point temperature between 140^0C to 160^0C to be moderately susceptible and above 160^0C to be poorly susceptible to spontaneous heating.

It may be noted that the clusters obtained by applying genetic algorithm only shows that the characteristics of different samples in the same cluster are similar. A judgement regarding the order of clusters or categorisation can be taken based upon the behavior of a few samples in each cluster in the field as well as based upon their susceptibility indices.

Sample nos. 21 (samla seam, ECL) and sample no. 27 (Jhingurda seam, NCL) are well known for their high susceptibility in Indian coalfields. These have been placed in a single cluster along with a few other coal samples. All the coal samples in this cluster may be termed as highly susceptible.

Sample no. 18(Bastacola-0 seam, BCCL) takes a very long time to catch fire in the field and is known to be a poorly susceptible coal. Its CPT is also very high. The samples in this cluster may be termed as poorly susceptible.

There have been instances of fire in coal seams represented by sample no. 26. This cluster therefore may be termed as highly susceptible. Sample no. 16 finds a place in this cluster in case of clustering with T_c of DTA thermogarm, where as it is placed in cluster no.1 in the rest two cases. Since in majority of the cases it is in cluster no. 1, it may be grouped with samples in cluster no. 1

Sample no 13 is placed in a separate cluster in all cases. From the aforementioned discussion it is clear that it may be termed as a moderately susceptible coal.

6.2 CONCLUSION

The classification of coal seams based on their proneness to spontaneous heating is either done empirically or by some thumb rule. The present classification is based upon genetic algorithm approach which is inspired by Darwins theory of evolution and it provides a mathematical base for classification of seams with respect to their proneness to spontaneous heating. By knowing the susceptibility of a few coal samples in each cluster the seams can been classified into four categories and these are as follows:

Susceptibility	Sample numbers
Very High	1,2,3,4,5,6,7,12,15,16,17,21,23,24,25,27
High	14, 26
Moderate	13
Low	8,9,10,11,18,19,20,22

The above classification has been confirmed by using three different susceptibility indices separately, which adds authenticity to this classification system. Any new coal seam can be placed in a category by using genetic algorithm, by knowing the constituents of proximate analysis, which are commonly determined in the field as they are required to determine the grade of coals in our country, and any one of the aforementioned susceptibility indices in the laboratory.

It is hoped that the output of the work will benefit the practicing mining engineers and researchers to a greater extent in categorizing coal samples, depending upon their spontaneous heating susceptibility and accordingly plan the mining activities and adopt advance precautionary measures to deal with fire problems in their mines.

Chapter 7

REFERENCES

7. REFERENCES

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