OPTIMIZATION OF HEATING RATE OF CROSSING POINT TEMPERATURE APPARATUS

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

BACHELOR OF TECHNOLOGY

IN

MINING ENGINEERING

BY

SUNIL KUMAR SINGH

108MN023

DEPARTMENT OF MINING ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY

ROURKELA – 769008

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Under the guidance of

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CERTIFICATE

This is to certify that the thesis entitled “**OPTIMIZATION OF HEATING RATE OF CROSSING POINT TEMPERATURE APPARATUS**” submitted by **Sri Sunil Kumar Singh** in partial fulfillment of the requirements for the award of Bachelor of Technology degree in Mining Engineering at National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance.

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

Prof. D.S. Nimaje

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Date: **Sunil Kumar Singh**

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CONTENTS

ABSTRACT

A further understanding of the heating rate of crossing point temperature apparatus was obtained by investigating the crossing point temperature (CPT) of different ranks of coal. The test was carried out using a designed experimental system for self-heating of coal. 4 gm. of coal sample of -100+200 mesh size were put into a copper reaction vessel place inside the spiral glass tube. The spiral glass tube is attached at the center of the furnace equipped with temperature controller. The temperature controller increases the temperature at different heating rates. Oxygen was permitted to flow into the coal reaction vessel at 80ml/min. The furnace temperature and the coal temperature were monitored by a temperature logger. The results indicate the CPT values affected by coal rank, moisture, sulphur and the experimental conditions. Higher rank coal show higher CPT values. A high moisture content causes a delay phenomenon during the self-heating of the coal. Drying at 40˚C decreases the effects of moisture. The flow rate of oxygen, and the heating rate of the furnace, also affects the spontaneous combustion of coal. The most appropriate experimental conditions for coal samples of a given weight and particle size were determined through contrastive analysis. For the evaluation of optimum heating rate a number of coal samples were tested at different heating rates (0.8, 1, 1.6 and 2˚C/min.) keeping the other experimental condition same or nearly same and comparing the obtained result with the standard heating rate (1˚C/min.) taking into account the degree of proneness of coal sample to spontaneous heating the optimum heating rate is decided. Correlation has been drawn between proximate analysis parameters and CPT. It is seen that CPT decreases with increase of moisture, volatile matter and fixed carbon. On the other hand it increases with increase of ash. It was also found that CPT at 1˚C/min. has better correlation with proximate analysis parameter than 2˚C/min (optimum heating rate).

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Chapter 1

INTRODUCTION

INTRODUCTION

1.1 GENERAL

Coal is the source of about 27% of the world‘s primary energy consumption and it accounts for about 34% of electricity generated in the world, so much attention has been focused in recent years on coal as an alternative source of energy (Nimaje et.al., 2010). Coal is the dominant energy source in India and meets 55% of country‘s primary commercial energy supply. Mine fires in Indian coalfields is generally caused by spontaneous combustion of coal despite various preventive technologies being adopted. The spontaneous heating of coal varies over a wide range and it is important to assess their degree of proneness for taking preventive measures against the occurrence of fires to avoid loss of lives and property, sterilization of coal reserves and environmental pollution and raise concerns about safety and economic aspects of mining (Tripathy, 2001).

Coal when reacts with atmospheric oxygen, undergoes oxidation reaction and this reaction is exothermic in nature. If the heat released during this process is allowed to accumulate, the temperature continues to rise resulting in fire and this phenomenon is known as spontaneous combustion of coal. Mine fire due to spontaneous combustion of coal is a serious hazard that develops during mining and storage of coal. It leads to environment pollution, huge economic loss and personal injury.

Spontaneous combustion of coal mainly depends on two factors – intrinsic and extrinsic. Intrinsic parameters are mainly related to the nature of coal, like physico-chemical characteristics, petrographic distribution and mineral make up whereas the extrinsic parameters are associated with geological, atmospheric and mining conditions dominating during extraction of coal seams and mainly site specific. Many researchers worked on understanding the mechanism of spontaneous combustion to prevent this hazard. Among these researchers, the crossing point temperature method has been frequently used.

The temperature at which the temperature of coal exceeds the surrounding temperature is called the crossing point temperature (CPT). Nubling and Wanner first employed an oil-bath method that used a constant heating rate to test CPT of coal (Nubling et al., 1915). Ramlu then studied the crossing point temperature of Indian coals using the crossing point temperature apparatus having manual and automatic control of temperature. Chen and Chong suggested a new testing method to find CPT that used a cubic or column basket (Chen et al., 1998). Mahidin propose that the CPT dropped with rise in volatile matter, moisture content and oxygen content (Mahidin et al., 2002). Kadioglu and varamaz found that CPT rose with increase in moisture content and particle size of the coal (Kadioglu et al., 2003). Kucuk and Kadioglu tested CPT using a column reaction vessel and proposed that CPT decreases with decrease in the coal particle size and the air humidity, but rose with a decrease in moisture content of coal (Kucuk et al., 2003)Mandal propose that CPT rose if some inhibitor was added into the coal sample (Mandal et al., 2006).

This project determines the optimum heating rate of CPT apparatus for ten different coal samples and analyses the relationship between CPT and moisture, volatile matter, ash and fixed carbon.

1.2 OBJECTIVE

To determine the optimum heating rate of crossing point temperature apparatus, the project work has been planned with following objectives:

- **Literature review** – Gaining information on the topic along with collection of past studies carried by national and international researchers.
- **Sample collection and preparation** –Ten samples from WCL were collected and prepared as per Indian Standards for the purpose of analysis.
- **Experimentation** –The experiments are carried out in two stages:
  - Determination of intrinsic properties of coal – proximate analysis
  - Determination of crossing point temperature of coal at four different heating rates keeping other experimental conditions same.
- **Analysis** –analyze the CPT values of various coal sample performed at different heating rate and correlating the optimum heating rate with proximate analysis parameters.

Chapter 2

LITERATURE REVIEW

LITERATURE REVIEW

2.1 SPONTANEOUS COMBUSTION

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.

2.2 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
Coal + oxygen → coal-oxygen complex →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 (Ramlu, 2007).

Various methods have been used in laboratory for studying the relative tendencies of coals to heat spontaneously. Most of the methods are based on the measurement of the oxidation rate and ignition temperature. One of the method commonly followed in India is crossing point temperature

2.3 CROSSING POINT TEMPERATURE METHOD

The temperature at which the temperature of the coal and the furnace/bath coincide is called the crossing point temperature (CPT) (Ramlu, 2007). CPT is one of the oldest method for determination of susceptibility of coal sample. This method evaluates the response of coal sample in a temperature controlled furnace/bath. A thermostat used in this method controls the temperature of the furnace, usually linear heating rate is maintained with gradient from 0.5 to 20˚C/min. or can be a non-linear heating by fixing the thermostat at a particular point. For the CPT method the non-linear temperature rise with a value of the temperature gradient in a range of 0.2 - 4.0°C/min. with the initial temperature rise of 4.0°C/min. and consequently a gradual temperature rise up to a value of 0.2°C/min. at the end of measurements upon a constant time period of 4 hours of the analysis in a temperature range of 25-200°C (Adamus,2004). The coal sample inside the furnace is thus exposed to temperature growth and oxidation medium is simultaneously added. The susceptibility of spontaneous combustion is measured on the basis of temperature growth of the coal sample.

Laboratory furnace used for determination of susceptibility of coal to spontaneous heating are often operated in adiabatic mode. The furnaces are of different medium (oil, glycerin, air, water, etc.). In this project air medium is selected for application of CPT method.

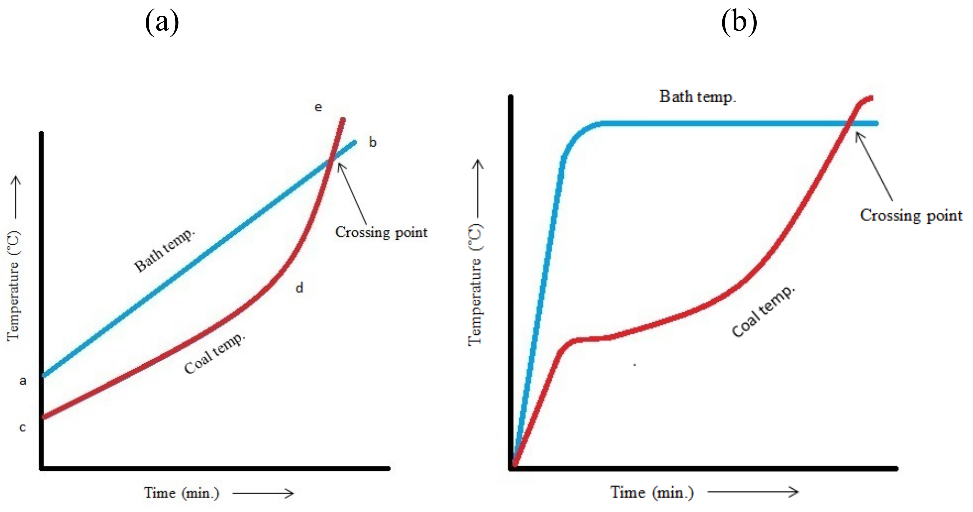


Figure 2.1 Determination of crossing point temperature of coal: (a) linear heating rate (b) nonlinear heating rate

From the figure 2.1 it can be inferred that initially due to release of moisture from coal sample the temperature decreases but after that it is found to be parallel to the constant rate of temperature line for some time. After that the temperature suddenly shoots up and crosses the furnace temperature line and rises steeply beyond that. The point on the figure at which the sample temperature cuts the oven temperature is called as crossing point temperature. Lower is the crossing point higher the susceptibility of the coal sample to catch fire. Table 2.1 shows the categories.

CPT value (˚C)	Spontaneous combustion risk
120 - 140	HIGH
140 - 160	MEDIUM
160 - 180	LOW

Table 2.1 Risk rating criteria based on CPT values (Ramlu et al., 1985)

Researchers considered the point 'd' in figure 2.1 to be more important than the crossing point for the reason that the temperature of the sample can overtake the furnace or bath temperature only after the process of perceptible self-heating has set in without additional heat. The heating curve can therefore be divided into three zones c-d, d-e, and e-f. The third zone starts from the crossing point to active combustion. (Ramlu, 2007)

The CPT rises with increasing heating rate but time taken by the coal sample to reach the CPT decreases a little. The rise in CPT value is greater for lower rank coals than for higher rank ones (Wang et al., 2010). Table 2.2 shows the CPT rise for Yima jet coal is 18˚C but for Kabuliang anthracite is 5˚C.

Coal samples	Heating rate (˚C/min.)		
	0.8	1.0	1.2
Yima jet coal	167.5	181.5	185.5
Chaili gas coal	169.2	179.0	182.5
Kabuliang anthracite	204.0	205.7	209.0

Table 2.2 CPTs for different heating rates (Wang et al., 2010)

2.4 NATIONAL AND INTERNATIONAL STATUS

The following are the brief view of work carried out by various researchers on crossing point temperature method.

Bagchi (1965) studied the effect of experimental condition and proposed the most appropriate flow rate of oxygen and the surrounding heating rate for a 20 gm. coal sample and also proposed a method to evaluate the propensity of coal towards spontaneous combustion based on the values of the CPT. He also found that the CPT is usually inaccurate for those coals with a high moisture content and suggested the evaluation of such coals by both CPT and temperature increasing rate.

Banerjee (1972) determine the CPT for a number of Indian coal samples following the crossing point temperature method. He observed that coals with crossing point temperature between 120°C and 140°C could be considered to be highly susceptibility to spontaneous heating and those above 160°C are poorly susceptible. The moderately susceptible ones showed values in between the above mentioned.

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

Feng et al. (1973) developed a composite liability index using the results of crossing point temperature experiments called FCC index. This is calculated using the following equation:-

$$\text{Liability index} = \frac{\text{Average heating rate between } 110^{\circ}\text{C} \ \& \ 220^{\circ}\text{C}}{\text{Relative ignition temperature}}$$

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

Ramlu et al. (1985) used CPT to study the susceptibility of Indian coals and objected to the selection of ranges for susceptibility index and proposed an index known as MR index as:

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

Tarafdar et al. (1987) reported results of wet oxidation of coal using alkaline permanganate solution involving measurements of differential temperature at different temperatures, at a constant heating rate, and potential changes between a saturated calomel electrode and a carbon electrode immersed in the coal oxidant mixture within a definite reaction time at a constant temperature. The measurements were made on seven coal samples coalfield of known crossing point temperatures (CPT). Four samples, considered to be highly susceptible to spontaneous heating, had CPT in the range 132-137˚C, and three, considered poorly susceptible to spontaneous heating, had CPT values in the range 162-168˚C, showing two distinct zones of correlation between CPT values and the corresponding differential peak temperatures, and between CPT and the observed potential changes. It was suggested that differential temperature and potential difference measurements during wet oxidation of coal may be used as alternative techniques for the assessment of tendency to spontaneous heating.

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

Barve et al. (1994) determined a binary quadratic equation for CPT that related it to moisture and ash content.

Panigrahi et al. (1997) conducted experiments for the determination of Russian U-index. 10 coal samples from Jharia coalfields have been analyzed using this method. The carbon, hydrogen, nitrogen and sulphur contents for these samples were been determined by using Fenton’s method of ultimate analysis. In addition to this, the crossing point temperature of these samples was also determined. Then, attempts were made to correlate the Russian index and CPT of coal samples with its basic constituent’s viz. carbon, hydrogen and ash contents. It has also been observed that from point of the susceptibility of spontaneous combustion, Russian U-index, shows similar relation with the basic constituents of as the crossing point temperature, which may prove to be a handy method of coal categorization in Indian context.
Thus it could be seen from the above review that there is no universally accepted method or procedure to determine the spontaneous heating tendency of the coal. Keeping this in mind, it is planned to carry out different experiments, viz. crossing point temperature, differential

thermal analysis and wet oxidation potential analysis to determine the spontaneous heating tendency of some coal samples in the present dissertation work.

Chen et al. (1998) proposed a new testing method to determine CPT that used a cubic or column basket.

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

Adamus A (2004) determine the CPT for a number of Czech Republic coal sample at nonlinear heating rate. Initially he found the temperature rises at a rate of 4˚C/min. and consequently there was a gradual fall of temperature up to 0.2˚C/min. and proposed the appropriate susceptibility index for Czech Republic coal samples.

Mandal et al. (2006) found that CPT rose if some inhibitor was added into the coal sample.

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

Ahmed et al. (2008) calculated liability index using CPT for studying the prosperity of coal towards spontaneous heating. CPT that has been in lab requires extra precaution for repeatable results. To overcome the difficulties, attempts were made to study the relationship between peripheral oxygen groups or the functional oxygen group in coals and their correlation with proneness to auto-oxidation using liability index. Also the correlation between liability index and CPT has been prevented.

Sahu et al. (2009) presents application of an empirical approach for classification of coal seams based on their proneness to spontaneous heating. In their research work, 29 coal samples of varying ranks belonging to both high and low susceptibility to spontaneous heating have been collected from all the major coalfields of India. Using moisture content, volatile matter, ash and CPT of the coal samples as the parameters, principal component analysis has been applied to classify the coal seams into three different categories. This classification will be useful for the planes and field engineers for taking ameliorative measures in advance for preventing the occurrence of mine fire.

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

Chapter 3

EXPERIMENTAL TECHNIQUES

EXPERIMENTAL TECHNIQUES

3.1 SAMPLE COLLECTION AND PREPERATION

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

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

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

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

For the project work, ten samples were collected from Western Coalfield Limited by channel sampling which is the most common method followed throughout.

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.

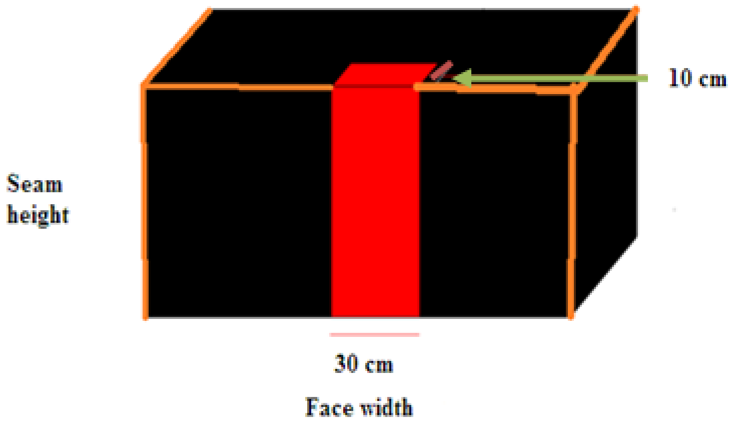


Figure 3.1 channel sampling (Nanda, 2010)

3.1.2 Sample preparation (IS 436 Part 1/Section 1-1964 and IS 436 Part II-1965)

The samples received from the field via channel sampling are crushed in the laboratory as per the experimental requirements. The crushed sample is then sieved to required sizes and stored in air tight polythene. The polythene is stored in air tight containers for further use in experimentation.

3.2 PROXIMATE ANALYSIS (Sarkar, 2010)

The proximate analysis of a coal indicates the moisture, volatile matter, fixed carbon and ash content of the coal in terms of percentage by weight and is calculated in several different basis:

- ar (as-received) – puts all variables into consideration and uses the total weight as the basis of measurement.
- ad (air-dried) – neglects the presence of moistures other than inherent moisture.
- db (dry-basis) – leaves out all moistures, including surface moisture, inherent moisture, and other moistures.
- daf (dry, ash free) – neglects all moisture and ash constituent in coal.

- dmmf (dry, mineral-matter-free) – leaves out the presence of moisture and mineral matters in coal.

3.2.1 Moisture

Moisture means the water expelled from the coal by specific methods without causing any chemical change to coal.

Procedure:

- Take 1 g of – 212 micron(- 72 mesh BSS) coal sample in a glass crucible.
- Put it in a furnace at 110˚C for 1.5 hours.
- Remove the sample after 1.5 hours and weigh the glass crucible again.
- Calculate the moisture content by the formula

$$\text{Moisture percentage (M)} = \frac{Y - Z}{Y - X} \times 100$$

Where,
X = weight of empty crucible
Y = weight of crucible with coal before heating
Z = weight of crucible with coal after heating

Plate 3.2 Oven for determination of moisture

Plate 3.3 Muffle furnace for determination of ash and volatile matter

3.2.2 Ash

Ash is the inorganic residue left when the coal is completely burnt in air under specified conditions. It is different from the original mineral matter associated with the coal because of changes that take place during incineration.

Procedure:

- Take 1g of -212 micron (- 72 mesh BSS) coal sample in a silica crucible.
- Heat the sample in a muffle furnace at 450˚C for 30 minutes and then further heat it for 1 hour with temperature rising from 450 to 850˚C.
- Remove the silica crucible and then allow it to cool in a desiccator for 15 minutes and weigh the crucible again.
- Obtain ash content by the formula

  $$\text{Ash percentage (A)} = \frac{Z - X}{Y - X} \times 100$$

  Where,

  X = weight of empty crucible

  Y = weight of crucible with coal before heating

  Z = weight of crucible with coal after heating

3.2.3 Volatile Matter

It is the total loss in weight minus the moisture when the coal is heated out of contact with air to a sufficiently high temperature under specific conditions.

Procedure:

- Take 1 g of -212 micron (- 72 mesh BSS) coal sample in a crucible and put the lid.
- Put the crucible in a furnace maintained at 925˚C for 7 minutes.
- Take out the crucible and weigh it again.
- Calculate the volatile matter content by using the relation

  $$\text{Volatile matter percentage (VM)} = \left(\frac{Y - Z}{Y - X} \times 100 \right) - M\%$$

  Where,

  X = weight of empty crucible

  Y = weight of crucible with coal before heating

Z = weight of crucible with coal after heating

3.2.4 Fixed Carbon

It is the residue obtained by subtracting the sum of the percentages by weight of moisture, volatile matter and ash from 100. It is essentially carbon containing minor amounts of nitrogen, sulphur, oxygen and hydrogen.

$$\text{Fixed carbon percentage (FC)} = 100 - (M + A + VM)$$

Where,

M = moisture percentage

A = ash percentage

VM = volatile matter percentage

3.2.5 Conversion of results

Dry basis (db):

$$\text{Ash} = \frac{\text{\% ash on air dried basis}}{100 - \text{\% moisture}} \times 100$$

$$\text{Volatile matter} = \frac{\text{\% volatile matter on air dried basis}}{100 - \text{\% moisture}} \times 100$$

Fixed carbon = 100 – (ash + volatile matter) % on dry basis

Dry ash free basis (daf):

$$\text{Volatile matter} = \frac{\text{\% volatile matter on air dried basis}}{100 - (\text{moisture} + \text{ash}) \text{ \% on dry basis}} \times 100$$

Fixed carbon = 100 – volatile matter on % daf basis

Dry mineral matter free (dmmf):

$$\text{Volatile matter} = \frac{\text{\% volatile matter on air dried basis} - 0.1 \text{ ash on air dried basis}}{100 - (\text{moisture} + 1.1 \text{ ash}) \text{ \% on air dried basis}} \times 100$$

Fixed carbon = 100 – volatile matter on % dmmf basis

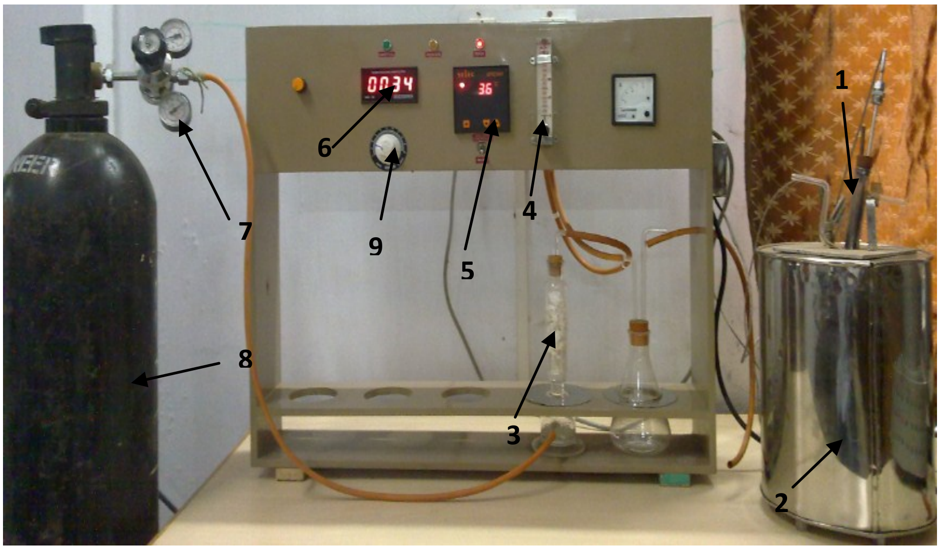
3.3 CROSSING POINT TEMPERATURE (Ramlu et al., 2007)

The temperature at which the temperature of the coal and the furnace/bath coincide is called the crossing point temperature. It is also called the relative ignition temperature. The heating rate, the air flow and particle size must be optimized. In this method, the coal sample (4gm.) is heated in a reaction tube in a furnace or bath at constant or rising temperature; with oxygen or air passing through it at a predetermined rate till the coal temperature crosses the furnace or bath temperature.

Experimental setup:

The following is the setup for determining crossing point temperature of coal:

- A vertical tubular furnace having heating capacity of 3kw. The furnace is provided with temperature controller and digital screen.
- The reaction tube is of glass having 26 mm internal diameter and 150 mm in length. The reaction tube is surrounded by spiraling glass tube of 6 mm internal diameter which is connected to the bottom of the reaction tube for air inlet and a small outlet tube at the top acts as air/gas outlet.
- Flow meter and pressure flow control valves.
- Potassium hydroxide is used to remove carbon dioxide in the incoming air.
- Concentrated sulphuric acid to remove moisture in air.
- Drying tower containing granular calcium chlorides to remove moisture from air.



1 – Reaction tube
2 – Tubular furnace
3 – Drying tower
4 – Rotameter
5 – Bath temperature
6 – Coal temperature
7 – Pressure gauge
8 – Oxygen cylinder
9 – Furnace Temperature controller

Plate 3.4 crossing point temperature apparatus

Experimental procedure:

4 gm. sample of size -100+200 mesh was placed in the reaction tube followed by glass wool at the bottom most portion. The tube is then tightly 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 center of the sample. The furnace is switched on and simultaneously oxygen is allowed to pass through the sample, with an average heating rate of 1˚C/min and oxygen purging at 80 ml/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.

Chapter 4

RESULTS and ANALYSIS

RESULTS

4.1 ABSTRACT FOR EXPERIMENTAL TECHNIQUES

4.1.1 Proximate analysis

A. Determination of moisture

Amount of coal: 1 gm. coal

Size of coal: - 212 micron (- 72 mesh BSS)

Heating time: 1.5 hours at 110˚C

B. Determination of ash

Amount of coal: 1 gm. of coal sample

Size of coal: - 212 micron (- 72 mesh BSS)

Heating time: 30 minutes at 450˚C and 60 minutes at 850˚C

C. Determination of volatile matter

Amount of coal: 1 gm. of coal

Size of coal: - 212 micron (- 72 mesh BSS)

Heating time: 7 minutes at 900˚C

4.1.2 Crossing point temperature

A. Air medium bath

Amount of coal: 4 gm. of coal

Size of coal: - 100 + 200 mesh BSS

Heating rate: 1˚C/min. (standard)

Oxygen flow rate: 80 ml/min.

B. Glycerine bath

Amount of coal: 20 gm. of coal

Size of coal: -212 micron (- 72 mesh BSS)

Heating rate: 5˚C/min.

Oxygen flow rate: 80 ml/min.

Table 4.1 List of coal samples

Sl. No.	Sample Code	Name of Organization
1	WCL-1	Western coalfield limited
2	WCL-2	
3	WCL-3	
4	WCL-4	
5	WCL-5	
6	WCL-6	
7	WCL-7	
8	WCL-8	
9	WCL-9	
10	WCL-10	

Coal samples collected from different seams of Western Coalfield Limited by channel sampling process are prepared according to Indian Standards and were coded with a sample code as tabulated above.

Table 4.2 Result of proximate analysis of WCL coal samples

Sl No	Coal samples	Basis	M %	A %	VM %	FC %
1	WCL-1	air dried	6.03	14.5	39.97	39.5
		dry	---	15.45	42.53	42.03
		daf	---	---	50.30	49.70
		dmmf	---	---	49.37	50.63
2	WCL-2	air dried	4	22	37	37
		dry	---	22.92	38.54	38.54
		daf	---	---	50	50
		dmmf	---	---	48.47	51.53
3	WCL-3	air dried	6.5	16	35.5	42
		dry	---	17.11	37.97	44.92
		daf	---	---	45.81	54.19
		dmmf	---	---	44.66	55.34
4	WCL-4	air dried	3.5	54	22.5	20
		dry	---	55.96	23.32	20.72
		daf	---	---	52.94	47.06
		dmmf	---	---	46.09	53.91
5	WCL-5	air dried	5.5	16	34.5	44
		dry	---	16.93	36.51	46.56
		daf	---	---	43.95	56.05
		dmmf	---	---	42.78	57.22
6	WCL-6	air dried	6	17.5	33.5	43
		dry	---	18.61	35.64	45.74
		daf	---	---	43.79	56.21
		dmmf	---	---	42.47	57.53
7	WCL-7	air dried	7	16	31.5	45.5
		dry	---	17.20	33.87	48.92
		daf	---	---	40.91	59.09
		dmmf	---	---	39.66	60.34
8	WCL-8	air dried	11	13.50	30	45.50
		dry	---	15.17	33.71	51.12
		daf	---	---	39.74	60.26
		dmmf	---	---	38.64	61.36
9	WCL-9	air dried	4	45	23.5	27.5
		dry	---	46.87	24.48	28.64
		daf	---	---	46.08	53.92
		dmmf	---	---	40.86	59.14
10	WCL-10	air dried	4	40	26	30
		dry	---	41.67	27.08	31.25
		daf	---	---	46.43	53.57
		dmmf	---	---	42.31	57.69

Table 4.3 CPT of WCL coal samples at different heating rate

Sample	Linear heating rate								Nonlinear heating rate	
	Heating rate (0.8˚C/min.)		Heating rate (1˚C/min.)		Heating rate (1.6˚C/min.)		Heating rate (2˚C/min.)			
	CPT(˚C)	Fire risk	CPT(˚C)	Fire risk	CPT(˚C)	Fire risk	CPT(˚C)	Fire risk	CPT(˚C)	Fire risk
WCL-1	193	Low	198	Low	201	Low	208	Low	195	Low
WCL-2	186	Low	189	Low	190	Low	192	Low	194	Low
WCL-3	180	Low	182	Low	200	Low	205	Low	192	Low
WCL-4	206	Low	210	Low	212	Low	219	Low	206	Low
WCL-5	178	Low	180	Low	183	Low	186	Low	187	Low
WCL-6	168	Low	169	Low	185	Low	188	Low	190	Low
WCL-7	171	Low	207	Low	209	Low	210	Low	186	Low
WCL-8	151	medium	155	medium	182	Low	184	Low	188	Low
WCL-9	192	Low	193	Low	197	Low	200	Low	202	Low
WCL-10	177	Low	180	Low	184	Low	188	Low	181	Low

The CPT curve of various coal samples performed at nonlinear and linear heating rates (i.e. 0.8, 1, 1.6 and 2˚C/min) are shown below. From the graph, it can be inferred that CPT increases with increasing heating rate. In nonlinear method, the uniformity of heating rate is not maintained and the furnace temperature controller knob is fixed at a particular point throughout the experiment.

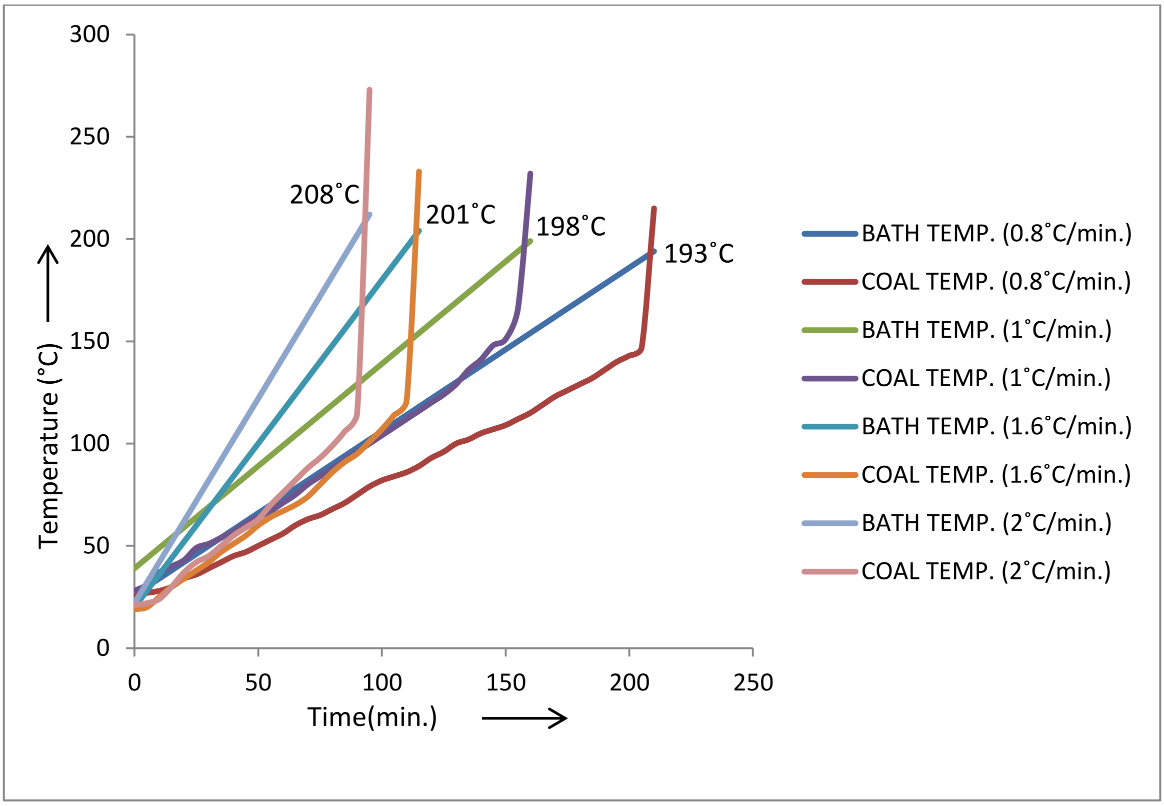


Figure 4.1 CPT curve of WCL-1 at different heating rate

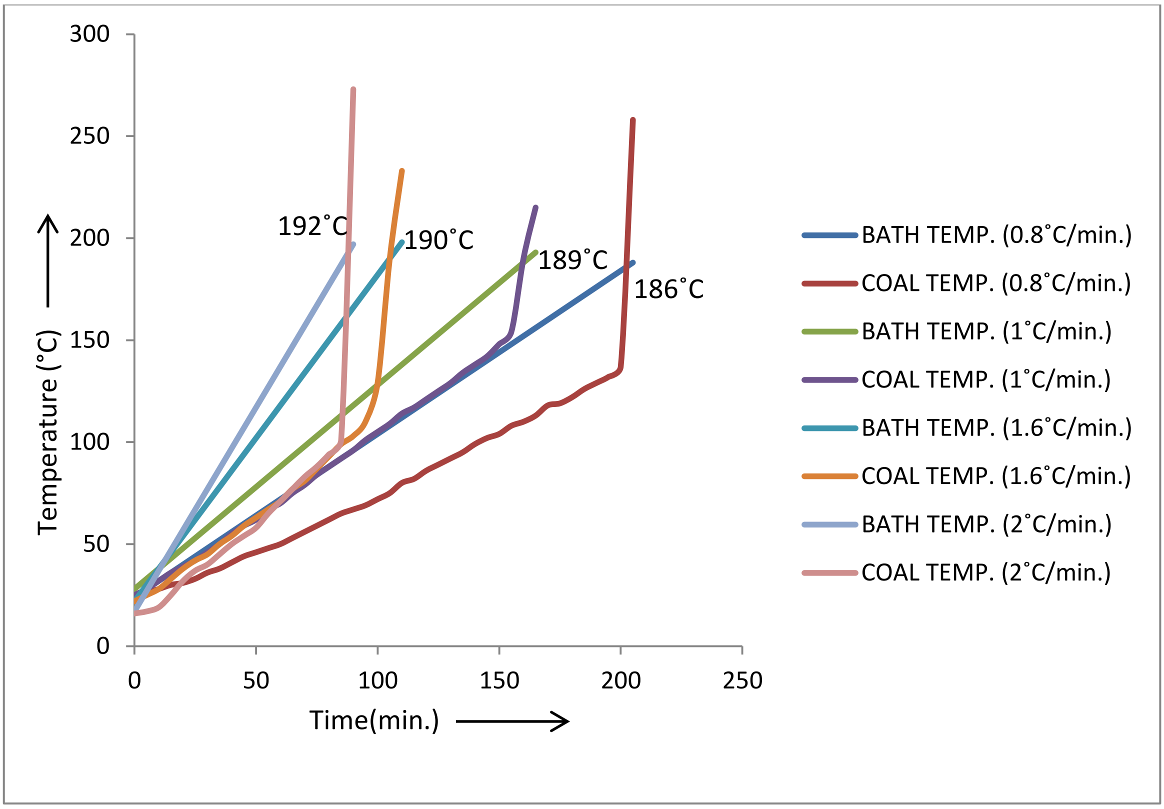


Figure 4.2 CPT curve of WCL-2 at different heating rate

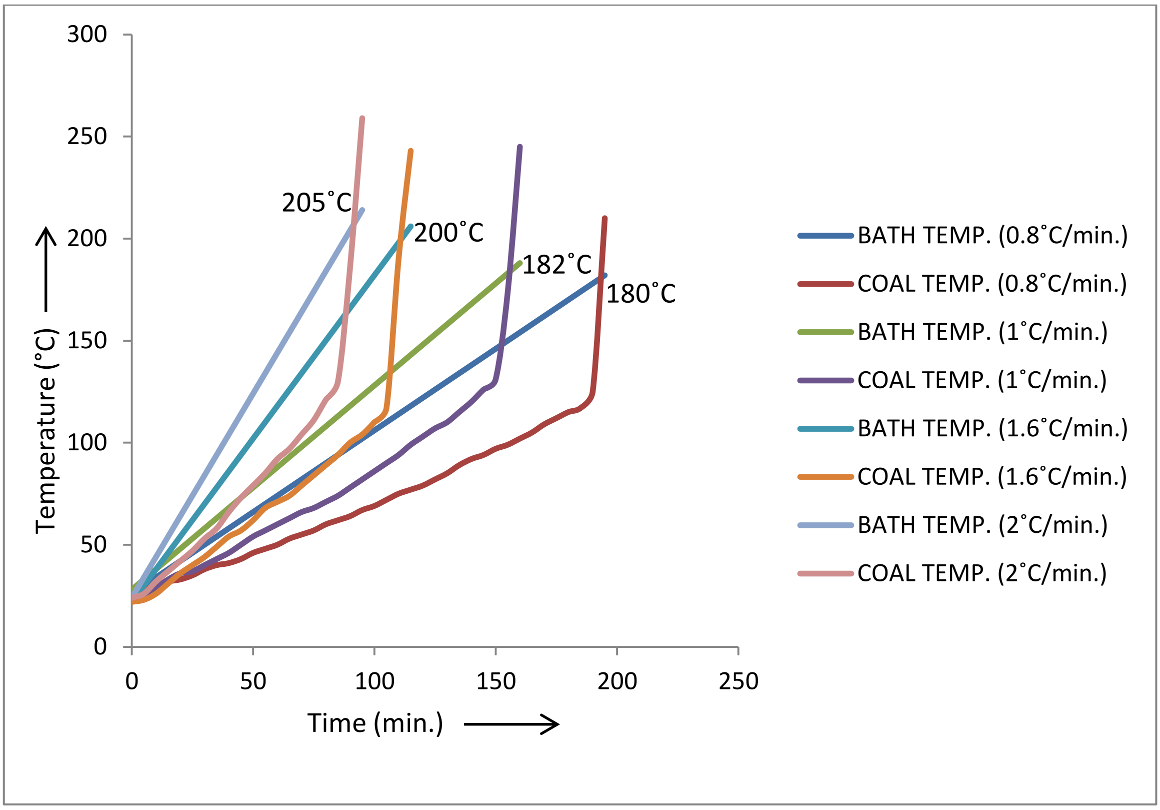


Figure 4.3 CPT curve of WCL-3 at different heating rate

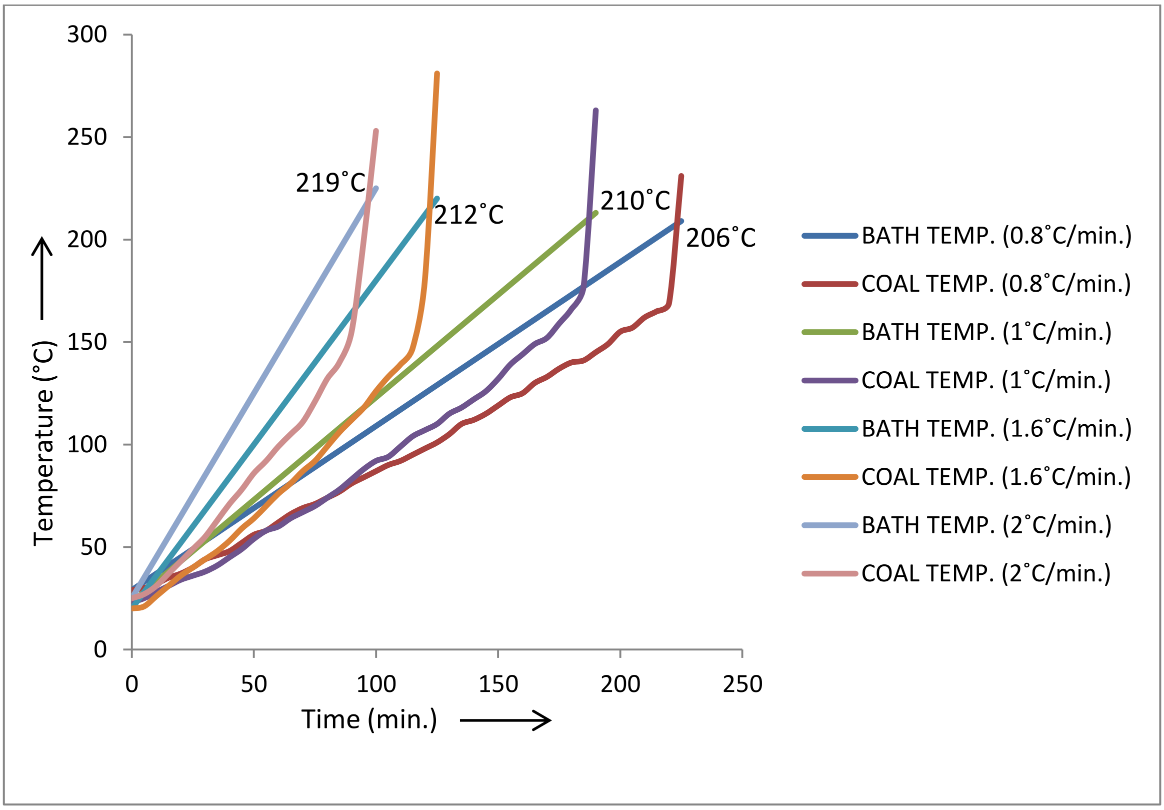


Figure 4.4 CPT curve of WCL-4 at different heating rate

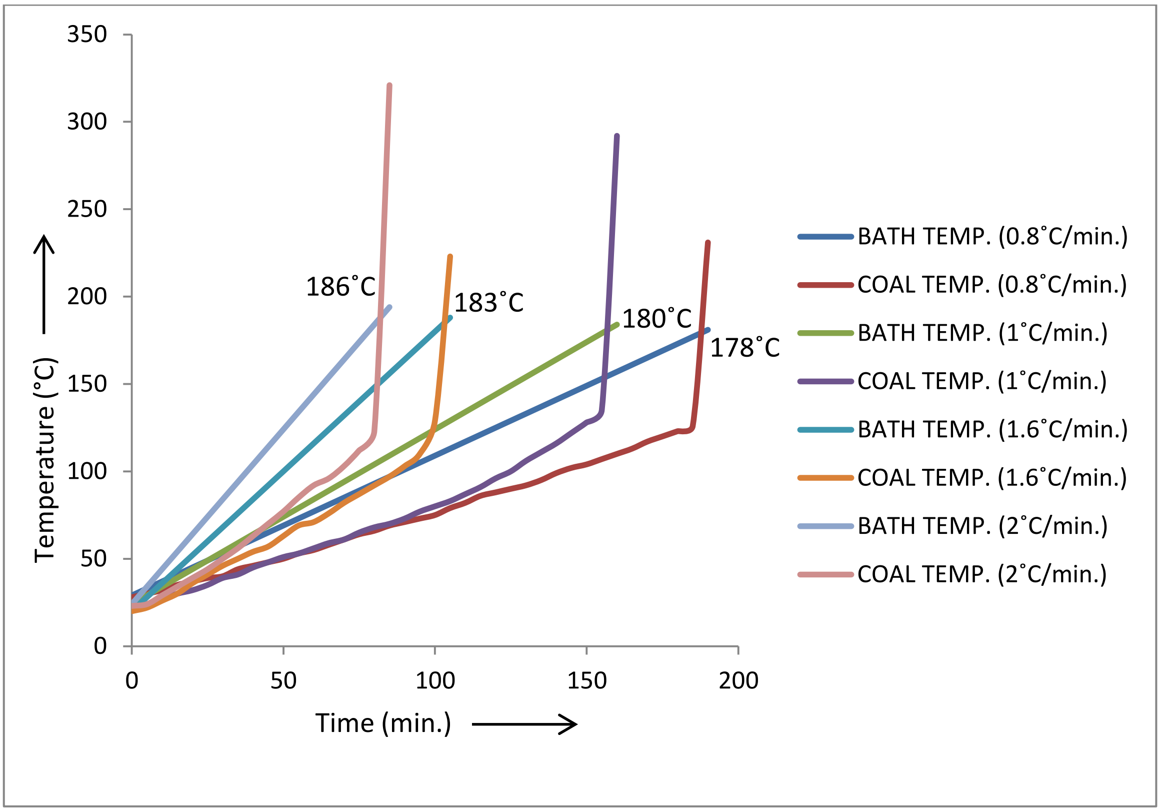


Figure 4.5 CPT curve of WCL-5 at different heating rate

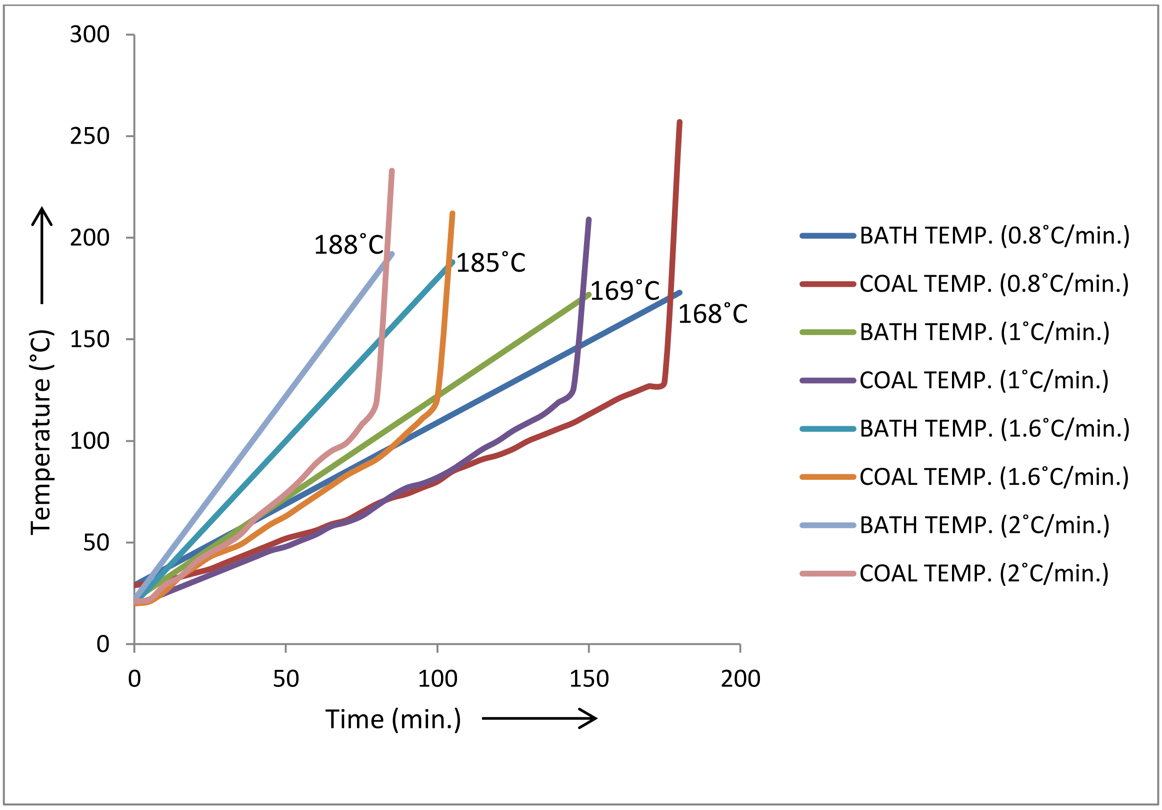


Figure 4.6 CPT curve of WCL-6 at different heating rate

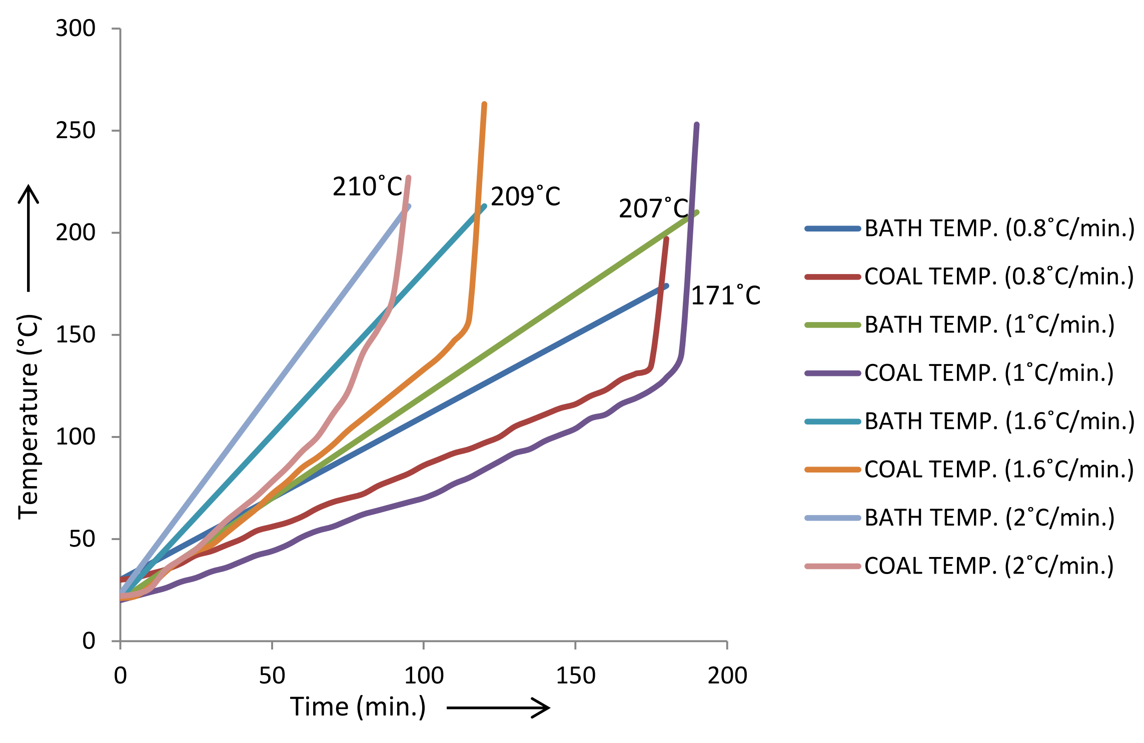


Figure 4.7 CPT curve of WCL-7 at different heating rate

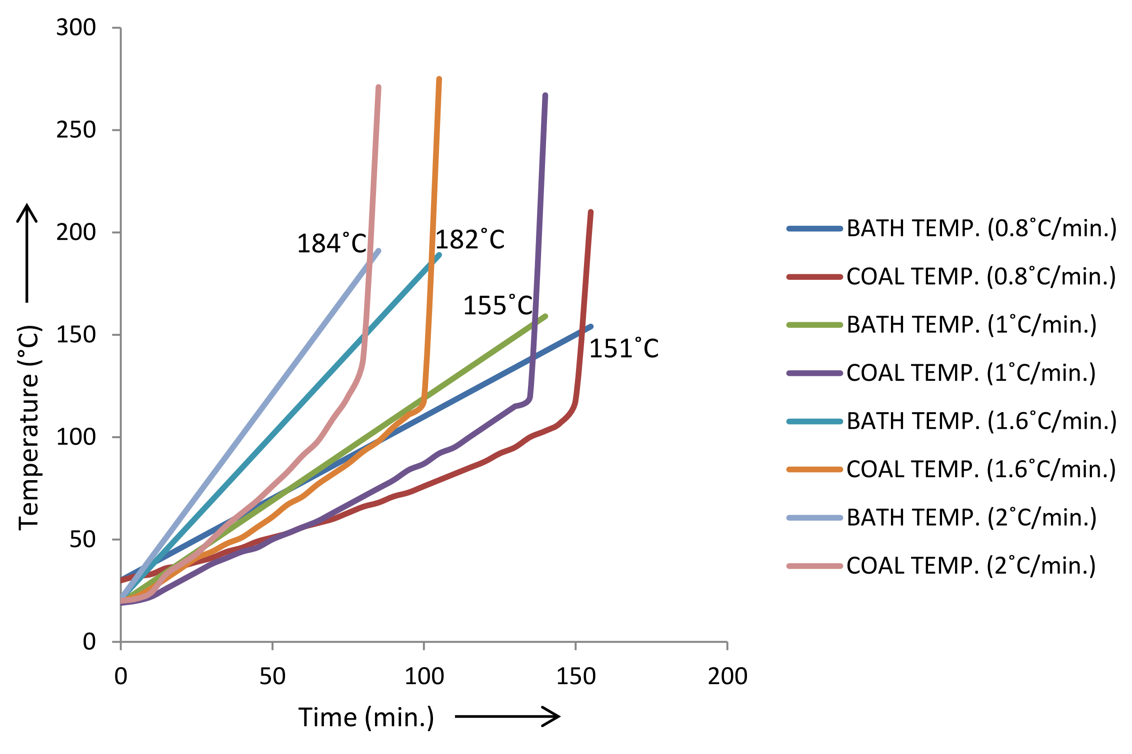


Figure 4.8 CPT curve of WCL-8 at different heating rate

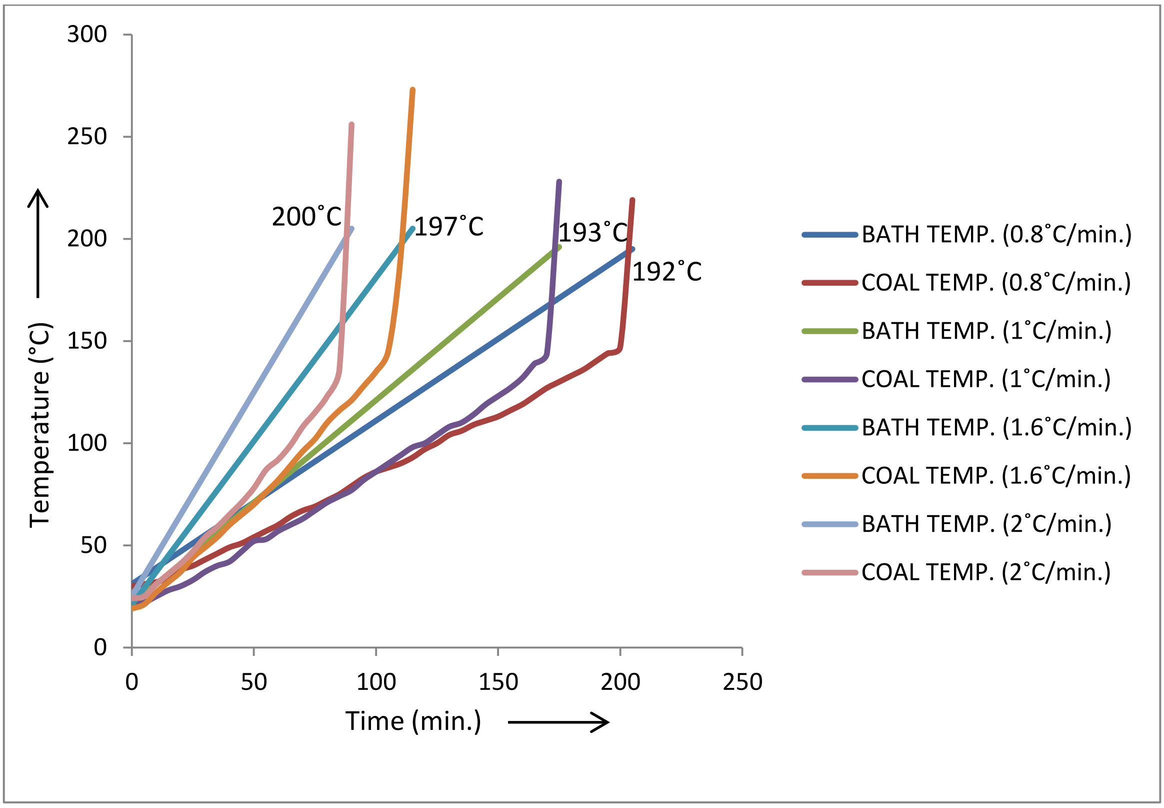


Figure 4.9 CPT curve of WCL-9 at different heating rate

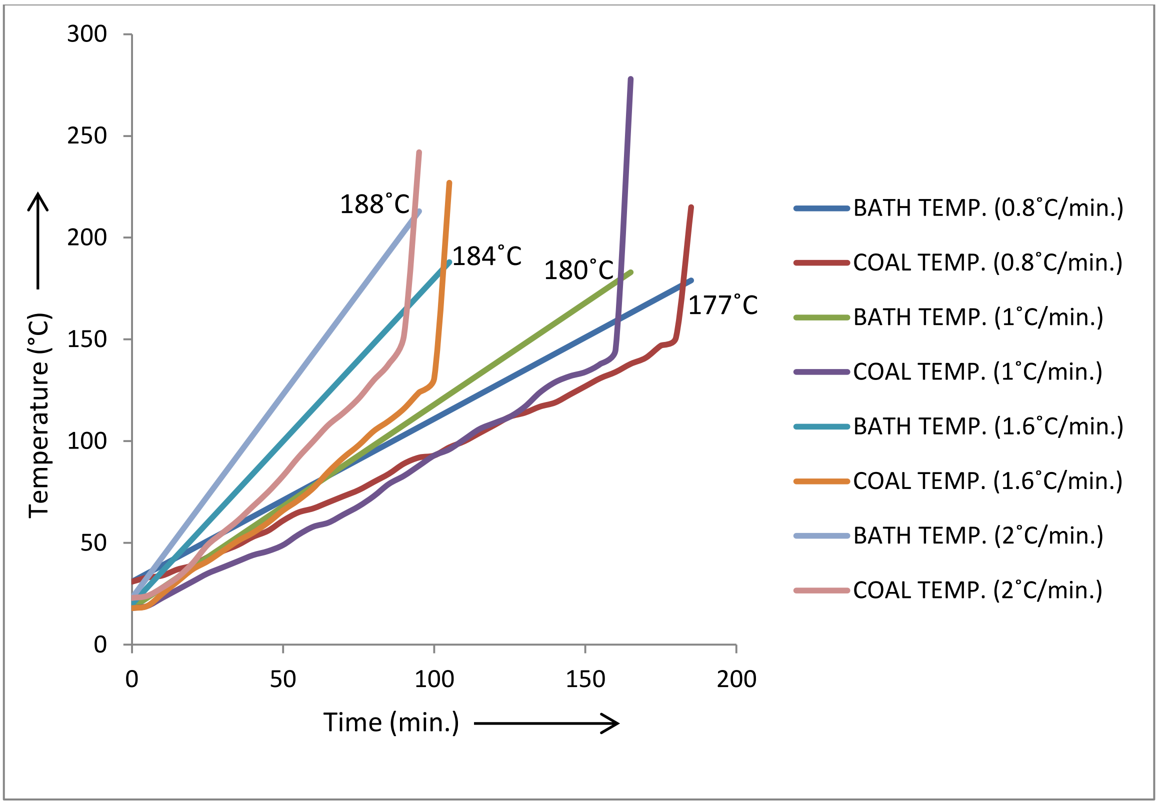


Figure 4.10 CPT curve of WCL-10 at different heating rate

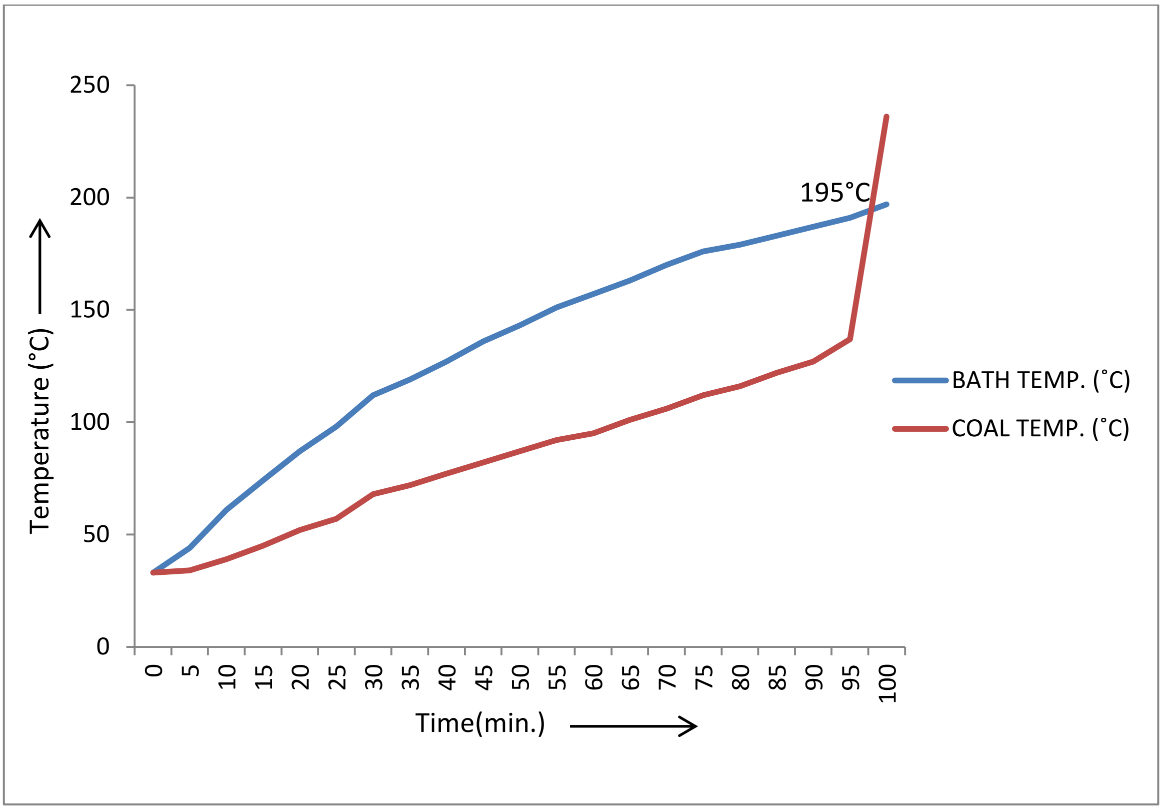


Figure 4.11 CPT curve of WCL-1 at nonlinear heating rate

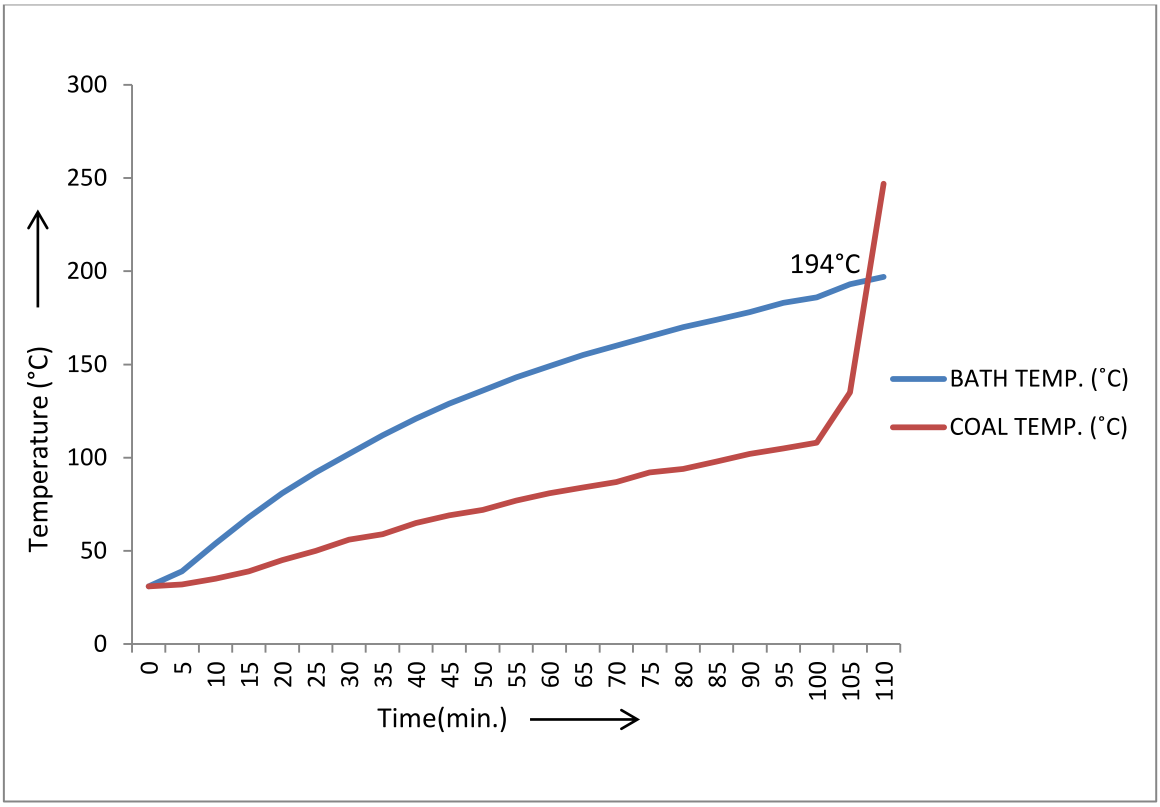


Figure 4.12 CPT curve of WCL-2 at nonlinear heating rate

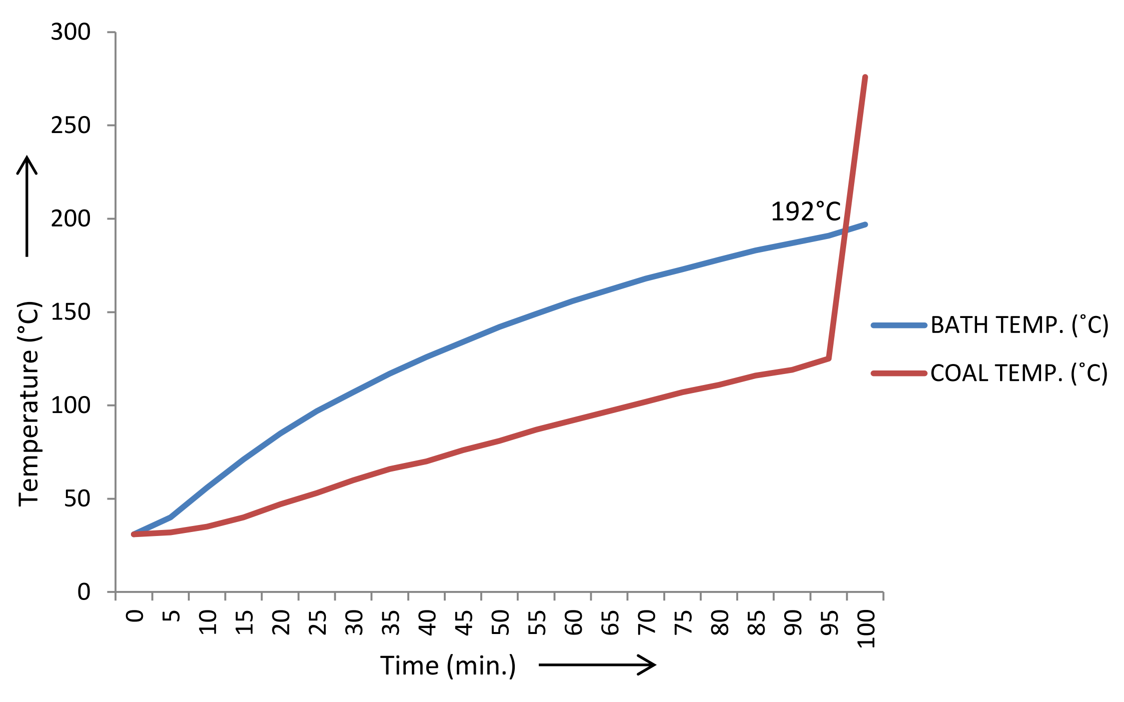


Figure 4.13 CPT curve of WCL-3 at nonlinear heating rate

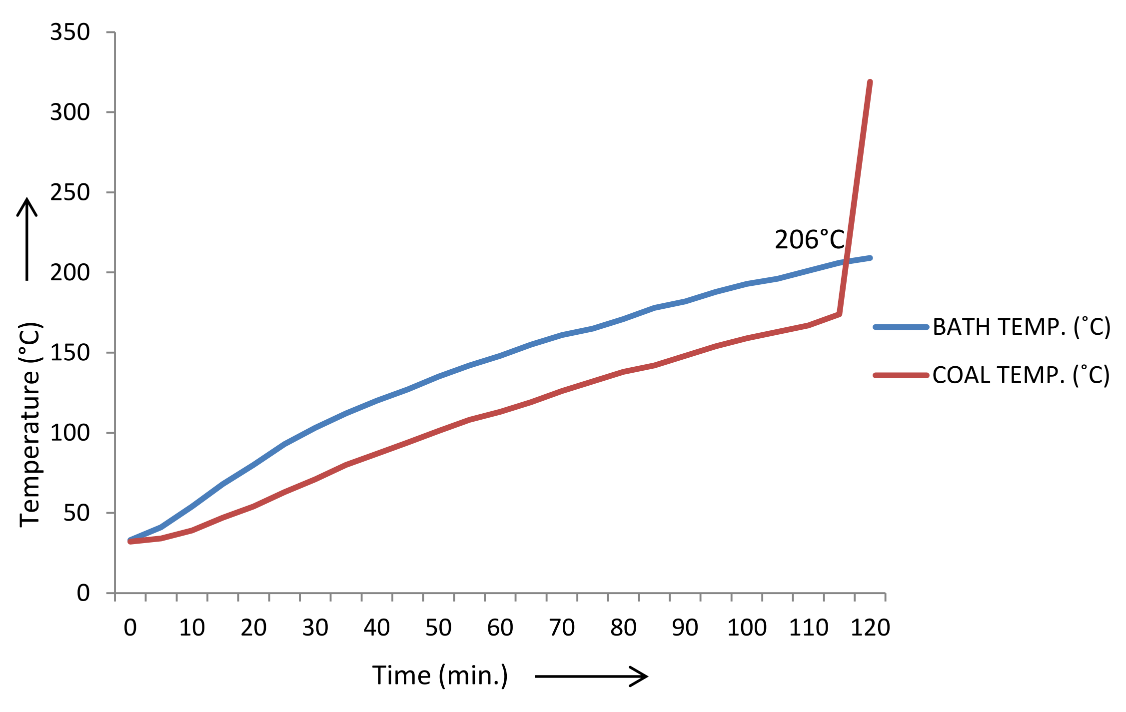


Figure 4.14 CPT curve of WCL-4 at nonlinear heating rate

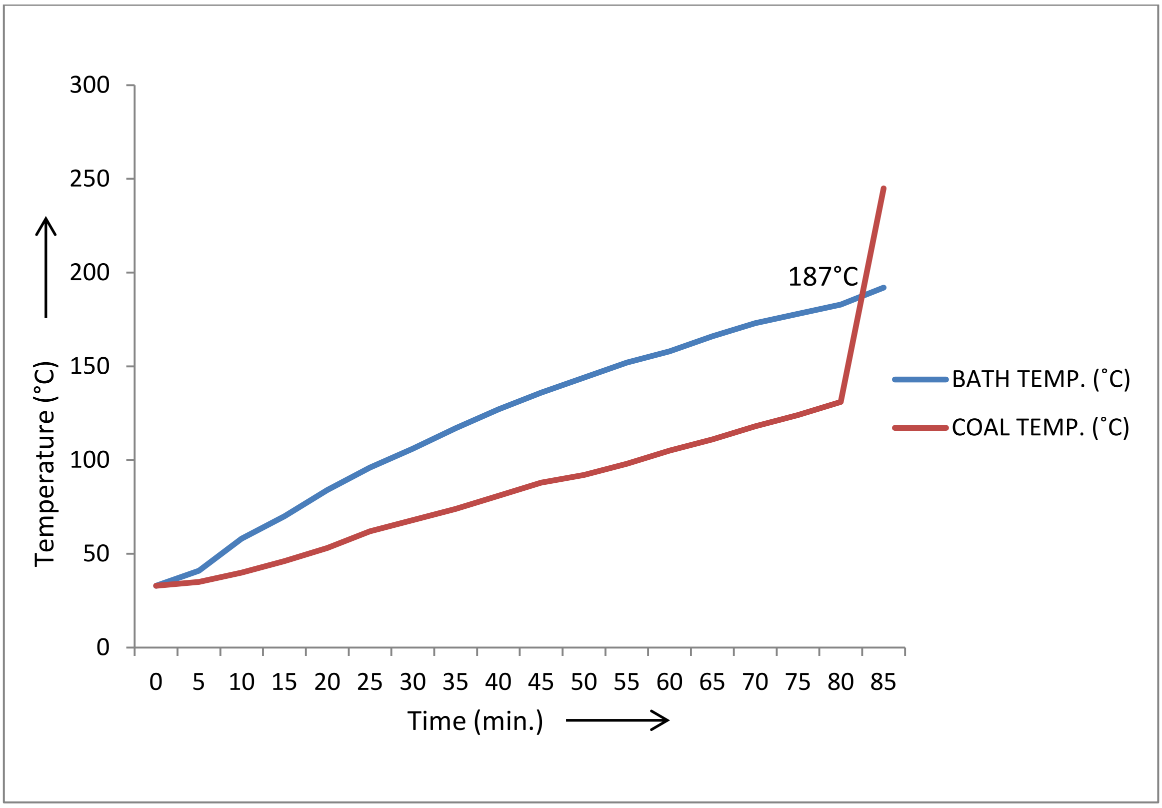


Figure 4.15 CPT curve of WCL-5 at nonlinear heating rate

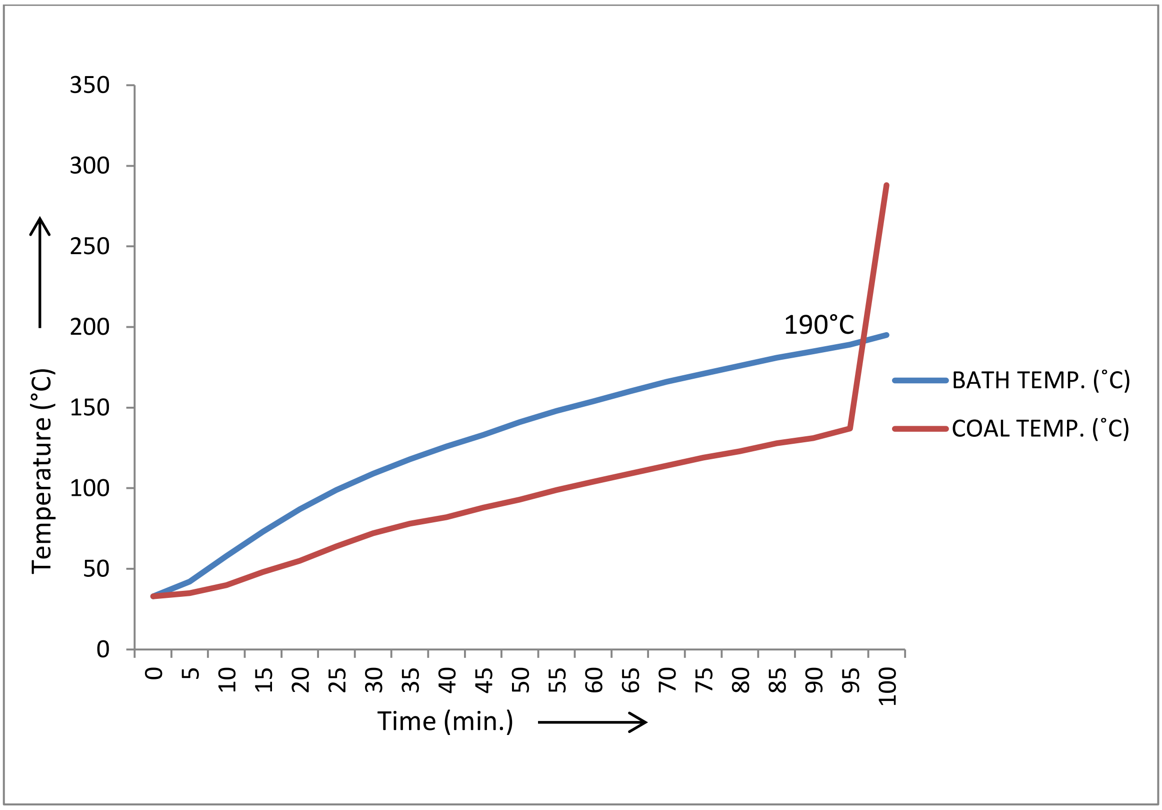


Figure 4.16 CPT curve of WCL-6 at nonlinear heating rate

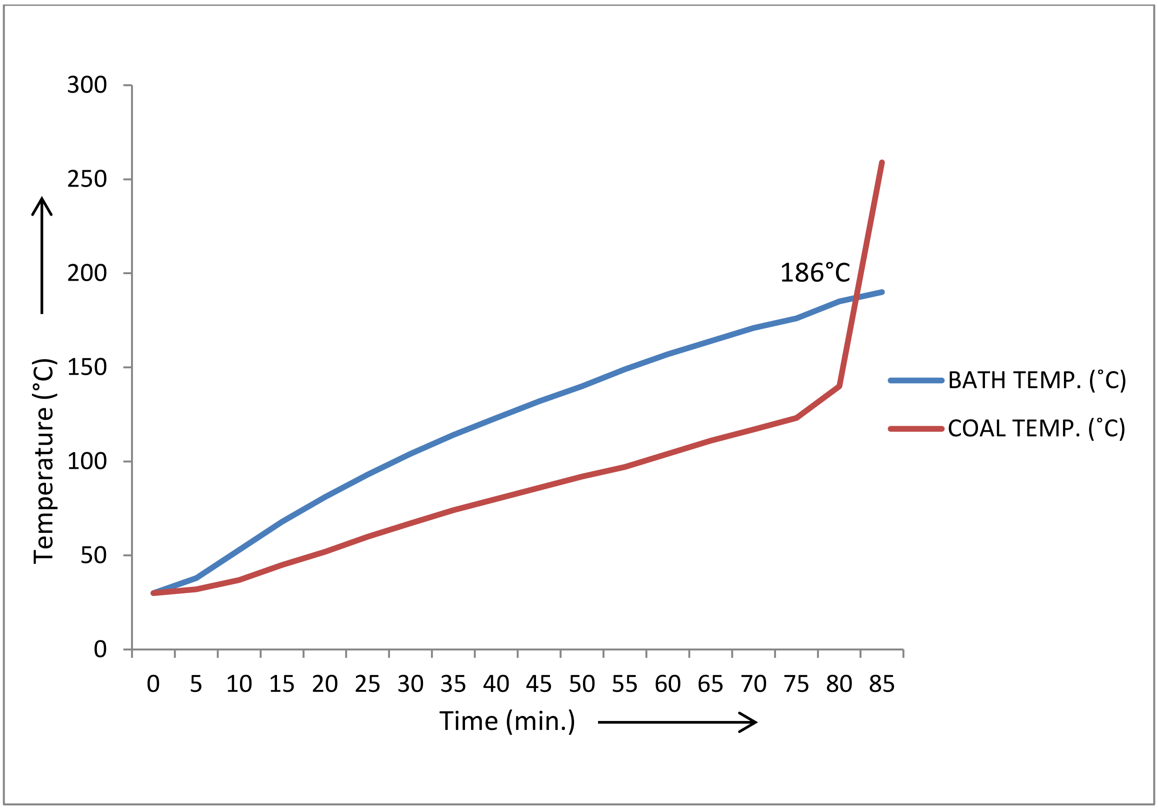


Figure 4.17 CPT curve of WCL-7 at nonlinear heating rate

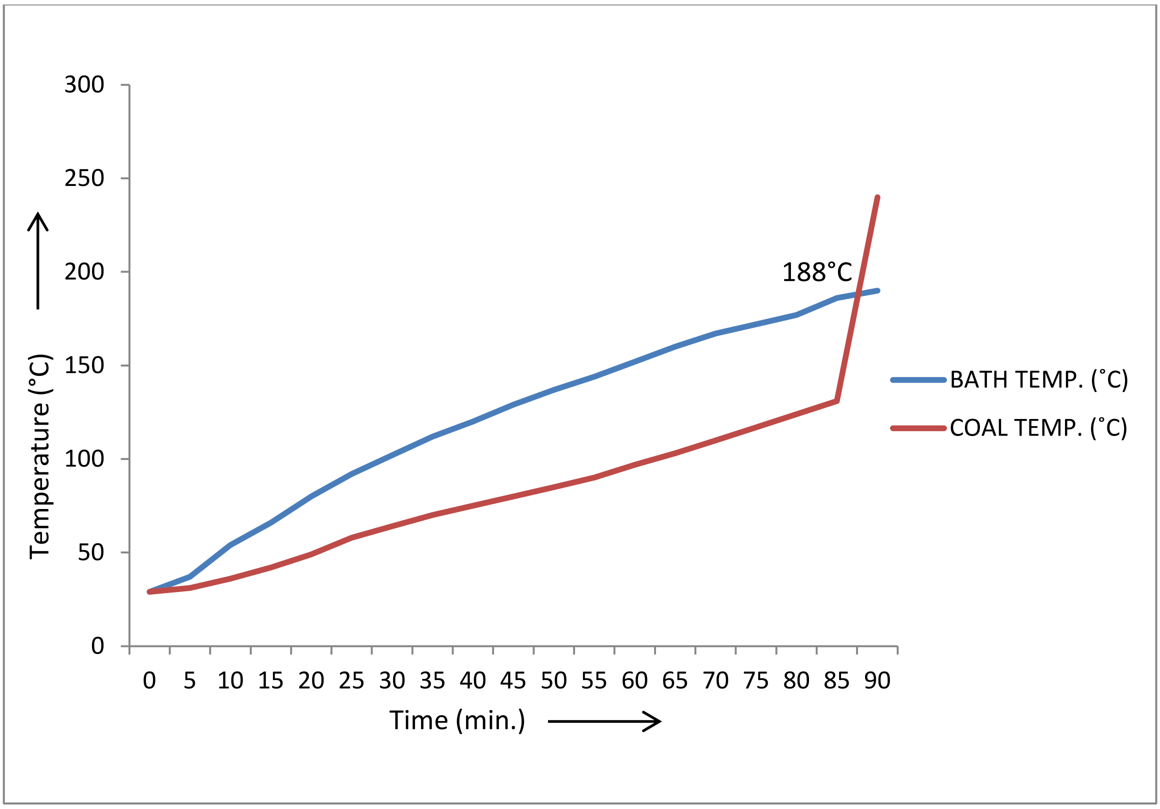


Figure 4.18 CPT curve of WCL-8 at nonlinear heating rate

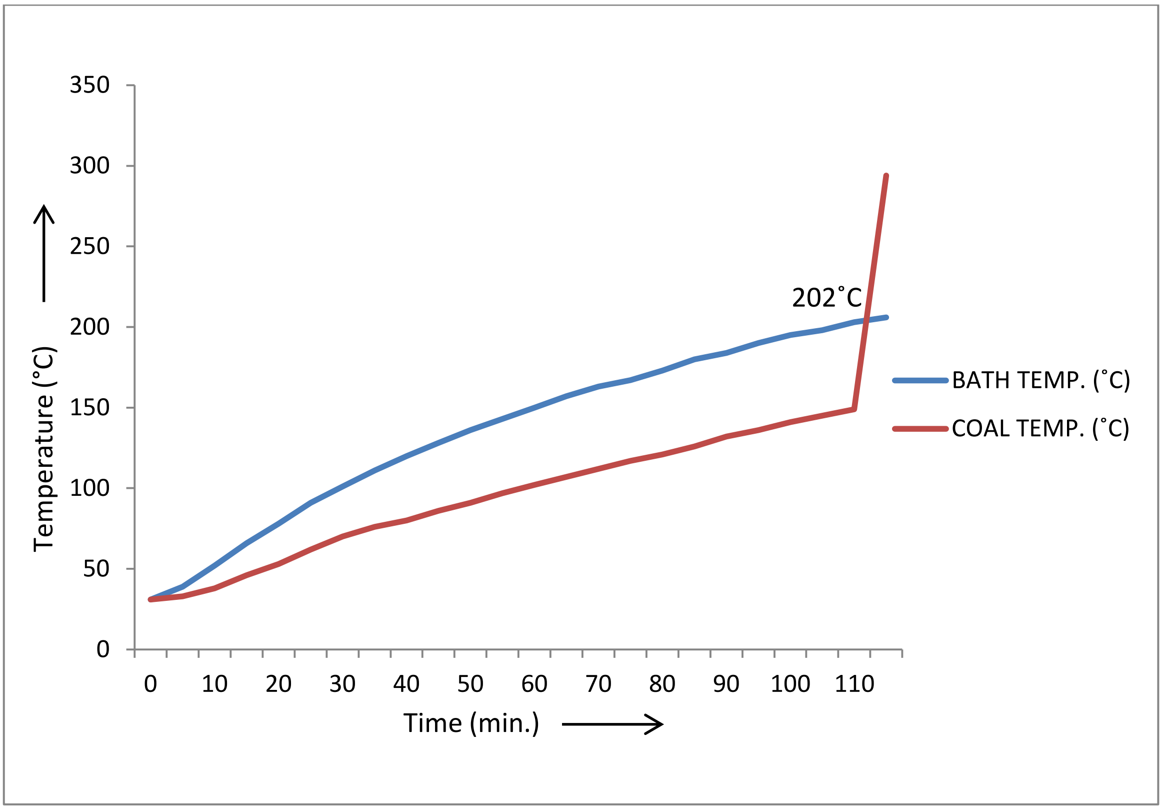


Figure 4.19 CPT curve of WCL-9 at nonlinear heating rate

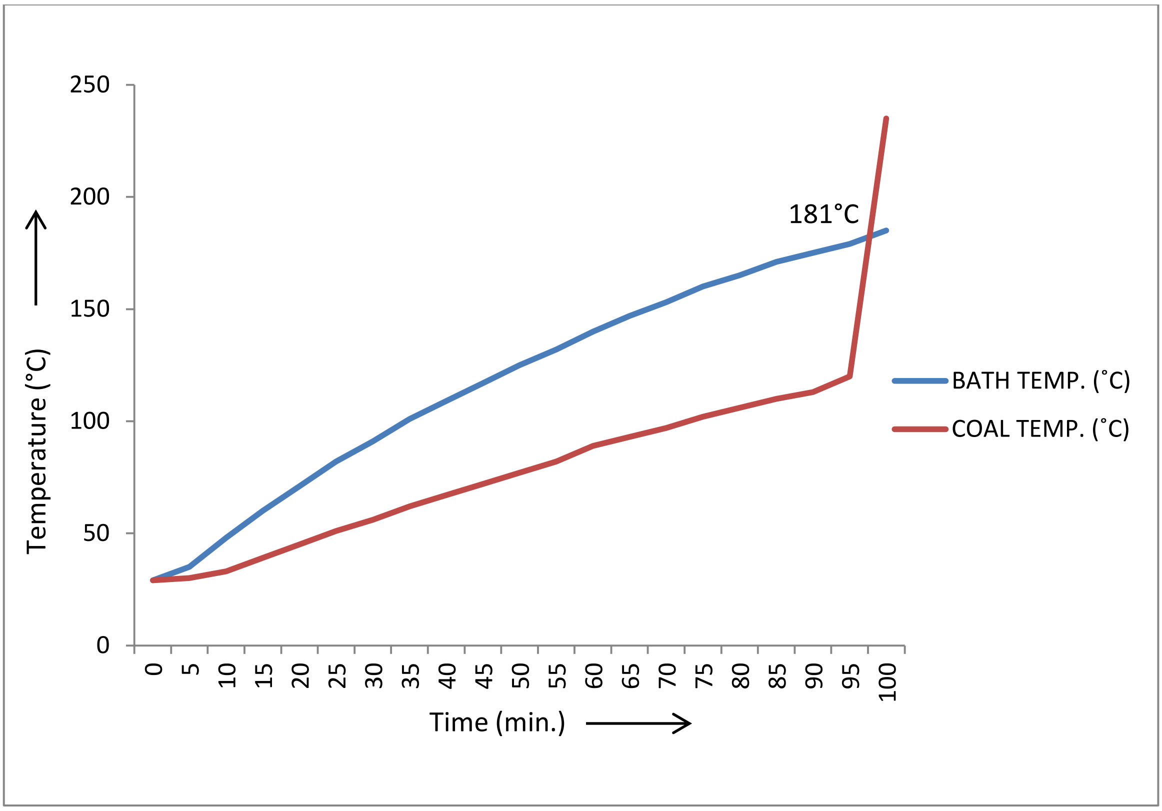


Figure 4.20 CPT curve of WCL-10 at nonlinear heating rate

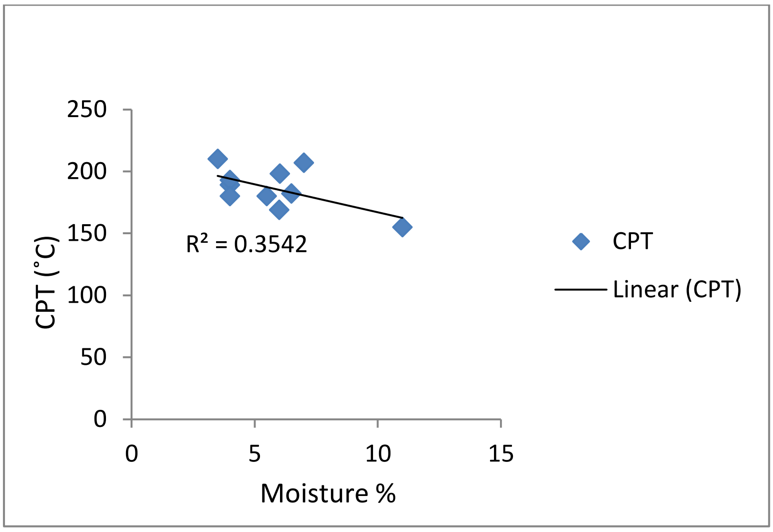


Figure 4.21 Correlation between moisture and CPT at 1˚C/min.

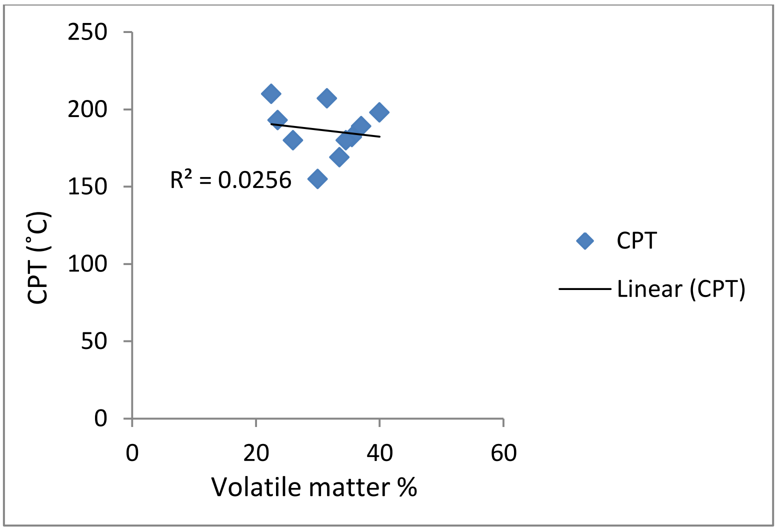


Figure 4.22 Correlation between volatile matter and CPT at 1˚C/min.

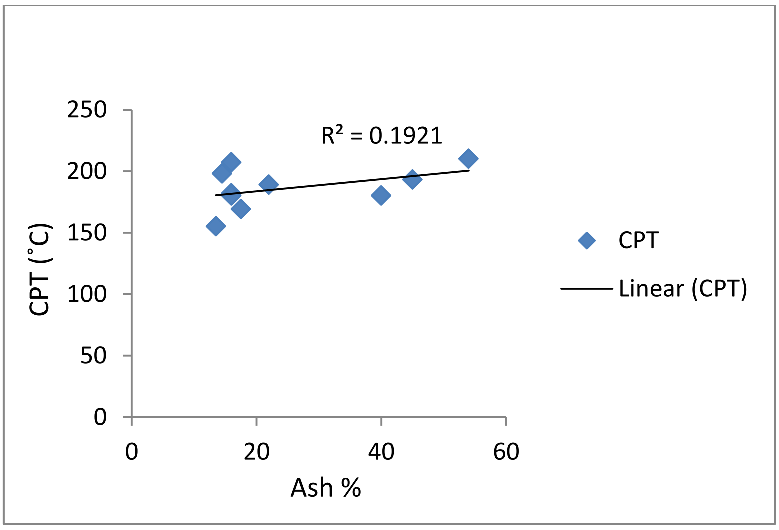


Figure 4.23 Correlation between ash and CPT at 1˚C/min.

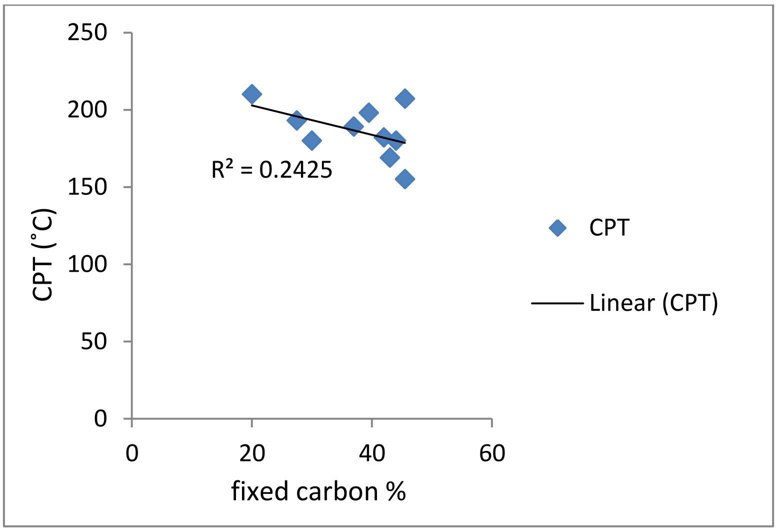


Figure 4.24 Correlation between fixed carbon and CPT at 1˚C/min.

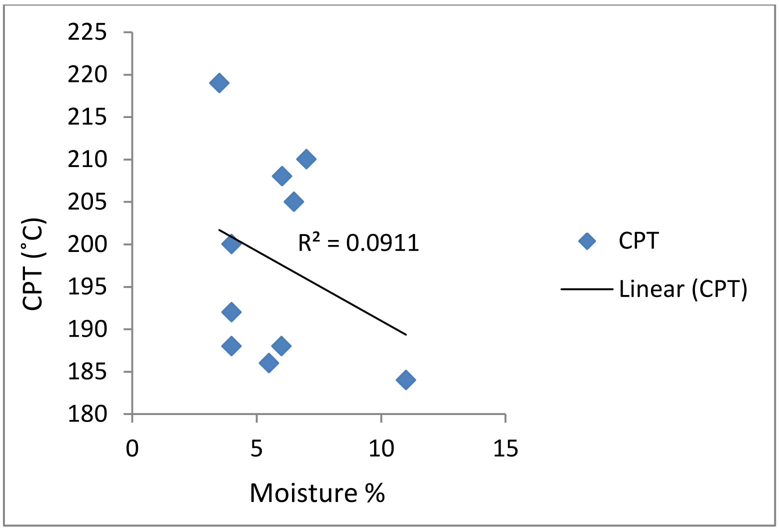


Figure 4.25 Correlation between moisture and CPT at 2˚C/min.

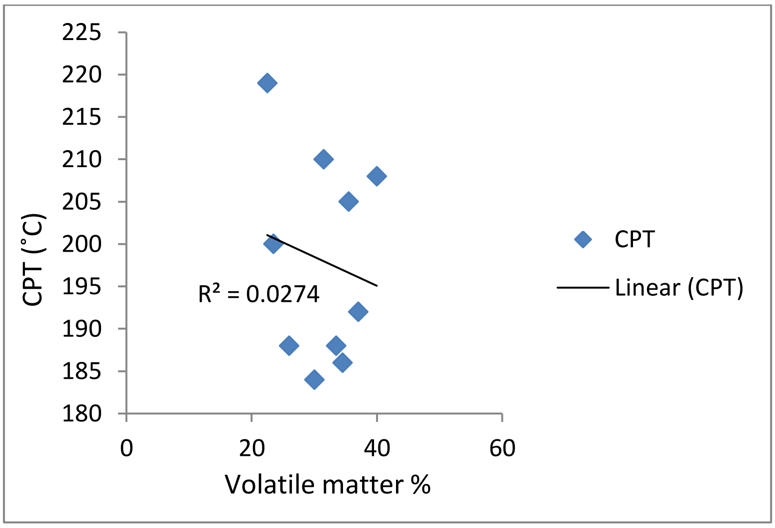


Figure 4.26 Correlation between volatile matter and CPT at 2˚C/min.

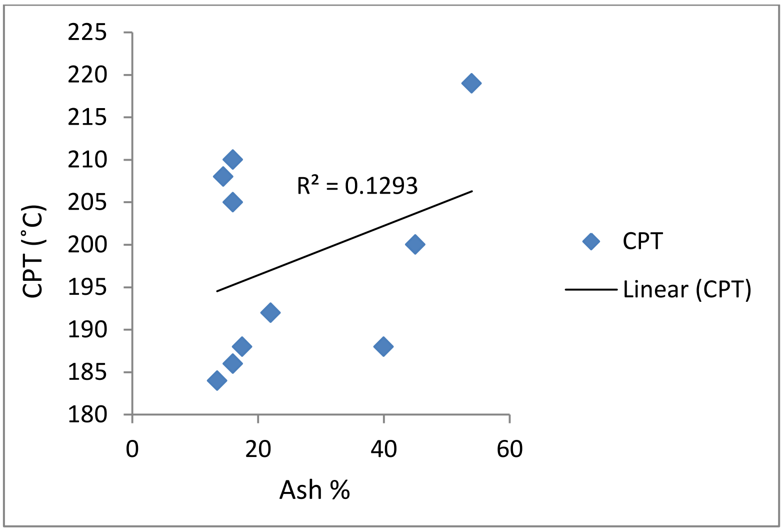


Figure 4.27 Correlation between ash and CPT at 2˚C/min.

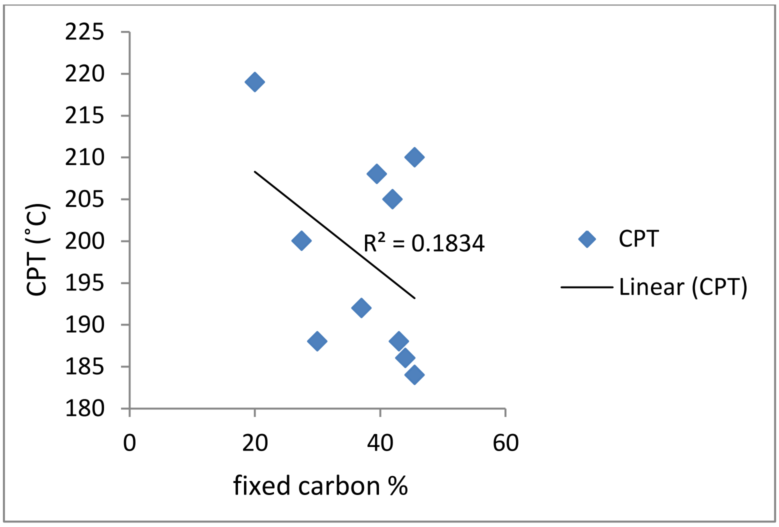


Figure 4.28 Correlation between fixed carbon and CPT at 2˚C/min.

Chapter 5

DISCUSSION and CONCLUSION

DISCUSSION and CONCLUSION

5.1 DISCUSSION

The proximate analysis of ten coal samples was performed using the Indian Standards procedure. It may be observed from Table 4.2, the moisture percentage of coal varied from 3.5 (sample WCL - 4) to 11 (sample WCL - 8). It was seen that samples of higher moisture content are more prone to spontaneous combustion.

The volatile matter percentage of coal varied from 22.5 (sample WCL - 4) to 39.97 (sample WCL - 1). It was found by several researchers that medium to high volatile coals oxidize faster than low volatile coals and high volatile coals are more susceptible to spontaneous combustion than medium volatile coals.

Ash content in coal decreases the oxidation rate but may influence to some extent by mineral composition of the ash. The ash percentage of WCL – 4 coal sample is 54 which is very high and from the Table 4.3 it is observed that the CPT values are above 200˚C which is very poorly susceptible to spontaneous heating.

Table 4.3 shows the CPT values of coal samples at different heating rates, it was seen that the CPT values rises with increase in heating rate of apparatus. Figure 4.2 shows the graphical view of coal samples at four different heating rates. It can be noticed that CPT value of WCL – 2 at 1˚C/min (standard) heating rate is 189˚C. When the same sample was performed at different heating rate i.e. 0.8, 1.6 and 2˚C/min. the result seems very close to the standard one, that means all CPT values are in same fire risk category. So, without wasting more time in lower heating rates 2˚C/min. is the optimum heating rate for WCL – 2 coal samples and this case is also similar with all coal samples collected except WCL – 8.

It can be observed from Figure 4.8, the WCL – 8 coal samples shows change in fire risk with increase in heating rate. It has a CPT value of 155˚C at 1˚C/min. heating rate and 151˚C at 0.8˚C/min. which is moderate susceptible. So, 1˚C/min. heating rate is better as it gives the same result in less time compared to 0.8˚C/min. Again when performed at 1.6 and 2˚C/min. the fire risk moves from moderate to poorly susceptible zone which is not considered.

Correlation has been drawn between moisture and CPT, ash and CPT, volatile matter and CPT and fixed carbon and CPT. It is seen that CPT decreases with increase of moisture, volatile matter and fixed carbon. On the other hand it increases with increase of ash.

5.2 CONCLUSIONS

Crossing point temperature method is primarily taken as the measure of spontaneous heating susceptibility of coal in India and also carried out in other places like Czech Republic. To obtain a better result the heating rate, air flow rate and particle size must be optimized.

From the aforementioned discussion, it may be concluded that the optimum heating rate of these WCL coal samples can be 2˚C/min. because the same result can be obtained in less time as it takes approximately 3 hours to determine the CPT which is time consuming. In the event of a power failure, the whole experiment has to be repeated. So, it's better to go with higher heating rate.

From the correlation analysis it is found that the susceptibility to spontaneous combustion of WCL coal samples increases with increase of moisture, volatile matter and fixed carbon whereas it decreases with increase of ash. It was also found that CPT at 1˚C/min. has better correlation with proximate analysis parameter than 2˚C/min.

To determine the optimum heating rate of CPT apparatus, required more number of coal samples of different category from different coalfields and also taken into account the field condition of the concerned mine.

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