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PREDICTION OF CALORIFIC VALUE OF INDIAN COALS BY ARTIFICIAL NEURAL NETWORK

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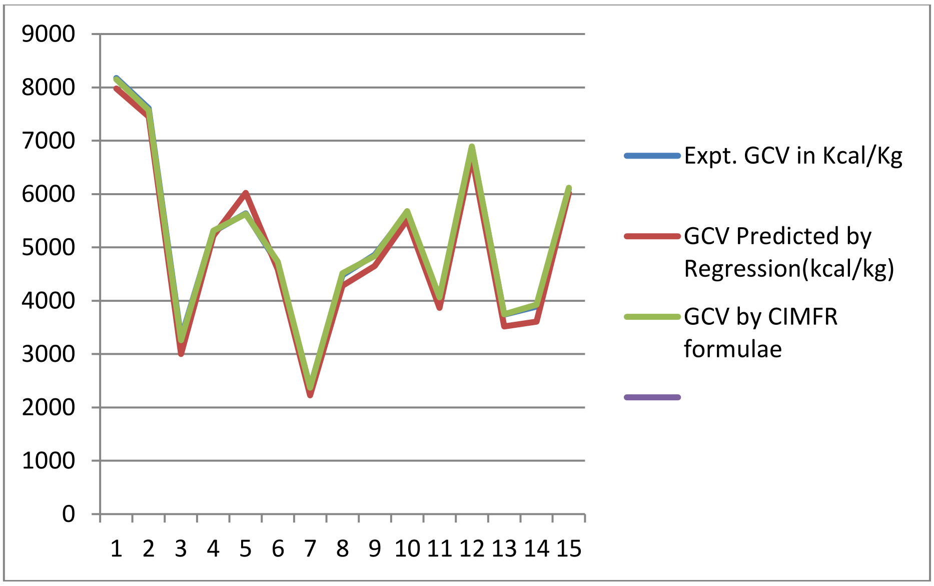
Abstract: The experimental determination of proximate analysis data can be obtained easily using an ordinary muffle furnace whereas calorific value of solid fuels is a cost intensive process, as it requires spatial instrumentation and highly trained analyst to perform the experiments, compared to calorific value. Regression analysis and CIMFR formula methods have been introduced to simplify the task and also reduce the cost of analysis. An endeavor has been made in this present study to access the applicability of these correlations and regression method with a spatial emphasize on Indian coals. Correlation have been created using simple linear regression and multivariable linear Regression analysis based on proximate analysis of data sets.

15 samples were collected from different coal fields of India including the South Eastern Coalfields (SECL), Singareni Collieries Company Limited (SCCL), Central Coalfields limited (CCL), Mahanadi Coalfield Ltd. (MCL), Jindal Steel and Power Limited. The intrinsic properties were determined by carrying out proximate analysis and gross calorific value (GCV) by using bomb calorimeter. The results for intrinsic properties and the gross calorific value are given in table 1.

Correlation analysis was carried out to analyze the individual effect of moisture, volatile matter, ash and fixed carbon on the gross calorific value (GCV). It is observed that moisture, ash have adverse impact and reduce the gross calorific value whereas volatile matter, fixed carbon have positive impact and increase the gross calorific value (GCV).

In the present study, 15 samples were used; the comparison of the results of calorific value determined by regression method, CIMFR formulae with that of the experimentally determined GCV has been presented in the figure below.



Comparison of GCV determined by Experiment and CIMFR formulae

It may be observed that both the results predict the calorific value fairly accurately.

Keywords: Coal Utilization; Energy Sources; Physical Properties; Ashes; Chemical Properties; Calorific Value; Combustion Temperature; Heat Measurement; Moisture Content; Volatility;

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I. INTRODUCTION

A. GENERAL

The rock that we refer to as coal is derived from decomposed organic matter consisting of the element carbon. When coal is burned, it produces energy in the form of heat, which is used to power machines such as steam engines or to drive turbines that produce electricity. Almost 67% of the electricity produced in India is provided by coal combustion. Coal is the world's most abundant and widely distributed fossil fuel. It is a global industry that makes a significant economic contribution to the global economy. Coal is used in more than 70 countries and mined commercially in more than 50. Annual consumption of coal is projected to nearly double by the year 2030 to meet the challenge of sustainable development and a growing demand energy.

The International Energy Agency (IEA) predicts that energy demand will grow around 60% over the next 30 years, most of it in developing countries. China and India are very large countries in terms of both population and land mass and both have substantial quantities of coal reserves. Together they account for 70% of the projected increase in world coal consumption. Strong economic growth is projected for both countries and much of the increase in their demand for energy, particularly in the industrial and electricity sectors, is expected to be met by coal.

For power plant and industrial application, it is a common practice to assess the quality of coals by using calorific value, proximate analysis and ultimate analysis. Calorific value is the amount of heat evolved by their complete combustion and experimentally it is determined by Bomb calorimeter, this method of determination is cost intensive and requires sophisticated equipment and also trained chemist.

Energy demands of the entire world is increasing recently and are mostly compensated by the fossil based fuels like natural gas, fuel oil and coal. Coal is very crucial energy sources for many countries, among the fossil fuels, which produce heat and electrical power to fulfill our daily life requirements. Hence it is very essential task to predict the coal quality and which mainly depend on knowledge about its chemical and physical constitution.

In present investigation 10 samples GCV is determined by using bomb calorimeter and are compared with the CIMFR values.

B. OBJECTIVES*:*

The objective of current work has been outlined as: Assessment of different parameters that affect the calorific value of coal.

1. Determination of intrinsic properties of the coal samples using proximate analysis and bomb calorimetry.
2. Development of the formulae for prediction of gross calorific value os coal by proximate analysis data using multivariable linear regression.

II. EXPERIMENTAL INVESTIGATION

A. Sampling

Sampling is the procedure of acquiring a representative set of data from the original population. The reason of collecting and preparing a coal sample is to provide a test specimen which when analyzed and study will provide the test results illustrative of the lot sampled. Coal is very difficult and heterogeneous mass in nature to be sampled. In India varying composition from combustible to non-combustible coal sample is available because of depth, length and breadth of the seam in the same mine. Sampling of coal and analysis is essential to check for the quality of coal where coal seams to be mined or under production and also very important for the coal reserve estimation. Coal sampling and analysis estimate whether coal can be sold as a cocking coal, prime coal, low grade coal, metallurgical coal.

1. Coal sampling methods:

Samples can collected from coal outcrop from exposed seam in open cast or deep mine, chips or core from drill holes and different sampling methods are:

1. Core samples
2. Grab samples
3. Pillar samples
4. Chip samples
5. Bulk samples
6. Channel samples

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1. Grab sampling: Generally this method of obtaining coal is not widely used because this method forces us for bias selection that means we used to collect those samples which attract us instead of our requirement like bright coal gains more attention.

2. Channel sampling: it is representative of the coal from which they are collected. If the coal sample which is collected is exposed in air then the out crop must be cleaned and a layer from sample is taken out to expose as fresh section.

Steps of channel sampling

Channel sampling is carried out in a series of steps:

1. Preparation of surface: the surface of coal is cleaned by using scrubbers or brushes in order to remove dirt, dust oxidized part of coal which is exposed to air and other soluble salts.
2. Demarcation of the channel: after cleaning the surface, a channel is marked by drawing two parallel lines 12-15 cm apart using chalk or paint.
3. Cutting of channel: in case of soft coal mines channel cutting is done by hand picks and is case of hard coal generally a light weight air operated drill machine is used.
4. Collection of sample: a sheet of canvas is spread on the floor to collect the coal chips as they fall from seam.
5. Labeling the sample: collected the coal sample is wrapped in the canvas sheet and marked. Then the marked canvas is brought out of the mine.

3. Bulk sampling: this method is the simplest sample collecting method. In this method a large mineralized rock around fifty tones is removed and is selected to represent of the potential ore body for mineral processing tests. It is used where schematic sampling procedure is unable to provide a representative scale. Large sampling or bulk sampling removes the adverse effect of irregular distribution of small value and then a small part of the sample is considered for the experimental purposes.

In the present study , 15 samples were collected from different coal fields of India following the channel sampling procedure. The samples belong to south eastern coal fields (SECL), Singareni Collieres company limited (SCCL) Cntral coal fields limited (CCL), Jindal steel and power limited. The collected samples from different mines are brought to the laboratory for analysis. It is crushed to smaller pieces using crusher. Coning and quartering procedure is done in order to get a small representative sample of the entire coal seam. Finally the samples are screened to different size of -212 (micron), -100 to 200,-100 etc. then the samples are stored and sealed for future analysis.

4. Core sampling: this technique is used in underground or under sea exploration. A core sample is of cylindrical shape which is taken out using special drills and brought to the surface fr analysis. This type of sample is needed to determine bulk properties of rock like its porosity and permeability, or to investigate the peculiar features of a given zone of strata.

The collected samples from different coal fields were brought to the laboratory. It was then crushed to smaller pieces. Coning and quarting procedure was done in order to get a small representative saple of the entire coal seam. Finally the samples were grounded and screened to different size of 212 micron, -100 to 200 etc. according to the desired requirement of the experiment. Then the samples were stored in sealed packets for further analysis process. It was placed in moisture oven to make it air dry.

The intrinsic properties of the collected samples were determined by proximate analysis and bomb calorimeter experiment.

B. Proximate analysis:

1. Moisture: Coals are extracted from the ground and have some amout of moisture with them. Heating of coal at a temperature of 100^0C causes a loss of weight due to drying of coal that moisture content is defined as inherent moisture. The moisture content of coals ranges from about 5% to 70%. Moisture is an unwanted constituent of coals as it reduces the calorific value. The inherent moisture is due to the inherent hygroscopic nature of coal.

2. Experimental procedure*:* it is found out by taking 1g of fine powder of air dried coal sample in a watch glass. This is then placed inside an oven at temperature of 108^0C. sample is kept in the oven for 1.5 hours and is then taken out using hand gloves. The sample is then cooled in a desicator for about 15 minutes and thn weighed. The loss in weight is noted as moisture.

The calculation is done by following formula,

%moisture= $Y - Z / X$

where,

X = weight of crucible, g.

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

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

3. Volatile matter:

Volatile matter includes all those components of coal, except for water, which are liberated when heated at high temperature in the absence of oxygen. Volatile matter increases the risk of spontaneous combustion of coal.

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When coal is heated at high temperature thermal decomposition of various constituents of coal takes place hence reduces the mass which is used in determinationof Volatile matter.

C. Experimental procedure:
an empty silica crucible is taken and weighed. 1g of coal sample is taken of -212micron size. Coal and crucible is weighed together and placed inside a Muffle furnace with the lid covering the crucible maintained at temperature 925 to 930^{0}C. The sample is heated for exactly seen minutes, after which the crucible is removed and allowed to cool in air, then in a desiccators and weighed agai. The calculation was done as per the following
% volatile matter= $Y – Z / X$
Where,
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

1. Ash content: Ash is the non- combustible residue formed from the inorganic or mineral components of the coal. Indian coals are of drift origin. The procedure followed for determination of ash content is follows. An empty silica crucible is taken and cleaned by heating it in furnace for 800^{0}C and allowed to cool and weighed. 1g of coal sample is taken of- 212 micron size. Coal and crucible is weighed together and placed inside a muffle furnace maintained at temperature 450^{0}C for 30 minutes and then temperature of the furnace is raised to850^{0}C for 1 hour. After which the crucible is removed and allowed to col in a desiccators and weighed again. The calculation is done by following formula,
% Ash = $Y – Z / Y - X$
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)
2. Fixed Carbon: it is determined by substracting the sum of all the above three parameters from 100 and is given as
FC = 100 – (M + V + A)
Where, M: Moisture content
V: Volatile matter content
A: Ash content
The results of proximate analysis has been presented in table 3.1

Table 3.1 Results of proximate analysis:

Sl. No.	Moisture (%)	Volatile matter (%)	Ash Content (%)	Fixed Carbon (%)
1	1.8	44.03	0.37	53.8
2	0.4	23.32	11.73	64.55
3	5.29	24.75	48.09	21.87
4	13.39	30.32	13.76	42.53
5	7.72	26.15	14.75	51.38
6	3.38	23.98	35.46	37.18
7	2.09	13.56	62.51	21.84
8	3.98	27.71	36.82	31.49
9	2.75	26.05	35.27	35.93
10	4	29.04	24.41	42.55
11	3.96	23.98	41.65	30.41
12	6.02	37.06	8.38	48.54
13	1.29	25.3	48.58	24.83
14	3.07	28.98	44.47	23.48
15	4.5	28	19	48.5

III. DETERMINATION OF CALORIFIC VALUE

A. Calorific value: the calorific value of any fuel is the quantity of heat produced by its complete combustion at constant pressure and under normal conditions. Due to the combustion process it generates water vapor and certain and

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certain techniques may be utilized to recover the quality of the heat contained in the water vapour by condensing it.
Gross calorific value (GCV) or higher calorific value or Hiegher heating value (HHV):
Water of combustion is completely condensed and here the heat contained in the water vapour is recovered.
Net calorific value (NCV) or Lower calorific value or Lower Heating value(LHV):
The products of combustion contains the water vapour and here the heat in the water vapour is not recvered and utilize.

Table: Grading of non-coking coal base on heating value of coal

Grade of coal	Useful heat value (Kcal/kg)
A	>6200
B	5601 TO 6200
C	4941 TO 5600
D	4201 TO 4940
E	3361 TO 4200
F	2401 TO 3360
G	1301 TO 2400

Bomb calorimeter is an arrangement consists of a hallow cylindrical vessel called bomb made up of stainless steel. The cylinder has an air tight cover which is screwed over the cylinder. The cover consists of three terminals. One for the filling oxygen into the bomb and other two terminals are passing electric current ignites the coal by producing spark. After the oxygen is forced into the bomb the terminal is closed.
The whole arrangement is then kept inside a water jacket containing water of a known amount. A mechanical stirrer is provided to mix the water inside jacket to maintain an even temperature distribution in water. A thermocouple is provided for recording the temperature of water**.**

B. Experimental procedure:
1 gm of coal is weighed in the digital balance and the reading imported to the bomb calorimeter using start pre-weight button and stored adjacent to the name of sample. Coal was then placed in the small crucible and fixed in the arrangement provided in the cover of bomb. A piece of nichrome wire was cut and attached to the rods below the cover such that the wire is in contact with coal. The whole arrangement was carefully screwed over the bomb and oxygen line was attached over the valve on the cover. Then oxygen fill button was pressed and oxygen was filled in the bomb. After that the bomb was carefully placed inside the water jacket. The bomb is placed in such a way that it does not come in contact with the stirrer. Then the leads are attached to the two terminals provided on the cover. The lid of machine is closed and the start button is pressed. After sometime the machine will ignite the coal and display the gross calorific value on screen.

Table: experimental gross calorific value (GCV) of coal samples:

Sample No.	GCV in Kcal/Kg
1	8175.50
2	7605.54
3	3301.80
4	5294.77
5	5635.60
6	4696.30
7	2367.97
8	4479.30
9	4861.10
10	5652.20
11	4030.06
12	6876.20
13	3742.81
14	3889.40
15	6099.80

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IV. MODEL DEVELOPMENT

A. Model Development by Regression Analysis

Linear Regression: Linear Regression is a statically approach for modeling the relationship between a scalar dependent variable (Y) and one or more explanatory variables or independent variable donated by X. The case of one explanatory variable is known as simple linear regression and for more than one explanatory variable the process is called multiple linear regression. In the linear regression process, data are modeled using linear predictor function and unknown model parameters are estimated from the data, such models are called linear models.

1. Multivariable linear regression:

Multivariable linear regression model attempts to the relationship between two or more explanatory variables and a response variable by fitting a linear equation to observed data.

Every value of the independent variable x is associated with a value of the dependent variable y.

In the least square model the best fitting line for the observed data is calculated by minimizing the sum of the squares of the vertical deviation s from each point to the line.

The deviations are firstly squared then summed, there are no cancellations between positive and negative values.

By using the 15 experimental data of proximate analysis and gross calorific value of coal in present study formulae were developed by using multivariable linear regression and all samples were used for checking purpose. Developed formulae given by:

$GCV = 7115.197 – 123.971 *M - 81.3121*A + 20.7421*F$

Where the M, A, F denote the moisture, ash content, fixed carbon percentage air dried basis, respectively. The comparison of the predicted GCV by regression and model and that of the experimentally determined value has been presented in Table below

Table 4.1 : Experimental GCV and predicted GCV by Regression model

Sample No.	Experimental GCV (kcal/kg)	GCV Predicted by Regression (kcal/kg)	Difference (kcal/kg)
1	8175.50	7977.80	197.7
2	7605.54	7450.80	154.73
3	3301.80	3002.79	299.01
4	5294.77	5218.65	76.12
5	5635.60	602410	388.5
6	4696.30	4584.06	112.24
7	2367.97	2226.30	141.67
8	4479.30	4821.04	198.26
9	4861.10	4651.68	209.42
10	5652.20	5517.08	135.12
11	4030.06	3868.43	161.63
12	6876.20	6694.32	181.88
13	3742.81	3520.15	222.66
14	3889.40	3605.68	283.72
15	6099.80	6021.03	78.77

V. RESULTS, DISCUSSION AND CONCLUSION

A. *Discussion*

In the present study, 15 samples were collected from different coal fields of India following the channel sampling procedure. The samples belong to South Eastern Coalfields (SECL), Singareni Collieries Company Limited (SCCL), Central Coalfields Limited (CCL), Jindal Steel and power Limited.

A study of Table 3.1 and 3.2 reveals that the moisture content of the coal sample varied from 0.4 (Sample 02) to 13.39 % (Sample 04). The volatile matter of the coal samples varied from 13.56% (Sample 07) to 44.04 (Sample 01). The

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fixed carbon content of the coal samples varied between 21.84% (Samples 07) to 64.55% (Sample 02). The gross calorific values varied between 2367.97 Kcal/kg (Sample 07 and 8175.5 Kcal/kg (Sample 01). Thus it could be seen that coals that have been collected for the study covers almost all major coalfields and the quality of the coals covers a broad spectrum.
In order to understand the relationship between the calorific value and the intrinsic properties, correlation study was carried out and this has been presented in Figure 5.1 to 5.4

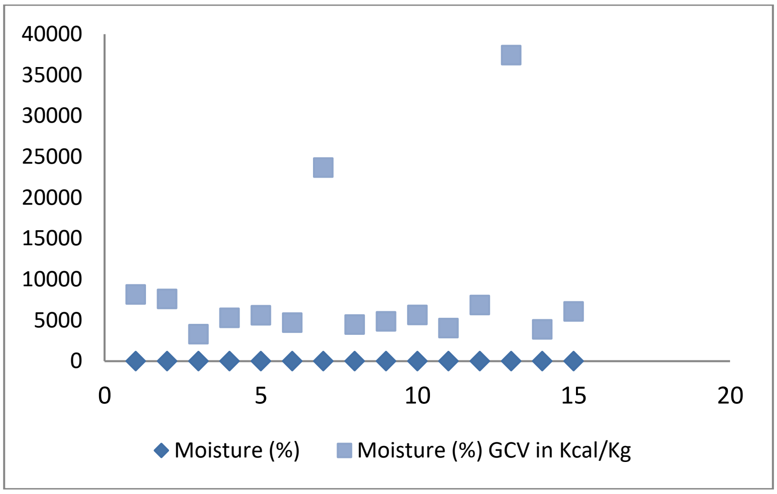

Figure 5.1: Correlation plot between moisture and experimental GCV

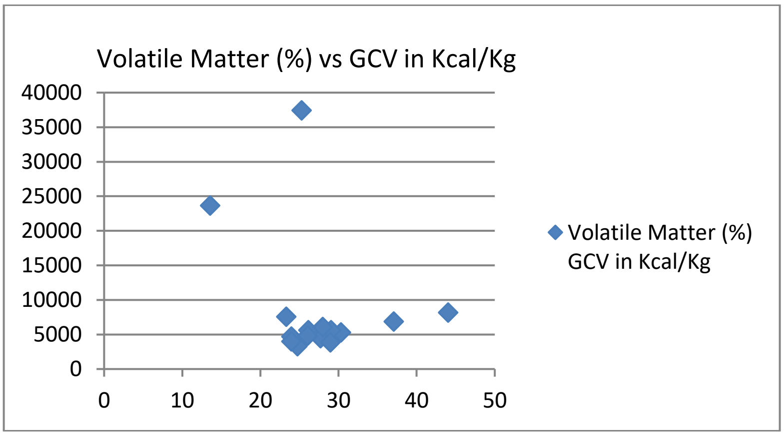

Figure 5.2: Correlation plot between volatile matter and experimental GCV

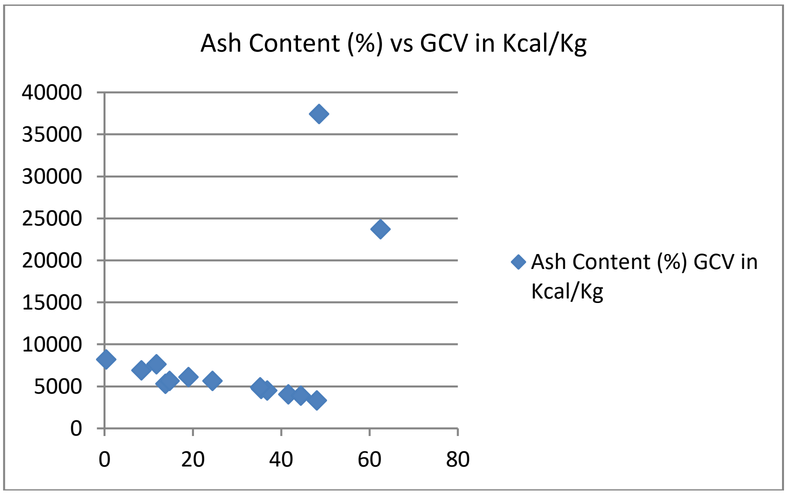

Figure 5.3: Correlation plot between Ash content and Experimental GCV

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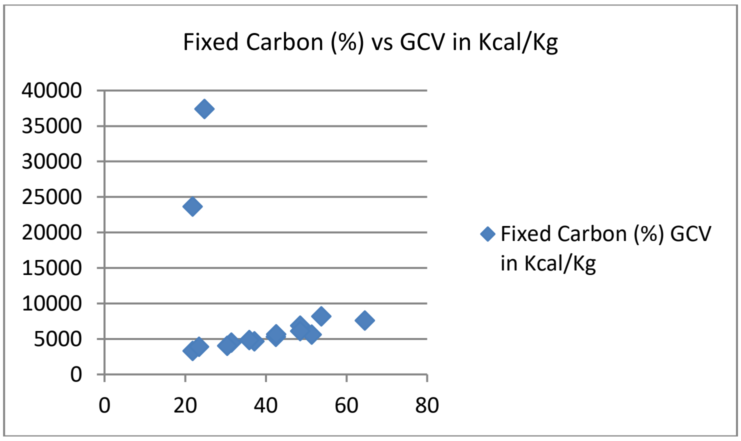
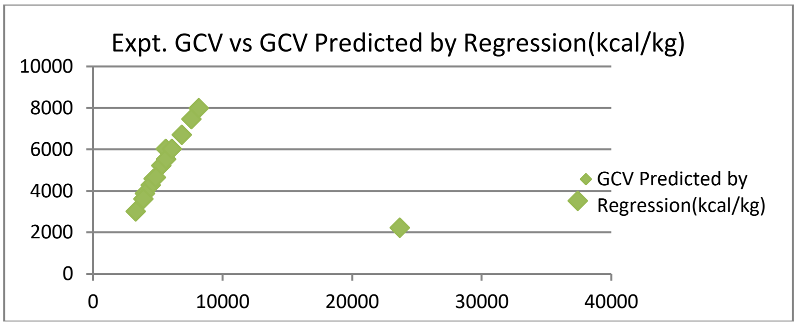


Figure 5.4: Correlation plot between fixed carbon and experimental GCV

5.1.1 Multivariable Relationships of GCV with proximate analysis parameters By regression method, the correlation coefficients of M,A and F with GCV, were determined to be -123.971, -81.312 and 20.742 respectively. Equation given by regression analysis is: GCV= 7115.197-123.971*M-81.312*A+20.742*FR_2=0.977
From the above equation it can be concluded that the worthy relations are for fixed carbon with positive effect and moisture, ash with negative effect, because they are rank parameters.



The following formulae have been developed by central Institute of Mining and Fuel Research (CIMFR), Dhanbad for the determination of calorific value of Indians coals from their proximate analysis:
1. For low moisture coals, M<=2%
C_G= 91.7 F + 75.6 (V-0.1A) – 60 M
2. For high moisture coals,
M >= 2%
C_G =85.6(100-(1.1A + M))-60 M
Where: M, V, A, F denote Moisture, Volatile Matter, Ash and Fixed Carbon, all in present air- dried basis, respectively. A comparison between the predicted calorific value and the value obtained by CIMFR formulae has been presented in Table below

Table 5.1: Comparison of Experimental GCV and predicted GCV by CIMFR formulae

Sample No.	GCV in Kcal/Kg	GCV by CIMFR formulae	DifferenceKcal/Kg
1	8175.5	8150.46	25.04
2	7605.54	7569.54	36
3	3301.8	3261.6	40.2
4	5294.77	5314.77	20
5	5635.6	5625.3	10.3
6	4696.3	4728.9	32.6
7	23679.7	2369.6	16.3
8	4479.3	4513.5	34.2
9	4861.1	4838.5	22.6

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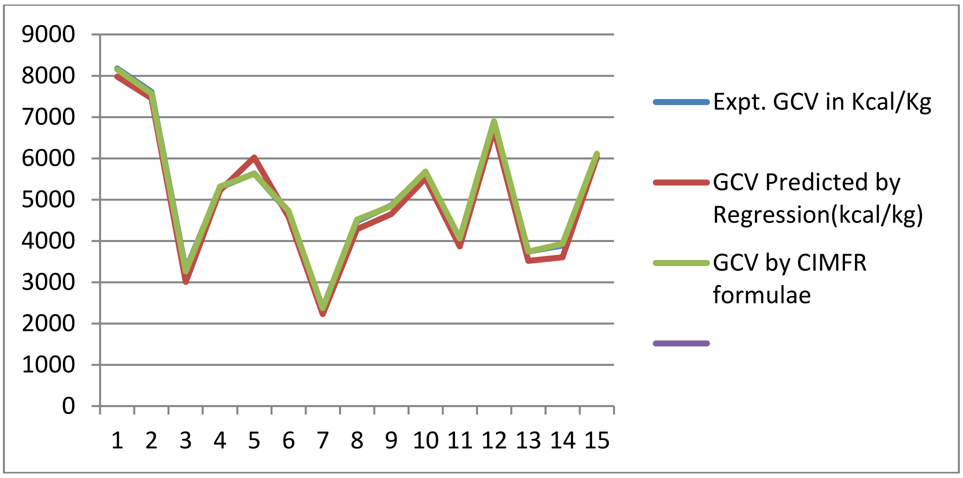
10	5652.2	5679.1	26.9
11	4030.06	4061.66	31.6
12	6876.2	6895.8	19.6
13	37428.1	3744.5	16.9
14	3889.4	3925.7	36.3
15	6099.8	6115.7	15.9



Graph showing correlation between experimental GCV and predicted GCV by CIMFR formulae

Here correlation coefficient between experimental GCV and predicted GCV by CIMFR formulae found to be 0.9965

B. Conclusion

Results from the regression analysis is show that difference between experimental and predicted is less and regression method can use for prediction of GCV.

Any industry where coal is utilized for heating applications, determinations of calorific value, proximate analysis and ultimate are common practice to assess the quality of coals in India, due to non – availability of consistent power supply and higher industrial tariffs many industries are opting for coal- fired captive power plants. Examination of coal deposites parameters, such as calorific value, ash content and moisture content, in order to manage the coal deposite. The developed correlation involves the effects of all the major variables affecting the gross calorific values of coals. Validation with a set of data at reasonable accuracy establishes the general acceptability of the developed correlation.

By this study it was concluded that predicted GCV by Regression method and CIMFR had very less difference with GCV determined by experiment. It is expected that the results of this study will benefit the practicing researchers to a great extent in predicting the spontaneous heating susceptibility of the seams and accordingly plan the mining activities and actives and precautionary Measures to deal with fire problems in mines.

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