A CORRELATION STUDY OF GROSS CALORIFIC VALUE WITH PARAMETERS OF PROXIMATE ANALYSIS OF COAL

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ABSTRACT
A correlation study of gross calorific value of coal with parameters of proximate analysis (the content of ash, moisture, volatile matter and fixed carbon) was studied on more than 200 samples of coal from different mining areas across India. Gross calorific value is increased with the decrease of the content of ash, moisture respectively, and gross calorific value is also increased with the increase in the content of volatile matter and fixed carbon respectively. The relevant experimental data and graphs are very useful for industries to estimate the quality of coal.

Keywords: Moisture, Ash, Volatile Matter, Fixed carbon, Gross Calorific Value

INTRODUCTION
Coal is one of the best non-renewable energy sources and abundantly available in India and used as the main fuel for the industrial process as well as household use in some parts of the country. India is the second-largest producer and importer of coal in the world.3 India’s electricity generation highly depends on coal only.3 It is used as fuel for power generation for thermal power plants, steel making industries, and cement manufacturing industries, etc. Every country are having coal with different physical/chemical properties. The ash of coal is one of the pozzolanic material used in the manufacturing of cement. Indian coal is having a variety of grades which is dependent on the gross calorific value. Chemical analysis of coal is very important concerning the correlation of gross calorific value with the parameters of proximate analysis which are very useful for the industries to estimate the quality of coal.

EXPERIMENTAL
Sampling
Coal samples were pulverized and passed through a sieve 212 micron1 as per Indian standard. Estimation of moisture, ash, volatile matter, and fixed carbon was analyzed by Eltra thermogravimetric analyzer (TGA) model Thermostep and results are recorded. Initially we are loading the sample in Eltra thermogravimetric analyzer, within 1.5 hours, we got the results of moisture, ash, volatile matter and fixed carbon respectively.

Gross Calorific Value (GCV)
Gross calorific value was determined by using a digital bomb calorimeter and results are recorded.2 According to environmental condition, we are going to find out water equivalent of a standard benzoic acid, based on that one, find out the calorific value of certified reference material. The calorific value of standard reference material is used for calibration of the digital bomb calorimeter. Then we are going for sample analysis. More than 200 Samples were analyzed and data recorded as follows in Table-1.

Table-1

| S. No. | Moisture % by mass | Ash % by mass | GCV, Kcal/kg | Volatile matter % by mass | Fixed Carbon % by mass |
|--------|--------------------|---------------|--------------|---------------------------|------------------------|
| 1      | 5.87               | 13.14         | 6300         | 33.22                     | 47.77                  |

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|   |   |   |   |   |
|---|---|---|---|---|
| 2 | 6.00 | 13.06 | 6270 | 33.11 | 47.83 |
| 3 | 6.09 | 11.92 | 6370 | 34.46 | 47.53 |
| 4 | 6.11 | 11.89 | 6380 | 34.47 | 47.53 |
| 5 | 5.56 | 13.41 | 6280 | 34.12 | 46.92 |
| 6 | 5.57 | 13.44 | 6260 | 33.84 | 47.15 |
| 7 | 5.56 | 13.11 | 6270 | 33.83 | 47.50 |
| 8 | 5.50 | 13.36 | 6250 | 33.53 | 47.61 |
| 9 | 5.49 | 13.36 | 6280 | 33.94 | 47.20 |
|10 | 5.61 | 13.45 | 6300 | 34.01 | 46.93 |
|11 | 5.72 | 13.14 | 6240 | 33.38 | 47.76 |
|12 | 5.59 | 13.34 | 6230 | 33.42 | 47.65 |
|13 | 6.09 | 13.20 | 6260 | 33.88 | 47.53 |
|14 | 5.74 | 13.46 | 6250 | 33.51 | 47.28 |
|15 | 5.65 | 13.46 | 6300 | 33.68 | 47.20 |
|16 | 5.89 | 13.06 | 6340 | 33.22 | 47.83 |
|17 | 5.70 | 13.42 | 6330 | 33.51 | 47.37 |
|18 | 5.88 | 13.13 | 6210 | 33.30 | 47.69 |
|19 | 5.99 | 13.03 | 6310 | 33.36 | 47.62 |
|20 | 5.79 | 20.33 | 5730 | 31.80 | 42.08 |
|21 | 5.77 | 13.45 | 6260 | 34.69 | 46.09 |
|22 | 5.94 | 12.98 | 6380 | 34.51 | 46.57 |
|23 | 6.23 | 13.10 | 6240 | 34.61 | 46.06 |
|24 | 5.99 | 13.00 | 6270 | 34.32 | 46.69 |
|25 | 5.96 | 13.65 | 6270 | 33.98 | 46.41 |
|26 | 6.92 | 11.80 | 6350 | 34.63 | 46.65 |
|27 | 6.73 | 11.88 | 6360 | 34.60 | 46.78 |
|28 | 6.64 | 11.91 | 6310 | 34.73 | 46.72 |
|29 | 0.75 | 12.82 | 6210 | 36.67 | 49.77 |
|30 | 6.08 | 13.21 | 6390 | 34.33 | 46.37 |
|31 | 5.90 | 13.09 | 6400 | 34.60 | 46.42 |
|32 | 5.98 | 13.46 | 6190 | 34.57 | 45.98 |
|33 | 5.90 | 13.10 | 6310 | 33.49 | 47.51 |
|34 | 6.01 | 13.37 | 6300 | 33.83 | 46.79 |
|35 | 5.97 | 13.14 | 6300 | 33.67 | 47.22 |
|36 | 6.25 | 22.05 | 5560 | 30.19 | 41.52 |
|37 | 5.67 | 13.37 | 6240 | 34.43 | 46.53 |
|38 | 6.42 | 11.80 | 6360 | 35.23 | 46.55 |
|39 | 5.77 | 11.77 | 6380 | 36.60 | 45.86 |
|40 | 4.97 | 13.47 | 6350 | 35.61 | 45.95 |
|41 | 5.82 | 12.72 | 6280 | 36.51 | 44.95 |
|42 | 4.96 | 14.42 | 6060 | 34.03 | 46.58 |
|43 | 5.05 | 13.49 | 6280 | 34.50 | 46.95 |
|44 | 5.49 | 13.60 | 6040 | 35.47 | 45.44 |
|   |   |   |   |   |
|---|---|---|---|---|
| 45 | 5.38 | 13.61 | 6270 | 35.45 | 45.56 |
| 46 | 5.19 | 13.47 | 6260 | 34.80 | 46.54 |
| 47 | 4.55 | 28.24 | 4800 | 29.18 | 38.03 |
| 48 | 6.27 | 11.82 | 6390 | 35.56 | 46.35 |
| 49 | 6.24 | 15.00 | 5920 | 34.39 | 44.37 |
| 50 | 6.11 | 12.75 | 6140 | 36.28 | 44.86 |
| 51 | 5.66 | 13.58 | 6320 | 34.83 | 45.93 |
| 52 | 6.21 | 12.71 | 6240 | 35.34 | 45.73 |
| 53 | 6.38 | 11.89 | 6350 | 34.99 | 46.74 |
| 54 | 5.61 | 21.28 | 5520 | 33.23 | 40.88 |
| 55 | 5.89 | 13.06 | 6420 | 35.14 | 45.91 |
| 56 | 5.81 | 12.94 | 6420 | 34.32 | 46.93 |
| 57 | 5.63 | 12.10 | 6350 | 36.50 | 45.77 |
| 58 | 6.08 | 12.79 | 6360 | 34.18 | 46.95 |
| 59 | 6.11 | 12.78 | 6210 | 34.08 | 47.04 |
| 60 | 5.97 | 14.41 | 6050 | 33.88 | 45.74 |
| 61 | 6.21 | 12.74 | 6360 | 33.87 | 47.18 |
| 62 | 6.30 | 12.76 | 6260 | 33.89 | 47.05 |
| 63 | 6.21 | 12.75 | 6300 | 33.89 | 47.15 |
| 64 | 6.27 | 12.74 | 6320 | 33.93 | 47.06 |
| 65 | 6.19 | 12.82 | 6290 | 34.03 | 46.96 |
| 66 | 6.16 | 14.38 | 6040 | 33.50 | 45.96 |
| 67 | 6.01 | 11.15 | 6290 | 34.37 | 48.47 |
| 68 | 6.56 | 12.76 | 6190 | 33.53 | 47.15 |
| 69 | 6.51 | 12.75 | 6360 | 33.73 | 47.01 |
| 70 | 6.60 | 12.77 | 5950 | 33.68 | 46.95 |
| 71 | 6.60 | 12.71 | 6180 | 33.53 | 47.12 |
| 72 | 6.66 | 12.80 | 6240 | 33.34 | 47.20 |
| 73 | 6.52 | 12.73 | 6090 | 33.19 | 47.56 |
| 74 | 6.31 | 21.28 | 5830 | 30.44 | 41.97 |
| 75 | 6.74 | 12.74 | 6270 | 33.77 | 47.15 |
| 76 | 5.81 | 11.98 | 5910 | 34.47 | 47.75 |
| 77 | 5.99 | 11.81 | 6040 | 34.07 | 48.13 |
| 78 | 5.94 | 11.81 | 6240 | 34.13 | 48.13 |
| 79 | 5.36 | 13.38 | 6260 | 33.73 | 47.53 |
| 80 | 5.37 | 13.36 | 6120 | 33.64 | 47.63 |
| 81 | 5.46 | 13.40 | 6150 | 33.79 | 47.35 |
| 82 | 5.34 | 13.28 | 6290 | 33.36 | 48.02 |
| 83 | 5.76 | 13.11 | 6210 | 33.73 | 47.40 |
| 84 | 6.44 | 14.00 | 5860 | 32.27 | 47.29 |
| 85 | 5.65 | 13.22 | 6340 | 33.27 | 47.86 |
| No. | Value 1 | Value 2 | Value 3 | Value 4 | Value 5 |
|-----|---------|---------|---------|---------|---------|
| 86  | 6.50    | 12.73   | 6270    | 32.91   | 47.85   |
| 87  | 6.03    | 12.29   | 6170    | 33.22   | 48.46   |
| 88  | 6.38    | 11.54   | 6050    | 33.39   | 48.69   |
| 89  | 6.33    | 12.08   | 6240    | 33.65   | 47.93   |
| 90  | 5.88    | 12.42   | 6330    | 32.73   | 48.96   |
| 91  | 5.97    | 13.48   | 5940    | 32.70   | 47.85   |
| 92  | 6.51    | 11.45   | 6080    | 33.25   | 48.79   |
| 93  | 5.89    | 14.44   | 5960    | 32.22   | 47.45   |
| 94  | 6.21    | 12.34   | 6320    | 33.05   | 48.40   |
| 95  | 5.89    | 11.87   | 6390    | 34.18   | 48.07   |
| 96  | 5.76    | 12.98   | 6280    | 33.75   | 47.50   |
| 97  | 5.39    | 12.55   | 6370    | 33.97   | 48.09   |
| 98  | 6.15    | 14.38   | 6000    | 33.43   | 46.04   |
| 99  | 5.91    | 12.06   | 6250    | 35.45   | 46.58   |
| 100 | 6.06    | 12.02   | 6340    | 35.47   | 46.44   |
| 101 | 5.65    | 13.93   | 6070    | 33.93   | 46.49   |
| 102 | 6.08    | 11.42   | 6050    | 34.30   | 48.20   |
| 103 | 5.32    | 14.21   | 6280    | 34.02   | 46.45   |
| 104 | 6.15    | 11.84   | 6210    | 34.99   | 47.02   |
| 105 | 6.27    | 14.49   | 6000    | 33.01   | 46.24   |
| 106 | 6.29    | 11.86   | 6250    | 35.02   | 46.82   |
| 107 | 6.31    | 11.88   | 6040    | 34.70   | 47.10   |
| 108 | 6.26    | 13.34   | 6270    | 33.81   | 46.59   |
| 109 | 6.47    | 11.79   | 6230    | 34.75   | 46.98   |
| 110 | 6.42    | 13.37   | 6340    | 33.63   | 46.58   |
| 111 | 6.55    | 13.32   | 6230    | 33.50   | 46.63   |
| 112 | 6.62    | 11.83   | 6120    | 34.38   | 47.77   |
| 113 | 6.58    | 15.16   | 6050    | 32.72   | 45.54   |
| 114 | 5.65    | 12.78   | 6150    | 35.51   | 46.07   |
| 115 | 5.52    | 12.08   | 6330    | 34.62   | 47.77   |
| 116 | 5.18    | 13.33   | 6380    | 33.46   | 48.04   |
| 117 | 5.21    | 13.02   | 6350    | 33.79   | 47.97   |
| 118 | 5.40    | 13.05   | 6360    | 33.57   | 47.98   |
| 119 | 5.68    | 12.04   | 6390    | 34.77   | 47.51   |
| 120 | 5.60    | 12.34   | 6420    | 33.25   | 48.80   |
| 121 | 5.59    | 13.91   | 6140    | 33.04   | 47.46   |
| 122 | 6.15    | 13.90   | 6010    | 32.91   | 47.05   |
| 123 | 6.30    | 13.48   | 6230    | 32.75   | 47.46   |
| 124 | 5.65    | 12.94   | 6340    | 33.93   | 47.49   |
| 125 | 6.00    | 12.16   | 6300    | 34.32   | 47.53   |
| 126 | 6.08    | 11.47   | 6380    | 34.00   | 48.45   |
|   |   |   |   |   |
|---|---|---|---|---|
| 127 | 5.42 | 13.07 | 6330 | 33.42 | 48.09 |
| 128 | 5.87 | 12.58 | 6380 | 33.29 | 48.26 |
| 129 | 5.49 | 13.37 | 6420 | 33.43 | 47.71 |
| 130 | 5.47 | 13.48 | 6360 | 33.34 | 47.71 |
| 131 | 6.34 | 12.04 | 6380 | 34.09 | 47.53 |
| 132 | 6.25 | 11.98 | 6310 | 33.87 | 47.91 |
| 133 | 6.39 | 11.45 | 6410 | 33.40 | 48.76 |
| 134 | 5.53 | 13.88 | 6390 | 33.67 | 46.92 |
| 135 | 5.98 | 17.15 | 5690 | 34.09 | 43.09 |
| 136 | 6.25 | 12.04 | 6340 | 34.85 | 46.89 |
| 137 | 6.20 | 12.13 | 6320 | 34.59 | 47.08 |
| 138 | 6.28 | 12.07 | 6340 | 35.04 | 46.61 |
| 139 | 6.21 | 12.04 | 6200 | 35.35 | 46.40 |
| 140 | 6.27 | 12.06 | 6120 | 35.20 | 46.47 |
| 141 | 5.58 | 14.11 | 6100 | 33.21 | 47.10 |
| 142 | 6.46 | 13.94 | 6020 | 33.47 | 46.13 |
| 143 | 6.37 | 12.08 | 6300 | 34.65 | 46.89 |
| 144 | 5.59 | 13.59 | 6160 | 34.27 | 46.55 |
| 145 | 6.45 | 11.99 | 6260 | 34.97 | 46.58 |
| 146 | 6.78 | 14.03 | 5870 | 32.73 | 46.47 |
| 147 | 6.54 | 12.04 | 6230 | 34.42 | 47.01 |
| 148 | 6.54 | 12.03 | 6350 | 34.40 | 47.03 |
| 149 | 6.67 | 12.60 | 6140 | 33.52 | 47.21 |
| 150 | 8.57 | 16.15 | 5920 | 31.66 | 43.62 |
| 151 | 5.81 | 13.42 | 6210 | 33.67 | 47.10 |
| 152 | 6.11 | 11.36 | 6180 | 34.22 | 48.31 |
| 153 | 6.86 | 14.42 | 6100 | 33.00 | 45.72 |
| 154 | 5.63 | 13.00 | 6030 | 34.53 | 46.85 |
| 155 | 5.68 | 12.73 | 6300 | 35.34 | 46.24 |
| 156 | 4.82 | 13.55 | 6160 | 33.84 | 47.78 |
| 157 | 5.35 | 13.22 | 6270 | 34.46 | 46.97 |
| 158 | 5.45 | 13.59 | 5870 | 34.97 | 46.00 |
| 159 | 6.06 | 13.94 | 6240 | 33.66 | 46.34 |
| 160 | 5.16 | 18.56 | 6360 | 32.12 | 44.16 |
| 161 | 5.91 | 12.74 | 6150 | 35.48 | 45.86 |
| 162 | 6.24 | 12.09 | 5920 | 34.21 | 47.46 |
| 163 | 5.49 | 13.06 | 6020 | 33.95 | 47.50 |
| 164 | 5.77 | 13.93 | 6180 | 33.51 | 46.79 |
| 165 | 5.83 | 13.00 | 5920 | 34.30 | 46.87 |
| 166 | 5.70 | 13.31 | 6320 | 33.83 | 47.15 |
| 167 | 6.22 | 12.14 | 6310 | 34.98 | 46.65 |
RESULTS AND DISCUSSION

Data have compiled an interval of 10 points to draw the graphical representation and correlation of Gross calorific value (GCV) with parameters of proximate analysis of coal. Gross calorific value is one of the important parameters as per the requirements of IS 1350 (part-2) for coal samples to determine the quality. The above (proposed) correlation studies are based on the data of thermogravimetric analysis (TGA) and bomb calorimeter. Already correlation studies were done based on the experimental data of coal to calculate the approximate calorific value by formula and Artificial Intelligence (AI) methods.
Neural Network (ANN) models. The proposed correlation studies are showing that the content of gross calorific value (GCV) is increased with the decrease of the content of moisture and ash respectively (Figs.-1 and 2). The content of ash of coal is an impurity that will not be burned. The gross calorific value (GCV) is also increased with the increase of the content of volatile matters and fixed carbon respectively (Figs.-3 and 4). Volatile matters are hydrocarbons such as methane and other gases etc., Fixed carbon is carbon in the free state that does not combine with other elements. This study of gross calorific value correlated with the parameters of proximate analysis is useful for determination of the quality of coal and also it may be useful for cement industries, thermal power plants, steel making industries, etc.

**Moisture VS Gross Calorific Value (GCV)**
The Gross calorific value was decreased with the increase in moisture content.

![Fig.-1: Graph between Moisture VS Gross Calorific Value (GCV)](image)

Moisture always lowers the heating value of coal, when moisture increases automatically gross calorific value decreases.

**Ash VS Gross Calorific Value (GCV)**
The Gross calorific value was increased with the decrease of ash content.

![Fig.-2: Graph between Ash VS Gross Calorific Value (GCV)](image)

Ash is an impurity will not burn. It is usually consists of silica, alumina, iron oxide, lime and magnesia etc., when high ash content, gross calorific value always decreases.

**Volatile Matter VS Gross Calorific Value (GCV)**
The Gross calorific value was increased with the increase of volatile matters. It consists of a complex mixture of gaseous and liquid products from thermal composition of coal. Volatile matter increases, gross calorific value also increases.
Fixed Carbon VS Gross Calorific Value (GCV)
The Gross calorific value was increased with the increase of fixed carbon.

Fixed carbon calculated from 100 - (moisture + ash + volatile matter) etc., Fixed carbon is free state does not combine with any other elements. Gross calorific value increases with the increase of the high fixed carbon content.

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