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Technical Scientific Article

Coal Quality Change Due to Handling and Stockpiling in an Indian Power Plant: A Case Study (Part-2-The Results and Inference)

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Abstract

Abstract: In the open transportation of coal by wagons or trucks, external moisture due to rain coupled with oxidation, the loss of quality in terms of the heat value of coal is nearly unavoidable. And when in the stock pile, there is a likelihood of loss up to 5% of the gross calorific value over a period of 3-4 months in open stocks/stacks. This study however, reports a technological challenge to ascertain the coal in the standard practice of coal handling from train to stock and then from the stock to the firing. The technological and practice level challenge is that as the coal gets crushed and milled, the heavier impurities during vibration and movement, an even in static condition, tend to settle at the bottom. And so measuring coal quality by sampling at the top of the belt or by cut sampling during flow provides higher than actual gross thermal value obtained for the whole mass. This aspect needs to be studied in detailed and correctional factor(s) may be adopted to find the actual thermal value of coal, finally being obtained at the firing circuit and the boiler.

(Continued from part-1)

5.0 Results and Discussion

After the coal samples were brought to IIT Kharagpur laboratory two types of analysis were done for collected coal samples *viz.* GCV analysis and proximate analysis using bomb calorimeter and Thermogravimetric analyzer (TGA) respectively.

The results obtained after GCV analysis on bomb calorimeter at the laboratory are tabulated in Table 2 along with their rake numbers, sample codes, sampling locations, GCV values and statistical results.

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Table 2. GCV readings of all the collected coal samples of NTPC Farakka

Rake No.	Sample Number	Sampling Location	GCV (cal/g)	Statistical results for GCV
	43	Staok Pile	4844.82045	Avg. value = 4821.36485 STD. Deviation = 452.5229 Maximum = 5549.7961 Minimum = 4403.39515
	44	Staok Pile	4403.39515	
	45	Staok Pile	4610.9033	
	81	Staok Pile	5449.7961	
864	46	Wagon Loading	5022.14515	Avg. value = 4464.39455 Std. Deviation = 1413.2306 Maximum = 5213.2553 Minimum = 1269.08335
	47	Before Crusher	4888.3382	
	48	After Crusher	4999.31045	
	49	Before Bunkering	4969.7437	
	50	Feeder Inlet	4888.8857	
	51	Pulverizer	5213.2553	
	52	Mill Reject	1269.08335	
712	53	Wagon Loading	3236.76425	Avg. value = 2967.3099 Std. Deviation = 738.6526 Maximum = 4115.8223 Minimum = 1605.6689
	54	Before Crusher	3004.0915	
	55	After Crusher	3031.16975	
	56	Before Bunkering	2960.04185	
	57	Feeder Inlet	2817.61105	
	58	Pulverizer	4115.8223	
	59	Mill Reject	1605.6689	
866	60	Wagon Loading	4487.66815	Avg. value = 4055.7876 Std. Deviation = 891.6383 Maximum = 4647.37345 Minimum = 2076.1766
	61	Before Crusher	4139.64725	
	62	After Crusher	4533.731	
	63	Before Bunkering	4280.7443	
	64	Feeder Inlet	4647.37345	
	65	Pulverizer	4225.1725	
	66	Mill Reject	2076.1766	

705	67	Wagon Loading	3224.0438	Avg. value = 3163.4581 Std. Deviation = 1305.9304 Maximum = 5164.8113 Minimum = 678.2608
	68	Before Crusher	3303.3082	
	69	After Crusher	3231.54295	
	70	Before Bunkering	3276.567	
	71	Feeder Inlet	3265.6725	
	72	Pulverizer	5164.8113	
	73	Mill Reject	678.2608	
852	74	Wagon Loading	4943.785	Avg. value = 5423.68202 Std. Deviation = 1589.1800 Maximum = 5508.1445 Minimum = 946.52405
	75	Before Crusher	5010.96425	
	76	After Crusher	5217.84195	
	77	Before Bunkering	5038.70005	
	78	Feeder Inlet	4999.81435	
	79	Pulverizer	5508.1445	
	80	Mill Reject	946.52405	
701	82	Wagon Loading	3295.3916	Avg. value = 2964.9349 Std. Deviation = 743.8786 Maximum = 3492.8801 Minimum = 1322.2602
	83	Before Crusher	3226.3447	
	84	After Crusher	3492.8801	
	85	Before Bunkering	3272.1586	
	86	Feeder Inlet	2918.0721	
	87	Pulverizer	3227.4372	
	88	Mill Reject	1322.2602	

5.1 GCV Analysis

From Table 2, it can be seen from statistical results, that all stack pile coal samples whose sample codes are 43, 44, 45 and 81 have a maximum GCV value of 5549.7961 (cal/g), minimum GCV value of 4403.39515 (cal/g), average GCV value as 4821.36485 (cal/g) and S.D. as 452.5229. Similarly, for rake number 864, GCV values for all coal samples from all processing units of CHP (from wagon loading to mill reject) have shown a maximum value of 5213.2553 (cal/g), minimum value of 1269.0833 (cal/g), average as 4464.39455 (cal/g) and S.D. as 1413.2306.

For rake number 712, GCV values for all coal samples from all processing units of CHP (from wagon loading to mill reject) have shown a maximum value of 4115.8223 (cal/g), minimum value of 1605.6689 (cal/g), average of 2967.3099 (cal/g) and S.D. as 738.6526. For rake number 866, GCV values for all coal samples from all processing units of CHP (from wagon loading to mill reject) have shown a maximum value of 4647.37345 (cal/g), minimum value of 2076.1766 (cal/g), average of

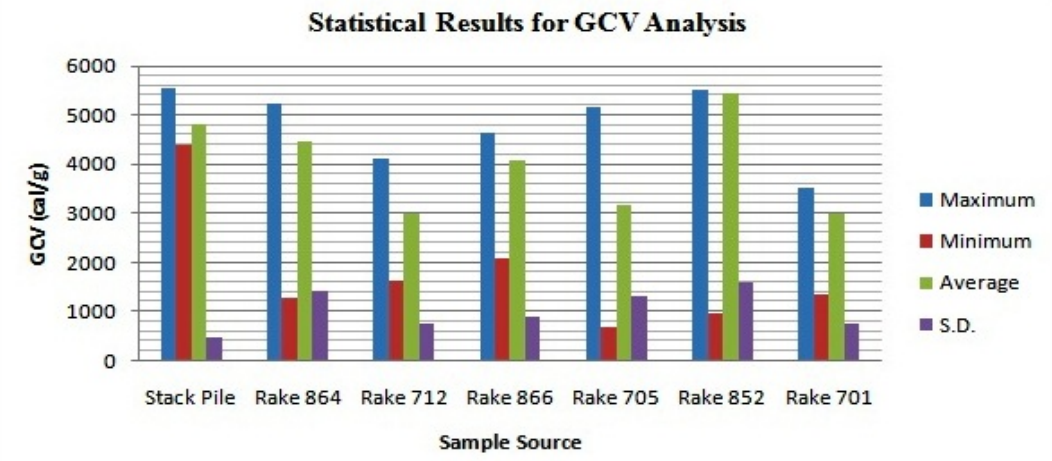


Figure 22. Statistical results for GCV analysis for different coal sampling sources.

4055.7876 (cal/g) and S.D. as 891.6383. For rake number 705, GCV values for all coal samples from all processing units of CHP (from wagon loading to mill reject) have shown a maximum value of 5164.8113 (cal/g), minimum value of 678.2608 (cal/g), average of 3163.4581 (cal/g) and S.D. as 1305.9304. For rake number 852, GCV values for all coal samples from all processing units of CHP (from wagon loading to mill reject) have shown a maximum value of 5508.1445 (cal/g), minimum value of 946.52405 (cal/g), average of 5423.68202 (cal/g) and S.D. as 1589.1800. For rake number 701, GCV values for all coal samples from all processing units of CHP (from wagon loading to mill reject) have shown a maximum value of 3492.8801 (cal/g), minimum value of 1322.2602 (cal/g), average of 2964.9349 (cal/g) and S.D. as 743.8786.

From Figure 22, it can be seen that the maximum S.D. for GCV values has been shown by rake number 852, followed by rake number 864 and 705 having values as 1589.18, 1413.2306 and 1305. 9304 respectively, whereas stack pile samples have shown the lowest deviation followed by rake numbers 712, 701 and 866 having values as 452.5229, 738.6526, 743.8786 and 891.6863 respectively. As far as average values are concerned, rake number 852 has shown the highest average GCV value followed by stack pile samples, rake numbers 864, 866, 705, 712 and 701 having values as 5423.6820, 4821.3648, 4464.3945, 4055.7876, 3163.4581, 2967.3099 and 2964.9349, respectively.

From Figure 23 to 28, bar graphs for GCV values variation from wagon loading points to mill rejects for

RAKE NO.-864

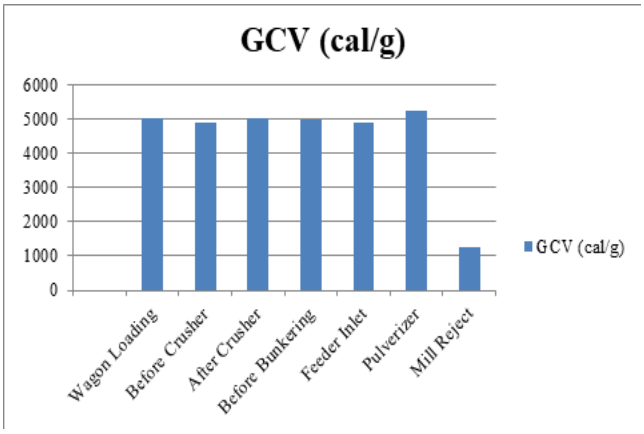


Figure 23. Bar graph for GCV values from wagon loading point to mill reject for rake number 864.

RAKE NO.-712

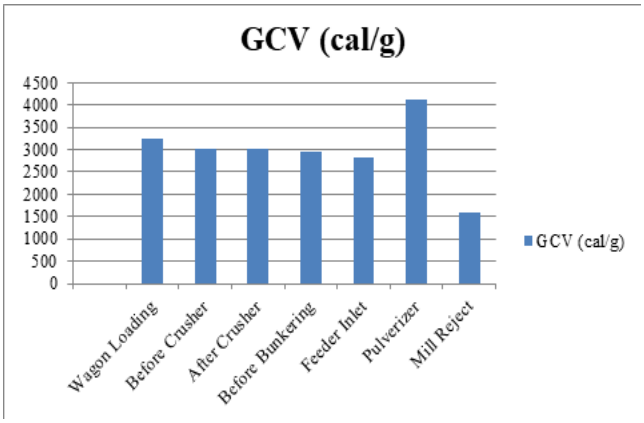


Figure 24. Bar graph for GCV values from wagon loading point to mill reject for rake number 712.

RAKE NO.-866

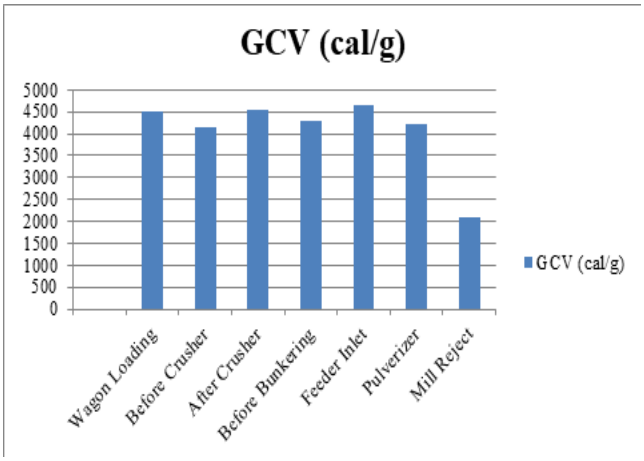


Figure 25. Bar graph for GCV values from wagon loading point to mill reject for rake number 866.

RAKE NO.-852

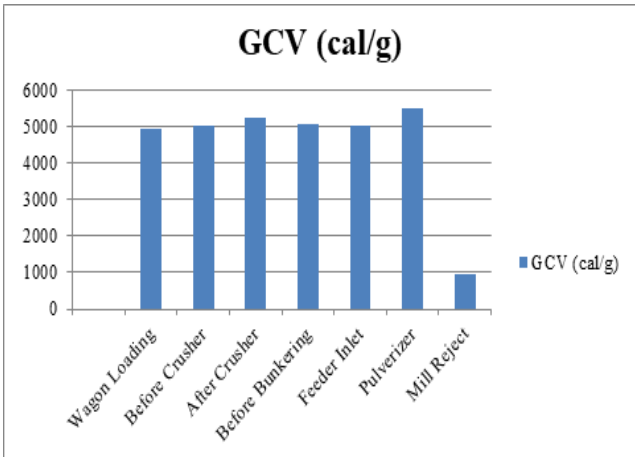


Figure 27. Bar graph for GCV values from wagon loading point to mill rejects for rake number 852.

RAKE NO.-705

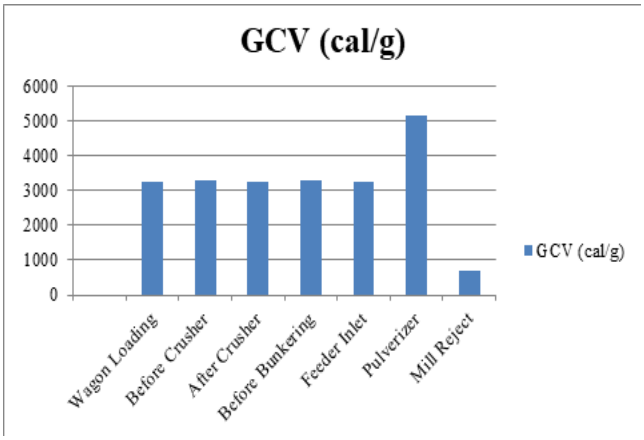


Figure 26. Bar graph for GCV values from wagon loading point to mill rejects for rake number 705.

RAKE NO.-701

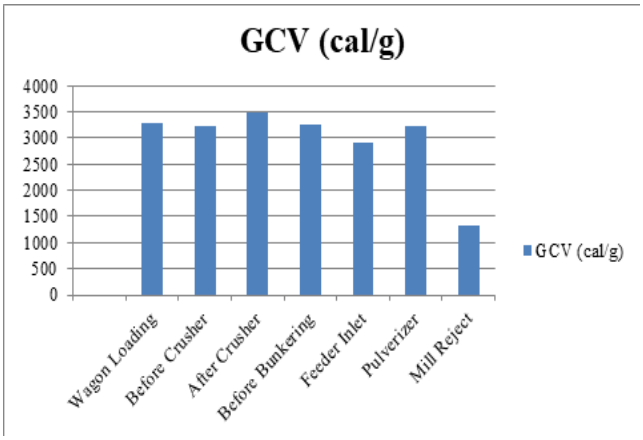


Figure 28. Bar graph for GCV values from wagon loading point to mill rejects for rake number 866.

all rakes have been shown. It can be seen from the bar graphs, for the rake number 864, GCV values are nearly uniform from wagon loading to pulverizer unit with a slight increment in GCV at the pulverizer unit, but instantly decreases at the mill reject unit.

For rake number 712, GCV values are nearly uniform from wagon loading to feeder inlet but increases in the pulverizer unit, and then suddenly decreases at the mill reject unit. For rake number 866, GCV values are uniformly distributed with slight increment after crusher and feeder inlet units and slight decrease before crusher and before bunkering units, but GCV drastically decreases at the mill reject unit. For rake number 705, GCV is uniformly distributed from wagon loading to feeder inlet, but increases at pulverizer unit and then suddenly decreases at mill reject. For rake number 852, GCV is uniform from wagon loading to pulverizer unit, but suddenly decreases at mill reject. For rake number 701, GCV is nearly uniform from wagon loading to pulverizer unit with a slight up and down trend, but abruptly decreases at mill reject.

Thus, from the given discussion, it can be seen that GCV is uniformly distributed from wagon loading to pulverizer units for most of the racks, but for some of the

racks like rake numbers 712, 705, 852, GCV at pulverizer units slightly increases. The reason attributed for these variations may be related to the quality of coal particles which after being processed at previous units of CHP get improved as most of the impurities and ash contents associated with coal are removed at different units. Further, the very small size of the coal particles after being pulverized increases the surface area of coal particles, which in turn increases the calorific value per unit area of the coal particles. Furthermore, the sources of the coal also have an impact on its calorific value as these coals are being supplied from different regions of the country and abroad as well.

5.2 Regression Analysis

In modelling, regression analysis is a statistical process for estimating the relationships among variables. It includes many techniques for modelling and analyzing several variables when the focus is on the relationship between a dependent variable and one or more independent variables (or 'predictors'). More specifically, regression analysis helps one understand how the typical value of the dependent variable (or 'criterion variable') changes when any one of the independent variables is varied, while the other independent variables are held fixed. Regression analysis is widely used for prediction and forecasting.

In our analysis for GCV, we have used a regression model to predict the variation of GCV of coal concerning their different processing units within CHP. In this model, a relationship between coal GCV and its processing units

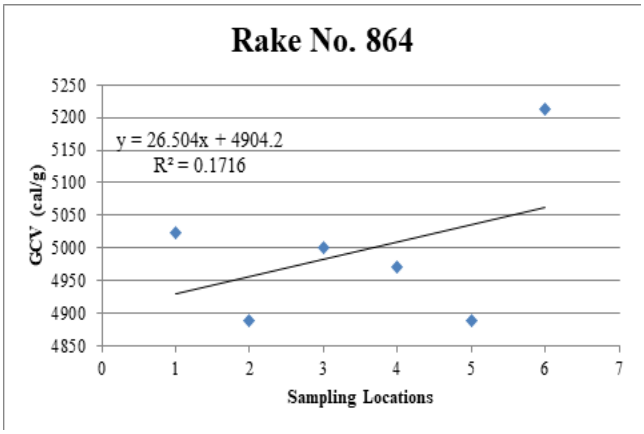


Figure 29. Regression curve for GCV values for rake number 864.

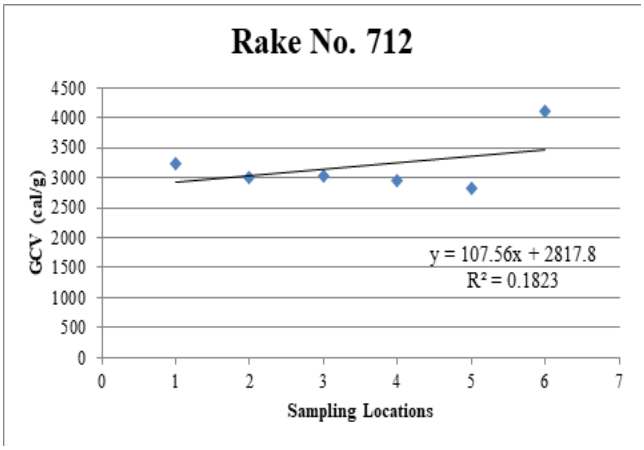


Figure 30. Regression curve for GCV values for rake number 712.

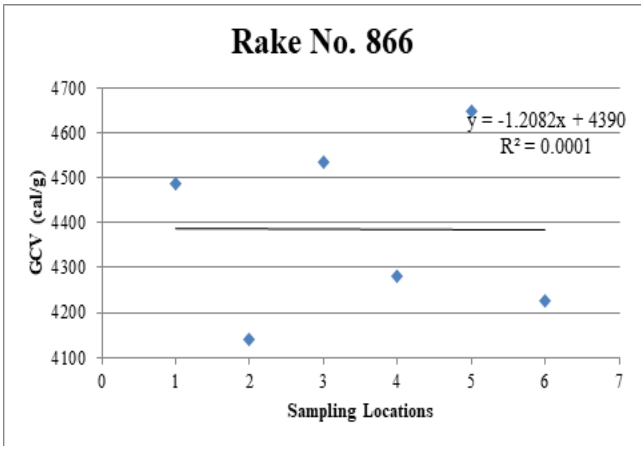


Figure 31. Regression curve for GCV values for rake number 866.

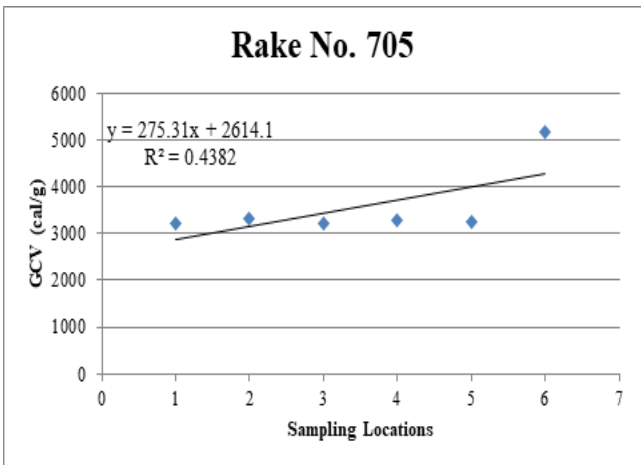


Figure 32. Regression curve for GCV values for rake number 705.

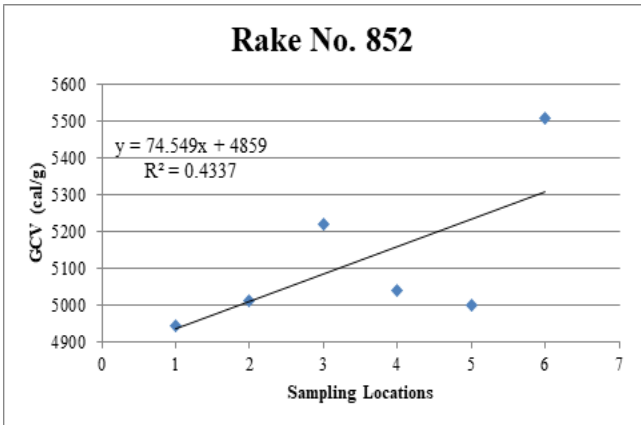


Figure 33. Regression curve for GCV values for rake number 852.

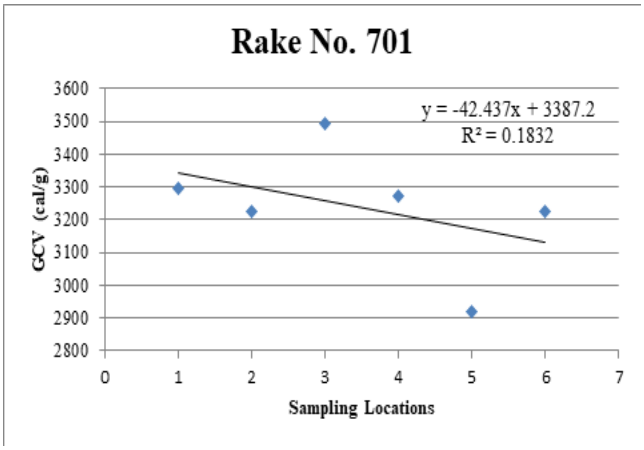


Figure 34. Regression curve for GCV values for rake number 701.

has been developed to explain how the different locations within CHP affect the GCV of the coal. From Figure 29 to 34, the regression model curve for different rakes for their GCV and sampling locations within CHP have been presented.

For rake number 864, the R^2 value is about 17.1% as shown in Figure 20 which means the best-fitted curve explains 17.1 % of the observed data about the mean value of the data. Such behaviour of the model explains that different locations within CHP have an impact on the GCV of the coal. Further, a variation on the right side of the best-fit curve is less as compared to the left-hand side of the curve, and this may be due to an increase in GCV value at the pulverizer unit. Similarly, for rake number 712, the R^2 value is 18.2 % as shown in Figure 21. For rake number 866, the R^2 value is 0 % as shown in Figure 22.

For rake numbers 705, 852 and 701, R^2 values are 43.8%, 43.3% and 18.3%, respectively.

From the said discussion, it can be seen that all the rakes except rake number 866 have shown very good goodness of fit which means different coal processing units and locations within the CHP affect the GCV of the coal up to a certain extent. The zero per cent R^2 value for rake number 866 may be due to either sampling error or due to large variations in GCV within different sampling locations of CHP due to which the model is not able to explain the deviations in GCV values.

5.3 Proximate Analysis

The proximate analysis for the coal samples has been done at IIT Kharagpur laboratory using a Thermogravimetric analyzer. Coal samples from different rakes viz. rake

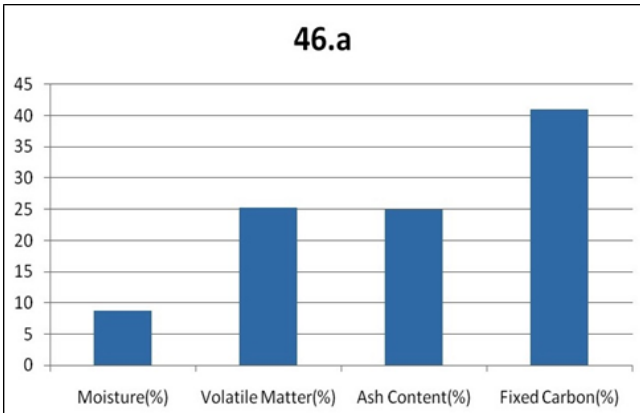


Figure 35. TGA analysis results for rake number 864 at wagon loading.

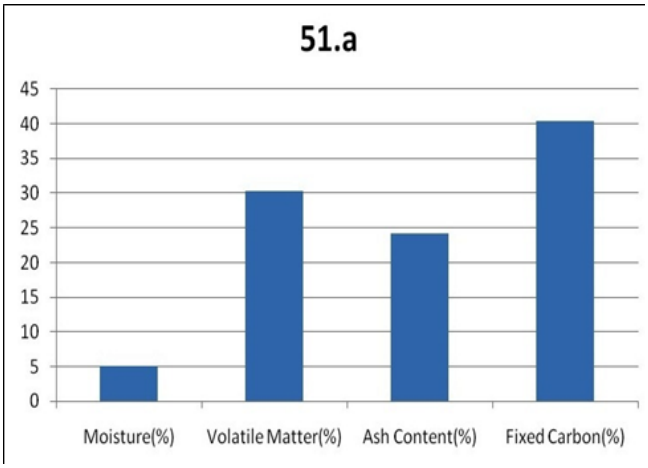


Figure 36. TGA analysis results for rake number 864 at Pulverizer.

Table 3. Results of Thermogravimetric analysis

S. No.	Rake No.	Sample Name	Sample Location	Sample Mass(mg)	Moisture (%)	Volatile Matter(%)	Ash Content(%)	Fixed Carbon(%)
1.	864	46.a	Wagon Loading	54.202	8.72	25.31	25.01	40.96
2.		51.a	Pulverizer	24.374	5.07	30.34	24.23	40.36
3.	712	53.a	Wagon Loading	44.236	10	23.16	43.35	23.49
4.		58.a	Pulverizer	47.874	4.9	34.95	37.67	22.48
5.	866	60.a	Wagon Loading	24.395	8.69	24.13	32.91	34.27
6.		65.a	Pulverizer	40.58	3.39	20.17	61.65	14.79
7.	705	67.a	Wagon Loading	26.87	8.81	28.93	45.33	16.93
8.		72.a	Pulverizer	46.832	6.85	32.9	24.78	35.47
9.	852	74.a	Wagon Loading	25.344	8.96	21.27	29.41	40.36
10.		79.a	Pulverizer	40.222	5.34	33.96	23.27	37.43
11.		81.a	Stack Pile	54.185	5.7	28.07	21.53	44.7
12.	701	82.a	Wagon Loading	52.085	2.39	19.15	70.11	8.35
13.		83.a	Before Crusher	40.735	5.44	30.49	30.14	33.93
14.		84.a	After Crusher	38.863	5.2	27.2	25.41	42.19

numbers 864, 712, 866, 705, 852 and 701 were analyzed for moisture content, volatile matter content, ash content and fixed carbon. The respective values for moisture content, volatile matter, ash content and fixed carbon have been tabulated in Table 3.

To represent the data clearly, these data have been plotted in graphical form in Figure 35 to 56. All these graphs represent the variation in moisture content, volatile matter content, ash content and fixed carbon content from wagon loading to pulverizer. We have analyzed all these contents for two points viz. one at the wagon loading point and another at the pulverizer unit within CHP to understand, how the mentioned contents vary from 1st unit to the last unit of the CHP.

It can be seen from Figures 36 and 37, for rake number 864, initially at the wagon loading point the ash content in coal is about 25%, volatile matter is 25%, moisture content is around 9% and fixed carbon is about 42%, but as we look the same figures at pulverizer unit, the ash content comes down to 23%, volatile matter increases to 30 %, moisture content decreases to 5% and fixed carbon decreases to 40%.

Similarly, as we look at rake number 712 at the wagon loading point, it can be seen that at this ash content in coal is quite high about 44%, volatile matter is about 23%, the

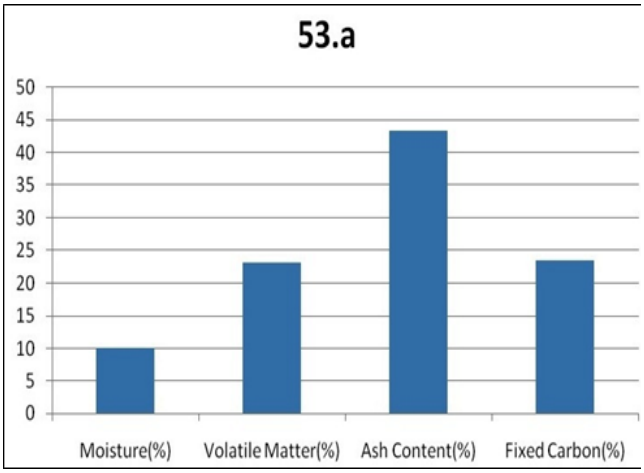


Figure 37. TGA analysis results for rake number 712 at wagon loading.

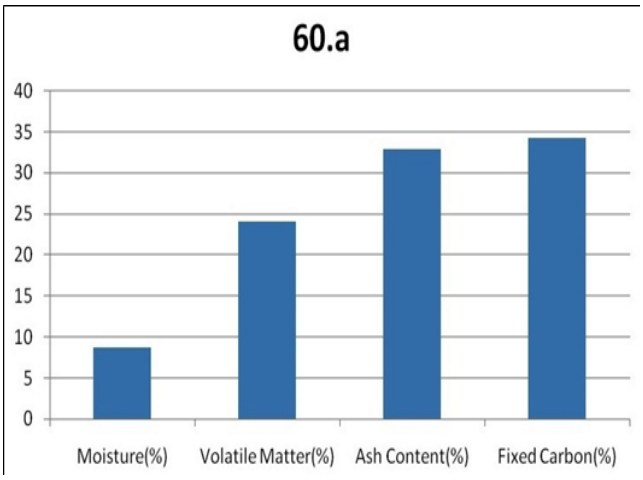


Figure 39. TGA analysis results for rake number 866 at wagon loading.

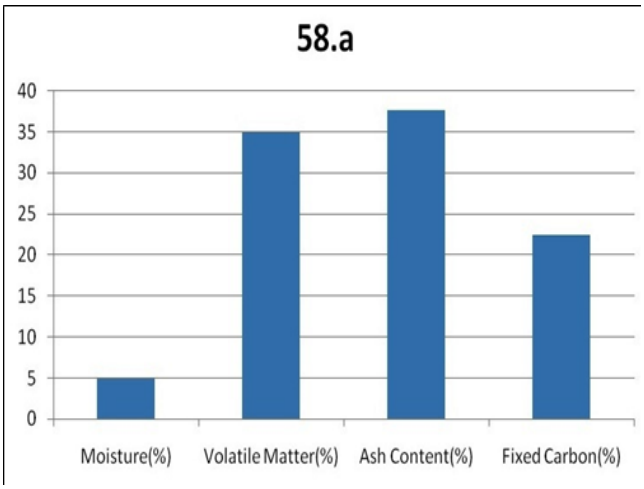


Figure 38. TGA analysis results for rake number 712 at pulverizer.

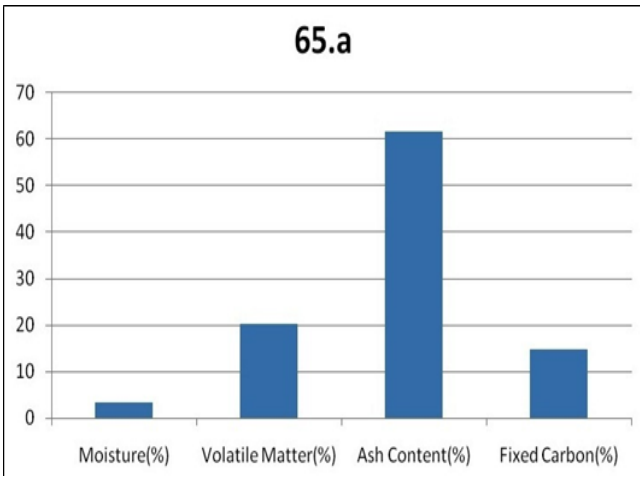


Figure 40. TGA analysis results for rake number 866 at pulverizer.

moisture content is about 10 % and fixed carbon is about 24%, but as we look these figures at pulverizer unit, it can be seen that the ash content decreases to 36%, volatile matter increases to 35%, moisture content decreases to 5 % and fixed carbon slightly decreases to 22%.

For rake number 705, ash content at the wagon loading point is about 45%, volatile matter is about 28%, moisture content is about 9%, and fixed carbon is about 16%, but at the pulverizer unit ash content comes down to about 25%, volatile matter increases up to 33%, moisture content comes down to about 6% and fixed carbon increases up to 35%.

For rake number 852, ash content decreases from 30% to 23%, volatile matter increases from 21% to about 34%, moisture content decreases from 9% to about 5% and fixed carbon increases from 37% to 40%.

For rake number 701, ash content decreases from 40% at the wagon loading point to 30% before the crusher and further reduces to 25% after the crusher, volatile matter content increases from 19% at the wagon loading point to 30% before the crusher and then decreases to 27% at after crusher, moisture content increases from 2% at wagon loading point to 6% at before crusher and again decreases to 4% at after crusher, fixed carbon increases from 8 % at

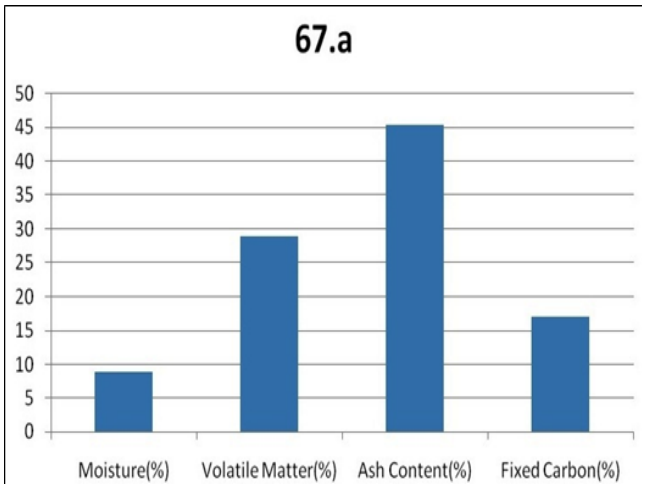


Figure 41. TGA analysis results for rake number 705 at wagon loading.

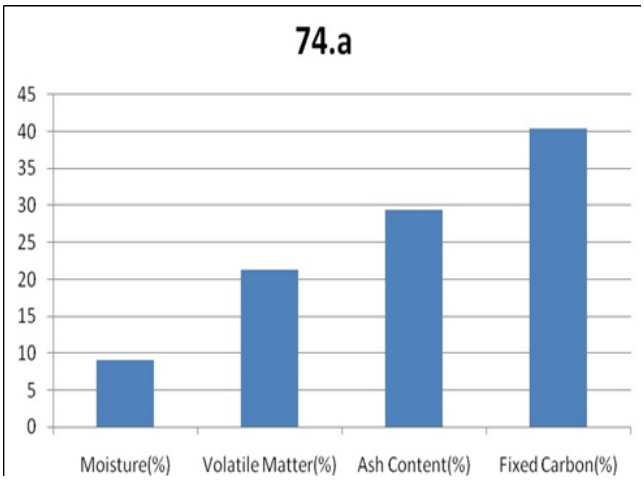


Figure 43. TGA analysis results for rake number 852 at wagon loading.

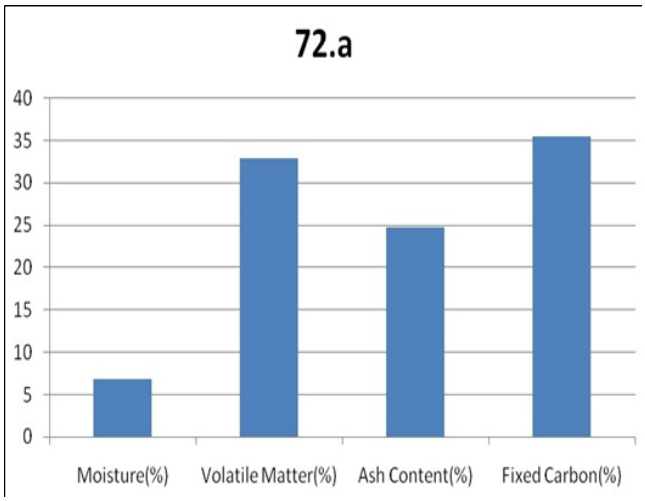


Figure 42. TGA analysis results for rake number 705 at pulverizer.

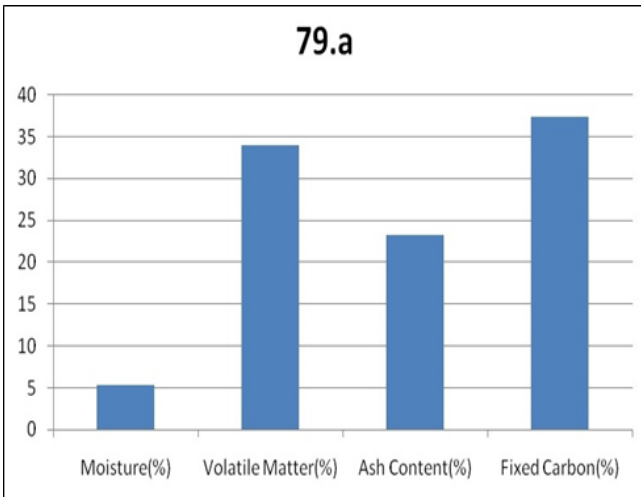


Figure 44. TGA analysis results for rake number 852 at pulverizer.

wagon loading point to 34% at before crusher and further increases to 43%.

Thus, from the above figures, it can be observed that things are going in the right direction for the final combustion of coal in the boiler. The ash content decreases by 5–10%, which improves the coal quality for combustion, similarly, an increment in volatile matter content by 10% improves the initial combustion of coal in the boiler and hence, reduces the dependency on secondary fuels to support initial combustion of coal in the boiler and also limits the flame length and hence, sets minimum limit on furnace height and volume. A decrease in the moisture content of coal from the wagon loading point to the pulverizer unit improves the combustion efficiency of coal and reduces the heat loss in boilers. Increment in fixed carbon from wagon loading to pulverizer unit improves the calorific value (GCV) of the coal to be used for combustion in the boiler and hence, increases the boiler efficiency and reduces the overall cost of power generation up to a certain extent.

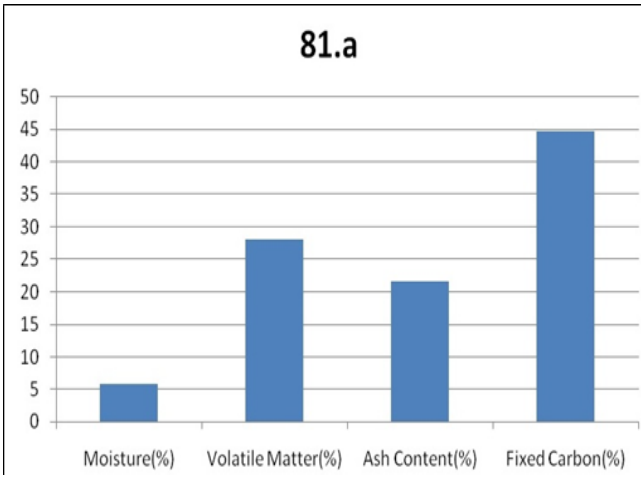


Figure 45. TGA analysis results for coal samples of stack pile.

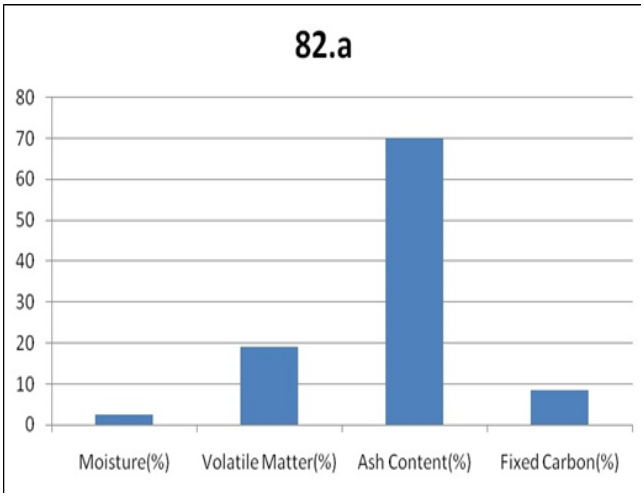


Figure 46. TGA analysis results for rake number 701 at wagon loading.

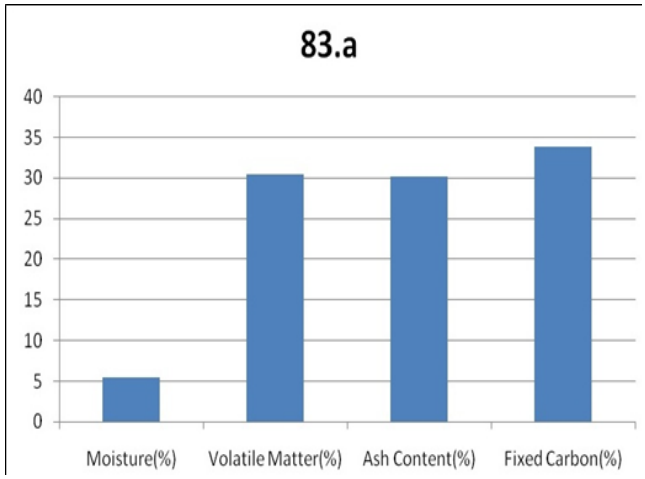


Figure 47. TGA analysis results for rake number 701 before crusher.

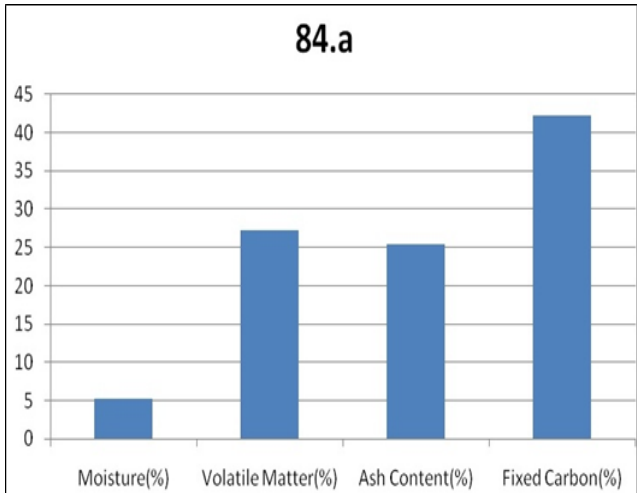


Figure 48. TGA analysis results for rake number 701 after crusher.

6.0 Conclusion

From GCV analysis and proximate analysis results, it can be concluded that all the rakes from where coal sampling was done have shown variations in GCV of the coal from the wagon unloading point to the mill reject point within the coal handling plant.

Maximum average GCV of coal has been shown by rake number 852 followed by rake numbers 864, 866, 705, 712 and 701. The variations in coal GCV for different rakes may be assigned to their different geological origins. However, the GCV of coal also depends upon the processes through which it passes in thermal or coal washery plants. GCV of coal within thermal power stations also depends upon the processes on which coal is processed within CHP. For all rakes, GCV at wagon loading point varies within range depending upon their geological background. Within CHP, right from the wagon unloading point, GCV variations start. For all the rakes, the GCV of coal remains more or less the same from wagon unloading point to feeder inlet except for rake numbers 712 and 705 but suddenly increases at the pulverizer unit and then abruptly decreases at mill reject. This sudden increase in GCV at the pulverizer unit may

be due to the impurities percentage, moisture percentage, surface roughness and size of the coal particles. As the impurities percentage and moisture percentage of coal decreases, GCV increases. Further, at the pulverizer unit, as the coal size reaches to micron level, the surface area increases, and ash per cent decreases as most of the ash percentage remains at the peripheral area of coal particles and more amount of carbon & other elements become available for burning. At stockyards, variations in coal GCV may be attributed to the spontaneous heating loss of coal in open space, and coal particles loss due to wind erosion.

Proximate analysis results are also supporting the GCV results as ash content and GCV of coal are inversely proportional to each other. As the ash contents of coal increase, the GCV of coal decreases and vice versa. Further, the GCV of coal depends on the moisture percentage and fixed carbon percentage present in coal. The higher the content of fixed carbon in coal the higher its GCV and the higher the moisture content in coal reduces its GCV. As can be seen from the above results, rake number 852 has shown maximum average GCV concurrently proximate analysis results supporting its value. For rake number 852, ash content varies from (29.41%-23.27%), fixed carbon from (40.36%-37.43%) and moisture content from (8.96%-5.34%), so its GCV values are up to 5508.1445 kJ/kg. For rake number 701 which has the lowest average GCV values, its proximate analysis results show that ash content varies from (30.14%-25.41%), fixed carbon from (33.93% - 42.19%) & moisture percentage from (5.44%-5.2%).

The major conclusions of the study are:

1. The major factors responsible for GCV variations in coal are geological origin parameters (ash content, fixed carbon and volatile matter percentage) and processing units within CHP and their working conditions.
2. The surface roughness of coal and other impurities like quartz also play an important role in maintaining the GCV.
3. The process plays a major part: As the bulk coal undergoes crushing and milling, the heavier impurities begin to settle at the bottom that cannot be captured by surface sampling of coal, as in a standard practice.

7.0 References

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2. Bureau of Indian Standards. IS 1350-1 (1984): Methods of Test for Coal and Coke, Part I; 1984. Available from: https://law.resource.org/pub/in/bis/S11/is.1350.1.1984.pdf