Central Power Research Institute

Vol. 17(2)/121-124, July-December 2021
ISSN (Print) : 0973-0338
DOI : 10.33686/pwj.v17i2.1076

Power Research

Characteristics of the HGI Fractions of the Indian Coal Blended with Imported Coals

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Abstract

The blends of a high ash Indian coal with three coals of different foreign origins -Australia, Russia and Indonesia were subjected to HGI testing as per ASTM D 409 and the resulted fractions obtained in the coarser and finer portions of ASTM 200 mesh (75 microns) were assessed for their characteristics in respect of proximate and ultimate parameters, alpha quartz and combustion reactivity. The similar studies were also carried out for the parent coals. HGI values were found additive in case of Indian-Indonesian coal blends and the same was found non-additive in respect of Indian-Russian and Indian-Australian coal blends. Considerable variation in properties was observed in the coarser and finer fractions of the ASTM 200 mesh for parent Indian and Indonesian coals compared to parent Australian and Russian coals. This indicates the disproportion of the coals and coal blends particles during the sieving process after subjecting to HGI test. The variation of alpha quartz content in the coarser and finer fractions indicate that there is a segregation of free minerals in the coarser and finer fractions. The conversion plots obtained through TGA for the coarser and finer fractions indicate that there is no maceral segregation.

Keywords: Blended Coal, Disproportionation, Hardgrove Grindability Index (HGI), Non-Additive, Thermogravimetric Analysis (TGA), Reactivity

1. Introduction

The coals are blended for number of reasons that includes reduction in emissions, cost savings enhancing fuel flexibility, etc.[1]. However, the qualitative behavior of blended coals may not be always proportional as that of the amount of parent coals in the blend and many times the parameters like grindability, slagging and fouling, etc. were found to be non-additive. This is attributable to the difference in the rank, origin and petrography of the individual coals blended and also the thermochemical interactions between the parent coals during combustion. The non-additive characteristics of the coal blends have significant effect on the power plant performance. In such cases the power plant parameters need to be accordingly optimized to obtain best performance out of the blended coals and this needs prior experimental studies before subjecting the coal blends to use in the power plant. Majority of the Indian coals used for the power generation are subbituminous variety and the maceral and mineral characteristics are significantly different that of the foreign coals[2]. Blending of high ash Indian coal with low ash foreign coals has been found to be an option in India for the dry beneficiation of Indian coals to eliminate coal washing[3]. Nevertheless, as the Indian coals have different rank compared to that of the foreign coals, the behavior of the coal blends may not be always predictable from the parent coal proportions.

The grindability of coal is one of the important parameters in pulverized coal power plants which influence the combustion behaviour of coal particles in the boiler. The grindability of a coal is empirically assessed by a parameter called Hardgrove Grindability Index (HGI). The HGI value is used as a predictive tool to determine the performance capacity of pulverizer mills. Many researchers[4–7] have reported that grindability characteristics of some of the coal blends were found to be additive and for others the same was non-additive. The studies made by them also showed that the coarse fraction moisture has no effect on HGI value of the blends.

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Numerous attempts have been made by the researchers to correlate HGI with the coal properties that includes, petrography, proximate and ultimate parameters, etc. The effect of microlitho types on HGI was explained by Hansen and Hower[5] and Mathews *et al.*[8] and Sengupta[9] have explained the correlation of HGI with ultimate and proximate parameters respectively. The R^2 value indicated by Mathews *et al.*[9] while correlating ultimate parameters with HGI is 0.75 which indicates the wider scatter in the correlation due to the influence of the properties other than ultimate analysis to HGI.

The rank effect on the HGI values was studied by Sarkar *et al.*[2] and they have brought out that the HGI value increases with increase in rank, within the high volatile bituminous rank range and decreases with increase in liptinite content for any specific rank. The studies made by the above researchers indicate that HGI value is being influenced by many independent variables that include rank, petrography, proximate and ultimate parameters, etc.

The complexity of the same increases for the blended coals when they are blended with the parent coals of different rank or origin. The coarser and finer fractions generated during the comminution in the HGI analysis may have independent characteristics which have not been addressed comprehensively by the researchers. There exists the possibility of segregation of macerals and minerals during sieving of the ground mass resulted from HGI test through ASTM 200 mesh. In respect of the coal blends, this kind of segregation will lead to additional complexity in interpreting HGI values of coal blends from their parent coals.

Attempts have been made in the present work to study in detail the characteristics of the coarser and finer fractions resulted from HGI test of a high ash Indian coal and three foreign coals from Australia, Indonesia and Russia and the coal blends of Indian with foreign coals.

The blends were made at 80:20, 60:40, 40:60 and 20:80 proportions. Detailed analyses were carried out on the coarser and finer fractions resulted from HGI tests for all the blends and the results obtained were assessed for addressing additive and non-additive characteristics of coal blends.

2. Experimental Work

The Indian coal from Western Coal Field Limited (WCL) mines with 38.6 % ash content on air dried basis was taken for blending with three foreign coals (Australia, Indonesia and Russia). The coal samples were air dried and made to pass through 1.18 mm and 0.6 mm. The samples retained between 1.18 mm and 0.6 mm was taken for the experimental work. The Indian coal was individually blended with Australian, Indonesian and Russian coals respectively at the proportion of 80:20, 60:40, 40:60 and 20:80. The parent coal samples and the blends were subjected to HGI test and the resulted coarser (+75 microns) and finer fractions (-75 microns) for all the samples were separately packed and coded. Table 1 indicates the coding of samples. Among the 32 numbers of samples all the samples were subjected. The total number of 32 samples that includes the original parent

Table 1. List of samples and its code

Sl. No.	Coal Sample	Code
1	INDIAN	IN100
2	AUSTRALIA	AU100
3	INDONESIA	IS100
4	RUSSIA	RU100
5	80IND-20INDO MINUS FRACTIONS	20ISM
6	80IND-20INDO PLUS FRACTIONS	20ISP
7	60IND-40INDO MINUS FRACTIONS	40ISM
8	60IND-40INDO PLUS FRACTIONS	40ISP
9	40IND-60INDO MINUS FRACTIONS	60ISM
10	40IND-60INDO PLUS FRACTIONS	60ISP
11	20IND-80INDO MINUS FRACTIONS	80ISM
12	20IND-80INDO PLUS FRACTIONS	80ISP
13	80IND-20AUS MINUS FRACTIONS	20AUM
14	80IND-20AUS PLUS FRACTIONS	20AUP
15	60IND-40AUS MINUS FRACTIONS	40AUM
16	60IND-40AUS PLUS FRACTIONS	40AUP
17	40IND-60AUS MINUS FRACTIONS	60AUM
18	40IND-60AUS PLUS FRACTIONS	60AUP
19	20IND-80AUS MINUS FRACTIONS	80AUM
20	20IND-80AUS PLUS FRACTIONS	80AUP
21	80IND-20RUS MINUS FRACTIONS	20RUM
22	80IND-20RUS PLUS FRACTIONS	20RUP
23	60IND-40RUS MINUS FRACTIONS	40RUM
24	60IND-40RUS PLUS FRACTIONS	40RUP
25	40IND-60RUS MINUS FRACTIONS	60RUM
26	40IND-60RUS PLUS FRACTIONS	60RUP
27	20IND-80RUS MINUS FRACTIONS	80RUM
28	20IND-80RUS PLUS FRACTIONS	80RUP

Table 2. Rank of the coals.

Parent Coals	Inherent Moisture, % (96% RH, 30°C)	Heating value kcal/kg, (air-dried basis)	Rank of Coal (as per ASTM D388)
IN100	16.4	3970	Sub Bituminous C
AU100	20.0	5170	Sub Bituminous B
IS100	26.8	5460	Sub Bituminous C
RU100	44.1	5590	Lignite A

Table 3. Proximate, and ultimate parameters of Indian and Foreign coals

Sample Code	Proximate Analysis, %, (air-dried basis)				Ultimate Analysis, %, (air dried basis)				
	M	VM	Ash	FC	C	H	N	S	O
IN100	4.2	25.2	38.7	31.9	40.4	2.2	0.6	1.2	12.7
AU100	3.5	20.7	26.7	49.1	56.5	2.7	1.0	0.5	9.1
IS100	15.1	40.9	9.1	34.9	56.9	4.1	0.6	0.9	13.3
RU100	15.3	38.8	4.6	41.3	57.9	3.8	0.5	0.1	17.8

Table 4. Internal reference standard for calibration of XRD

Sl No	Pure α-Quartz powder	Calcite	Zinc-Oxide
1	0.05	0.45	0.5
2	0.10	0.40	0.5
3	0.15	0.35	0.5
4	0.20	0.30	0.5
5	0.25	0.25	0.5

Table 5. α-Quartz analysis results

Sl No	Sample Name	α- Quartz (%)
1	IN100-raw coal	9.95
2	IN100P	9.92
3	IN100M	11.45
4	IS100-raw coal	1.35
5	IS100P	1.26
6	1S100M	1.79
7	AU100-raw coal	3.53
8	AU100P	3.16
9	AU100M	3.79
10	RU100-raw coal	0.76
11	RU100P	0.71
12	RU100M	1.01

coals, coarser and finer fractions obtained from HGI tests were subjected to following tests.

The ranks of the parent coals were determined as per ASTM D 388 by the determining inherent moisture as per ASTM D 1412 and the Gross Calorific Value as per ASTM D 5865 results are given in Table 2. The proximate and ultimate analysis for all the samples were carried out as per ASTM D 7582, 5373 and 4239 respectively and

Table 6. HGI values of parent coals and blends

India-Indonesia			India-Australia			India-Russia		
Sl No	Sample code	HGI	Sl No	Sample code	HGI	Sl No	Sample code	HGI
1	IN100	82	1	IN100	82	1	IN100	82
2	20IS	77	2	20AU	75	2	20RU	76
3	40IS	72	3	40AU	72	3	40RU	71
4	60IS	64	4	60AU	70	4	60RU	67
5	80IS	57	5	80AU	69	5	80RU	70
6	IS100	56	6	AU100	68	6	RU100	72

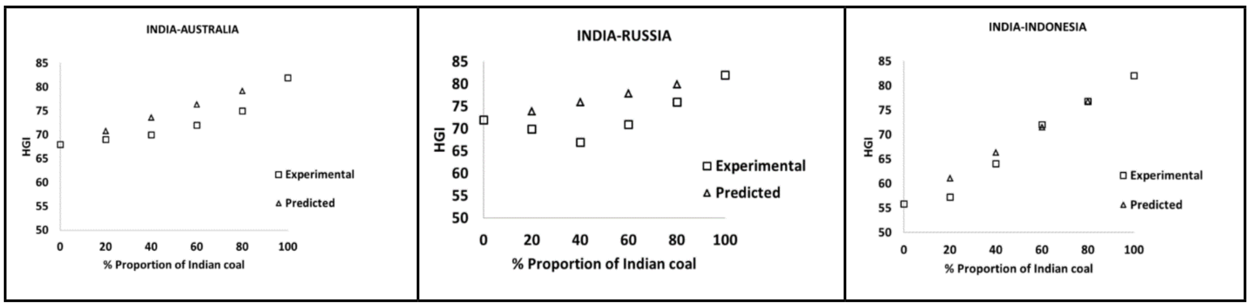

Figure 1. HGI values of the blends.

Table 7. Proximate and Ultimate parameters of coarser and finer fractions of Parent coals and their blends

Sample	Proximate analysis, % (air-dried basis)				Ultimate analysis, % (air-dried basis)				
	M	VM	ASH	FC	C	H	N	S	O
IN100M	5.2	20.8	45.5	28.5	40.0	2.2	0.6	1.2	5.3
IN100P	6.1	25.8	35.3	32.8	41.9	2.5	0.6	1.2	12.4
IS100M	6.6	48.1	11.8	33.5	62.6	4.5	0.7	1.0	12.8
IS100P	10.3	42.5	8.2	39.0	59.6	4.4	0.6	0.9	16.0
RU100M	10.9	43.0	5.3	40.8	60.9	4.0	0.6	0.1	18.2
RU100P	13.7	41.1	4.3	40.9	57.5	3.4	0.2	0.1	20.8
AU100M	4.0	21.3	24.4	50.3	56.2	2.7	1.0	0.5	11.2
AU100P	3.8	22.1	24.2	49.9	57.2	2.8	0.8	0.6	10.7
20ISM	5.2	24.0	41.7	29.1	35.4	2.3	0.5	0.9	14.1
20ISP	7.0	29.2	30.2	33.6	44.9	3.0	0.5	1.2	13.2
40ISM	5.3	28.7	36.0	30.0	39.1	2.7	0.4	0.9	15.6
40ISP	7.7	32.9	24.4	35.0	49.0	3.2	0.6	1.2	13.9
60ISM	5.8	34.6	28.5	31.1	44.0	3.2	0.3	0.9	17.2
60ISP	8.8	36.1	18.9	36.2	52.3	3.6	0.5	1.1	14.8
80ISM	6.0	40.7	21.3	32.0	49.4	3.9	0.4	0.8	18.2
80ISP	9.6	39.2	13.2	38.0	55.9	4.0	0.6	0.9	15.8
20AUM	4.7	20.3	42.0	33.0	36.0	1.8	0.3	0.7	14.4
20AUP	5.7	25.4	32.9	36.0	42.9	3.1	0.5	1.1	13.9

40AUM	4.4	20.9	37.9	36.8	40.3	2.0	0.5	0.6	14.4
40AUP	5.2	23.9	30.2	40.7	48.9	2.6	0.7	0.9	11.6
60AUM	4.3	21.0	34.7	40.0	44.3	2.1	0.6	0.5	13.5
60AUP	4.9	22.8	28.5	43.8	52.1	2.6	0.7	0.8	10.4
80AUM	3.9	20.5	29.9	45.7	49.5	2.4	0.7	0.5	13.2
80AUP	4.1	22.2	26.8	46.9	54.6	2.7	0.7	0.6	10.5
20RUM	6.0	24.5	39.3	30.2	35.4	2.0	0.2	0.6	16.5
20RUP	8.5	29.6	29.1	32.8	44.6	2.8	0.4	1.0	13.6
40RUM	6.9	27.9	32.0	33.2	39.8	2.4	0.2	0.5	18.2
40RUP	10.2	32.3	23.1	34.4	47.4	2.9	0.4	0.7	15.3
60RUM	8.2	31.4	23.5	36.9	44.2	2.5	0.2	0.4	21.0
60RUP	11.0	34.3	17.1	37.6	50.9	3.2	0.3	0.5	17.1
80RUM	9.3	35.8	14.8	40.1	47.9	3.0	0.1	0.2	24.7
80RUP	12.7	36.6	10.7	40.0	54.5	3.6	0.4	0.3	17.8

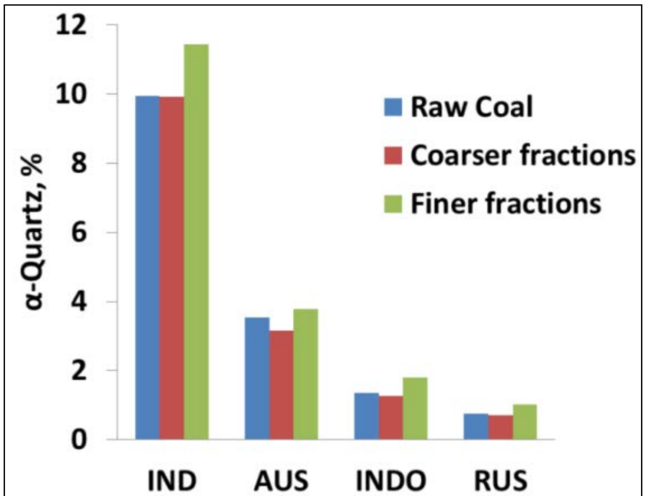

Figure 2. α-Quartz analysis.

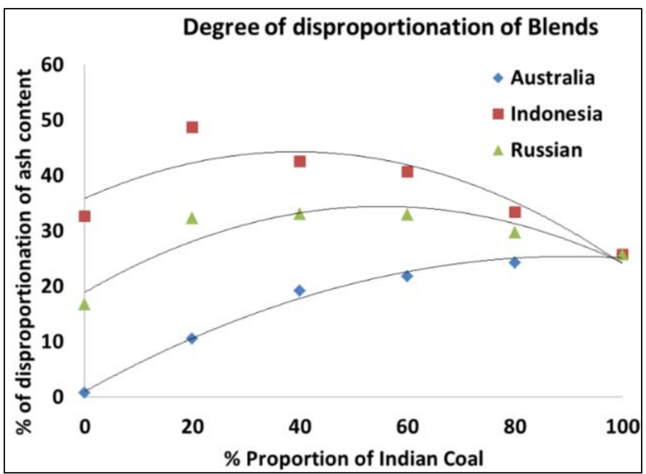

Figure 3. Degree of disproportionation.

the results are given in Table 3. The alpha quartz content was determined by the quantitative XRD analysis. The zinc-oxide reference material was used for the α-quartz analysis.

The calibration was done by analyzing the reference standard sample prepared as per the mixing proportions of pure α-quartz, calcite and zinc-oxide given in the Table 4.

The α-quartz analysis was carried out for these prepared standard samples and the intensity for the different proportion of α-quartz was obtained. The slope was determined for the intensity ratio ($I_{unknown}/I_{ZnO}$) and α-quartz content of reference standard samples. The slope was determined for the reference standard and was used in determining the α-quartz content of the unknown samples. The alpha quartz results obtained for the parent coals and blends are given in Table 5.

The combustion reactivity for the coarser and finer fractions was assessed from the peaking and burnout temperatures of Thermogravimetric Analysis (TGA). The TGA was carried out in air atmosphere by heating the samples from ambient to 800°C at the heating rate of 5°C/min. The peaking temperature was determined from the Derivate Thermogravimetry (DTG) and the ignition and burnout temperatures were obtained from the conversion plots. The conversion was calculated using the equation, $X = (m_o - m)/(m_o - m_a)$, where, m_o = original dry mass of the char, m = instantaneous weight loss and m_a = mass of ash.

3. Results and Discussions

The rank analysis carried out as per ASTM 388 indicates that Indian and Indonesian coals are similar rank (Subbituminous C), the Australian and Russian coals are found to be Subbituminous B and Lignite A respectively. The proximate analysis Table 2 of the parent coals on air dried basis indicates that the Indian coal and Australian coal have low moisture and high ash content and the Indonesian and Russian coals have high moisture and low ash content respectively. The HGI of the parent coals and the blends are given in Table 6. The HGI values of the Indian coal was found to be higher (82) than all other foreign coals; Russia (72), Australia (68) and Indonesia (56). The HGI values for the parent coals and the blends along with predicted values as per the additive rule are given in Figure 1. The figure indicates that the HGI values for all the Indian – Australian and Indian- Russian coal blends are not additive and the Indian-Indonesian coal blends are found to be additive except for Indian 20% -Indonesian 80% blend.

The proximate analysis of the fractions obtained from HGI test of Indian, Indonesian and Russian coals are given in Table 7. This indicates that the ash content of the finer fractions are higher than the coarser fractions except Australian coal. In all the coal blends the finer fractions were found to have more ash content compared to coarser fraction. The ash content of the original coal blends before subjecting to HGI is in closer agreement with the coarser fraction. This reveals that there is a clear disproportionation of minerals between finer and coarser fractions. This is attributed to the separation of free minerals like α-quartz and pyrites released during comminution having particle size less than 75 microns from coal, passing through ASTM 200 mesh and adding to finer fraction. This is supplemented by the presence of more amount of α-quartz content in the finer fraction compared to coarser fractions shown in Figure 2.

The degree of disproportionation of minerals with respect to the original mineral content was calculated for parent coals and also their blends. This is the percentage of difference in ash content in the coarser and finer fractions with respect to the original ash content of unground coal. The values are plotted in Figure 3. The order of degree of disproportionation observed is given as follows.

Indonesia > India > Russia >Australia

As the separation of extraneous mineral particles from the carbonaceous matter is relatively easier than inherent minerals associated with the same, it is anticipated that the amount of extraneous particles separating and passing through the sieve would be relatively higher, compared to inherent minerals associated with the carbonaceous matter. The density of extraneous minerals is significantly more (2 to 3 times) compared to coal and this will give additional force for the separation of extraneous minerals and passing through the sieve. As the degree of disproportionation was found to be more in the case of Indonesian coal, this infers that the Indonesian coal would have been associated with more extraneous minerals compared to the other coals and the Australian coal would have been associated with least extraneous minerals which have shown least disproportionation among all the coals.

The Figure 3 indicates the non-linear trend of degree of disproportionation for the coal blends. The disproportionation of minerals is found to be one of the major reasons for the non-additive nature of the HGI values of blended coals. The reason is explained as follows. The quantity of finer fractions is directly proportional to the HGI values. In case of a coal rich in extraneous minerals, the segregation and free falling of extraneous minerals during sieving after comminution in the HGI test, add additional mass to the finer fraction contains the ground coal. When a coal rich in extraneous minerals blended with a coal of different origin with lean extraneous minerals, the free falling of extraneous minerals is getting non-linearly decreased while the composition of coal with lean extraneous minerals is increasing. This non-linearity leads to the non-linearity in the HGI values of the blended coals which does not match with the values calculated using additive rule. The Indian coal blends constituting the Australian coals and Russian coals show non-additive HGI behavior due the reason mentioned above. The reason for the additive nature of Indian and Indonesian coal blends is attributed to the similar degree of disproportionation (higher in the case of both Indian and Indonesian coal) in which one will compromise other when the composition is changing from one coal to another. Though there are clear evidences for the disproportionation and its effect towards the additive and non-additive nature of HGI values, the effect of rank, macerals [4] and moisture play their roles in adding further complexity to the additive and non-additive characteristics of HGI values of coal blends.

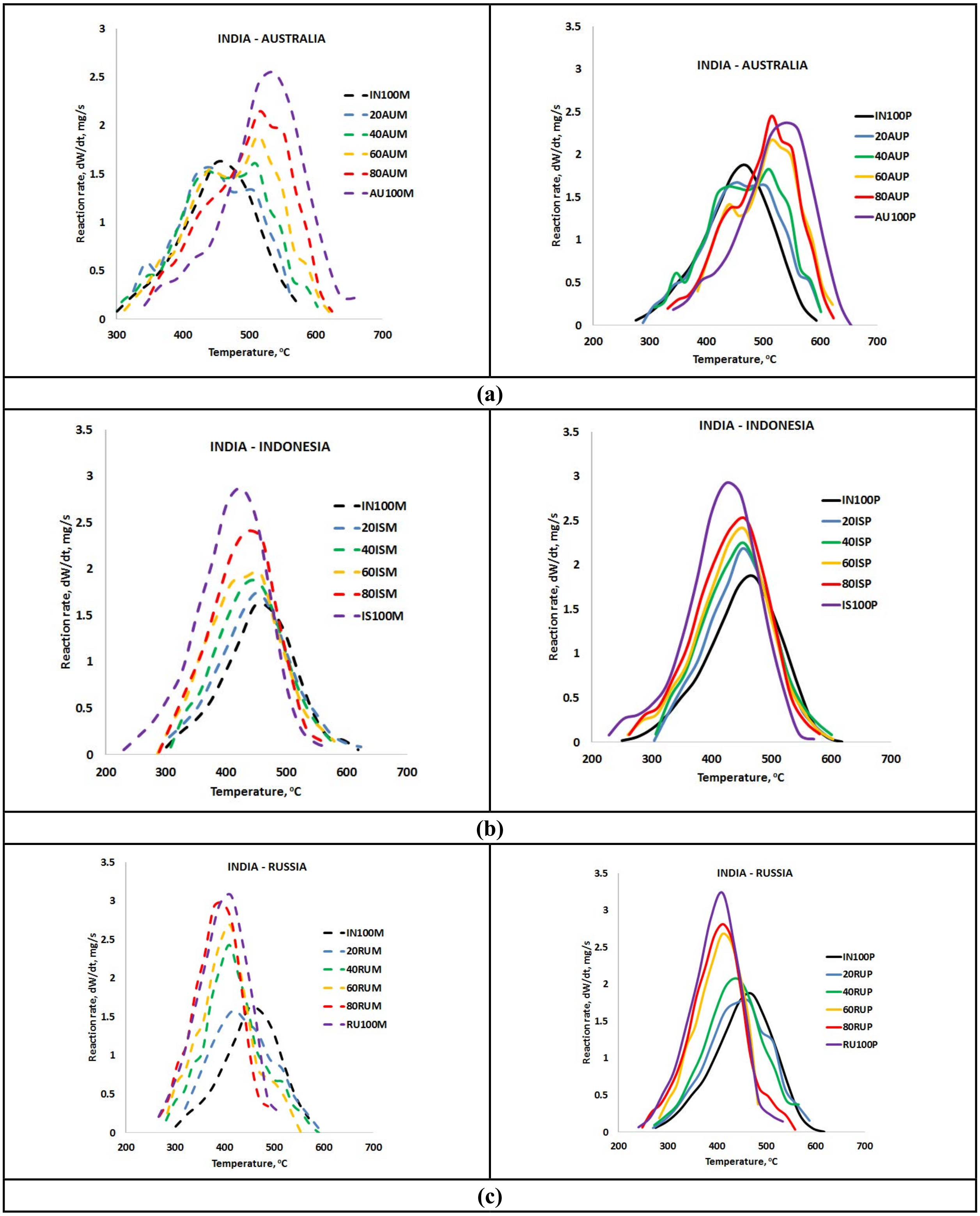

Figure 4. **(a).** Peaking Temperatures of India-Australia coal blends (-75 and +75 Fractions). **(b).** Peaking Temperatures of India-Indonesia coal blends (-75 and +75 Fractions). **(c).** Peaking Temperatures of India-Russia coal blends (-75 and +75 Fractions).

The combustion reactivity of the coarser and finer fractions of the HGI test samples are found to be additive for all the coal blends which has been shown by the trend of peaking temperature with respect to blend proportion in Figure 4 (a) to 4(c). The additive behavior of the peaking temperature indicates that there are no maceral separations during comminution in the HGI test for the selected coals as the reactivity of the coal is significantly affected by the nature of macerals present in the coal[10,11]

4. Conclusion

The HGI study and the assessment of coarser and finer fractions obtained from HGI test for the coals and blends indicate that there is a clear disproportionation during comminution. The degree of disproportionation varies from coal to coal and the extraneous minerals contribute more to the degree of disproportionation. The HGI values were found to be non-additive for Indian coals blended with Australian and Russian coals respectively and additive for Indian-Indonesian coal blends. The degree of disproportionation minerals during sieving after comminution in the HGI test play a major role in the additive and non-additive characteristics of Indian coal blended with foreign coals. The additive combustion reactivity profile obtained for coarser and finer fraction indicates that there is no separation of macerals. In respect of the power plant pulverisers the disproportionation occurs in the similar fashion during comminution and classification. This may alter the premixed blend proportion in the output mass of the pulverisers. However, there is no variation found in the reactivity of the coarser and finer fractions indicates that the combustion characteristics of the particles in the boiler would not get affected due to disproportionation in the pulveriser for the coals selected for the study.

5. Acknowledgements

The authors thankfully acknowledge the management of Central Power Research Institute for extending the facilities to carry out the experimental work.

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