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Analysis and Design of Different Coal Blends For The Production of Coke By Using Linear Programming Model

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Abstract
Coke production is a major pollution source since the presence high carbon content and other impurities. Therefore, instead of one specific coal, the blended coal should be designed which may help in achieving better coal properties due to selection of optimum metallurgical content. In present study linear programming approach has been used to achieve desirable proportion of constituents. MATLAB programming has been incorporated further, for making coal blends having diverse characteristics and exhibit various applications e.g. blast furnace in steel production industries etc. Seven coal samples are used for making coal blends. Results indicate that low ash, low moisture, low Sulphur ensures superior coke production with improved efficiency of coke oven plant and coke quality.
Keywords: Coke production, Blended coal, Linear Programming model, MATLAB, Blast furnace

1. Introduction
Coal is a biological/organic rock available in the earth's crust and contains mostly carbon (C). It also has a hydrogen, oxygen, sulfur and nitrogen, as well as some inorganic constituents/minerals. To fulfill the requirement of good quality coke, metallurgical coals are used in India. Hence, preparation/design of coal blends for carbonization is very much important in terms of cost, quality, and resourceutilization [1]. Coal blend design mainly targets improving the coke quality like hot strength and cold strength of coke. Hot strength is defined by the value of CSR (coke strength after reaction), and CRI (coke reactivity index), while the value of M40 is the measure of cold strength of coke. CRI is a reaction rate of coke and CSR indicates the strength of coke to break into smaller size. Cold strength measure strength and hardness of coke which is depends upon fluidity, volatile matter and heating value of coal (calorific value of coal). CSR is greatly influenced by ash composition of coal blend. It is possible to predict CRI from ash chemistry by using non-linear equations [2-3].

Traditionally, "by product coke oven processes" is utilized for coke formation, where selective coals are blended, oiled in a proper bulk density fluid and then pulverized before carbonization

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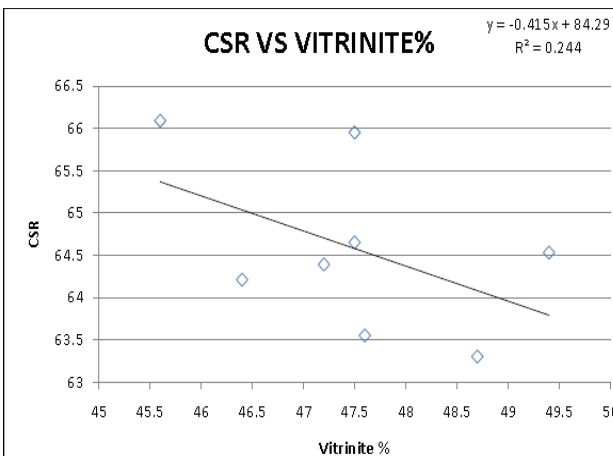
process [4]. In this process, heat is transferred from brick wall to charging coal. Firstly, moisture is removed at temperature 200˚C. The coal is decomposed in the form of plastic layer near the walls in between 375˚C to 475˚C and when the temperature is further raised between 475˚C to 600˚C, plastic layer is converted into semi coke with the help of re-solidification process. Finally, coke stabilization phase begins at 600˚C to 1100˚C [5].

2. Related work

Relations which are given below is used for calculation of hot strength and cold strength of coal and are obtained from TATA steel Jamshedpur, India according to its experimental data. Figure 1 shows that with increase in vitrinite %age the CSR value goes down, which also hinders the strength of coke. The vitrinite %age also affects the M40 value of a coal and previous experimental results indicates that more is the availability of vitrinite %age, lesser would be the value of M40 (figure 2).



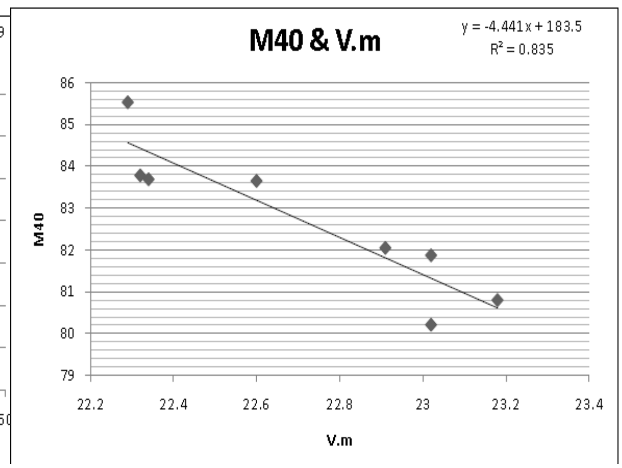


Figure 1: Graph between CSR and Vitrinite %Figure 2: Graph between M40 and VM

The selection of an appropriate coal most importantly depends on CSR and CRI values and these two are found to be inversely proportional to each other (figure 3). The CSR and CRI values are further dominated by various constituents of coal, therefore to get better coal properties, the coal blend should be prepared with optimum proportions of all such elements.

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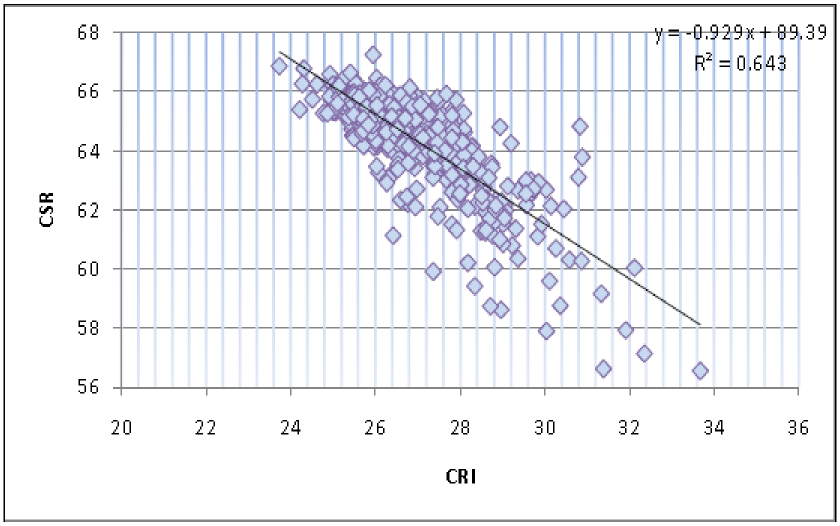

Figure 3: Graph between CSR and CRI

Comprehensive literature survey stipulatesthe target properties of a coal blend as given below.

Target properties of coke:

CSR $\geq$ 65	M40 $\geq$ 82	CRI $\leq$ 28

CSR = -0.415 (Vitrinite %) + 84.29
M40 = -4.441 (VM) + 183.5
M40 = 0.022 (Fluidity) + 73.76
CRI = -0.929 (CSR) + 89.39

3.Methodology and Experimental Data

3.1 Linear programming model

Basis = 1 gm

Min $Z = Z_1X_1 + Z_2X_2 + Z_3X_3 + Z_4X_4 + Z_5X_5 + Z_6X_6 + Z_7X_7$

Subjected to

$X_1 + X_2 + X_3 + X_4 + X_5 + X_6 + X_7 = 1$
$A_1X_1 + A_2X_2 + A_3X_3 + A_4X_4 + A_5X_5 + A_6X_6 + A_7X_7 \leq 13\%$
$VM_1X_1 + VM_2X_2 + VM_3X_3 + VM_4X_4 + VM_5X_5 + VM_6X_6 + VM_7X_7 \leq 24\%$
$S_1X_1 + S_2X_2 + S_3X_3 + S_4X_4 + S_5X_5 + S_6X_6 + S_7X_7 \leq 0.83$
$M_1X_1 + M_2X_2 + M_3X_3 + M_4X_4 + M_5X_5 + M_6X_6 + M_7X_7 \leq 0.75$
$V_1X_1 + V_2X_2 + V_3X_3 + V_4X_4 + V_5X_5 + V_6X_6 + V_7X_7 \leq 54.2$
$C_1X_1 + C_2X_2 + C_3X_3 + C_4X_4 + C_5X_5 + C_6X_6 + C_7X_7 \leq 6$

The value of variables must be, $0 < X_1, X_2, X_3, X_4, X_5, X_6, X_7 > 1$

These linear equations were further solved by MATLAB software.

Fluidity of blend = Antilog [∑ (% of coal Ai X (Fluidity of Ai)]

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A= Type of coal, i = 1, 2, 3 …

3.2 Experimental data

Differentcoal samples used in coke oven plant for making coal blend, weretaken into account to formulate the linear programming model. The information available regarding the various analysis including ultimate analysis, proximate analysis and other properties of coal were collected. The ultimate analysis (table 1) is a chemical approach which incorporates the carbon (%), hydrogen(%), nitrogen(%), sulphur(%) and oxygen(%) in a coal. The nitrogen content in coals are almost found in the range of 1-2%. The oxygen present in coals helps it burn more easily and better ignition efficient.

Table 1: Ultimate analysis of coal

Type of coal	Carbon %	Oxygen %	Sulphur %
Anthracite	78	3.79	0.7
Bhelatand	73.02	2.87	0.59
Russian coal	74.9	17.85	0.53
New Zealand	76.03	13.85	2.28
West Bokaro	73.45	4.73	0.77
Semi soft coal	80	4.07	0.51
R.P.C.	86	5.45	2.5

Proximate analysis (table 2) of coal is done to find ash (%), volatile matter (%), moisture content (%) and fixed carbon (%).

Table: 2 Proximate Analysis and Calorific value of coal:

S.No	Type of coal	Ash %	Volatile matter %	Moisture %	Fixed Carbon %	Calorific Value Kcal/kg
1	Anthracite	12.59	13	0.58	76	7260
2	Bhelatland	17.98	18	0.5	63.65	6990
3	Russian coal	0.68	27	2	71	7275
4	New Zealand	5.12	32.03	2.45	56.78	7548
5	West Bokaro	14.1	24.37	0.5	58.45	7065
6	Semi soft coal	10	17.54	0.49	72.67	7800
7	R.P.C.	0.68	9.1	0.3	91	7575

4. ResultsandDiscussion

The optimum blend contribution with the help of linear programming model and MATLAB software were analyzed. The linear equations included various coal properties like ash, VM, moisture, vitrinite, blend cost etc. Further calculations evolve, attainment of theoretical hot strength and cold strength of coke with the help of co-relations between coal and coke properties.

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The coal contribution of different blend samples was obtained as specified in table 3. The coal properties vary for dissimilar blends and so the cost as well (table 4). According to selected target properties we suggest blend 4, blend 5, blend 8, blend 11 and blend 13 as better coal blend (table 5).

Table 3: Blend's coal Contribution

Blend	West bokaro coal (A)	New Zealand coal (B)	Bhelatland coal (C)	Russian coal (D)	Semi soft coal (E)	R.P.C (F)	Anthracite coal (G)
1	78.35%		10.44%	11.21%			
2	86.48%			5.85%	7.67%		
3	80.60%	6.24%			13.16%		
4			27.24%			8.89%	63.87%
5	64.37%					4.72%	30.91%
6			53.85%		32.24%	13.92%	
7	84.60%				10.37%	5.03%	
8	55.66%	5.76%					38.58%
9	91.80%			4.15%		4.04%	
10	87.35%			7.63%			5.02%
11		9.69%	21.04%				69.27%
12			73.19%	20.18%	6.63%		
13			38.90%	14.16%			46.93%

Table 4: Coal blend properties

Blend	Blend cost	Ash	VM	Sulphur	Moisture	Vitrinite	CSN
1	3774	13	23.99	0.72	0.67	53.31	4.7
2	3400	13	23.99	0.74	0.59	52.04	4.5
3	3622	13	23.94	0.83	0.62	52.20	4.5
4	8785	12.84	14.01	0.80	0.52	41.41	1.5
5	5220	12.82	19.86	0.80	0.51	46.2	3.2
6	5790	12.82	16.42	0.83	0.47	53.03	3.4
7	3225	13.44	22.92	0.83	0.49	52.11	4.4
8	6105	12.80	19.94	0.80	0.61	45.02	3.0
9	3100	13.02	23.86	0.83	0.55	53.05	4.7
10	3136	12.95	24.01	0.74	0.62	51.92	4.5
11	9632	12.95	15.89	0.83	0.74	41.69	1.5
12	6245	13.33	19.22	0.70	0.80	56.31	4.4
13	8612	12.99	16.73	0.63	0.75	45.69	2.4

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Table 5: Hot and cold strength of coke

Blend	CSR	CRI	M40
1	62.16	31.64	91.64
2	62.70	31.14	94.47
3	62.62	31.21	91.05
4	67.10	27.05	97.69
5	65.11	28.90	87.93
6	62.28	31.43	94.06
7	62.66	31.17	96.50
8	65.60	28.44	86.20
9	62.27	31.54	99.80
10	62.74	31.10	92.17
11	66.98	27.16	93.47
12	60.92	32.80	88.37
13	65.32	28.70	91.88

5. Conclusion

The hot and cold strength of various feasible/possible coal blends were calculated in view of miscellaneous parameters like ash, VM, fluidity, vitriniteetc. The estimation of the hot and cold strength of coke were done taking the diverse coke properties into consideration. The results show that the blast furnace performance can be increased by hot strength of cokewhich mainly encountered by numerous coke parameters. It has been found that the linear programming model may assist in obtaining a correct coal blend.

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