Study on spontaneous combustion of boiler grade coal and optimization of consumption at rinl

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Abstract: Coal burning in stockpile is a serious problem for all coal handling plant & power plant, because of related safety and environment implications. The purpose of this paper is to discuss various methods of boiler coal bed management, techniques of specifying boiler coal quality and blending practices for efficient utilization.

1. Introduction

Spontaneous combustion in coal is a major concern to mining and power plant operators. The issue can be addressed by developing proper understanding regarding factors which are responsible followed by implementing handling practices which nullify such problems effectively. Several research works made in that direction reveals that, both nature of coal and the practices associated with the handling are combinedly responsible for the spontaneous combustion of coal.

RINL over the year, while using various grades of boiler coal, developed a systematic approach to eliminate burning of coal in yard. This encompasses aspects such as; characterization of coal, mode of consumption and practices of handling of coal at yard. The present paper highlights how the propensity towards self-ignition can be pre-assessed using various quality-based indexes in procurement specification before the coal reaches for use into the plant. This can provide a reasonable base to assess the purchaser the tendency of the coal under consideration towards self-combustion, which otherwise can lead to huge loss due to burning. The paper also discusses approaches to develop optimization models using the quality parameters and the indexes derived from it. These models provide alternate blends of various coal sources that can provide higher benefit to the power generation in terms of Rupees per MWH. It is also noted that though quality of coal and its nature decides the intrinsic character towards spontaneous burning, under majority cases, extrinsic factors such as; size distribution, profile of pile, compaction, moisture, and humidity, temperature of surrounding, wind velocity and mode of handling are found to be responsible. The paper records various such operational aspects which will be of references quite useful to users of boiler grade coal.

2. Phenomenon of Self-Ignition in the Boiler Coal Beds.

All types of coal generally absorb oxygen and oxidize to evolve CO, CO_2, and H_2O along with heat. This heat slowly dissipates into air. If the rate of oxidation is slower and the amount of heat dissipation is higher than the amount of heat accumulation then coal doesn't reach ignition temperature (Critical Temperature for Oxidation) and the process is referred as weathering. But in case the oxidation rate is faster and the amount of heat accumulation is higher than the amount of heat dissipation, it makes the coal reach the critical temperature for oxidation resulting in coal ignition which is referred as Spontaneous combustion (figure 1).
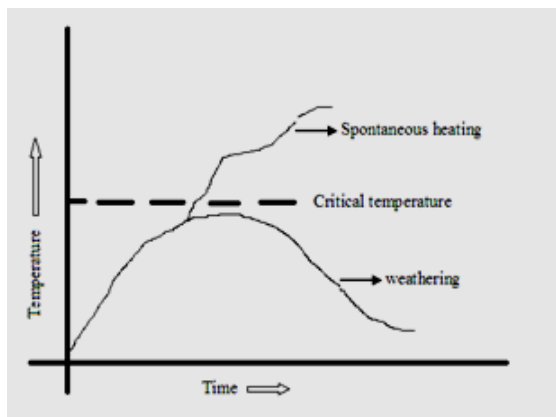

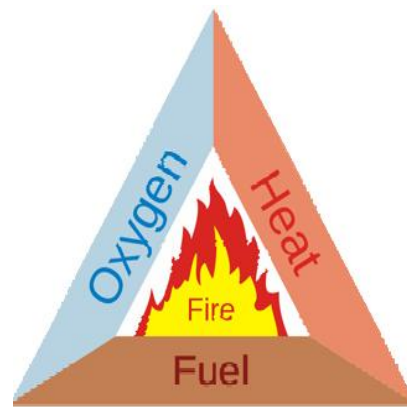**Figure1.** Threshold limit for spontaneous combustion   **Figure2.** Fire Triangle

Spontaneous combustion is an oxidation reaction that occurs without an external heat source. The process changes the internal heat profile of the material leading to a rise in temperature. This can eventually lead to open flame and burning of the material. Spontaneous combustion of coal is a fire initiated by the oxidation of coal. Coal fires require three basic elements to exist i.e., oxygen, heat and fuel (figure 2). The process leading to spontaneous combustion can also be depicted schematically as follow (figure 3).
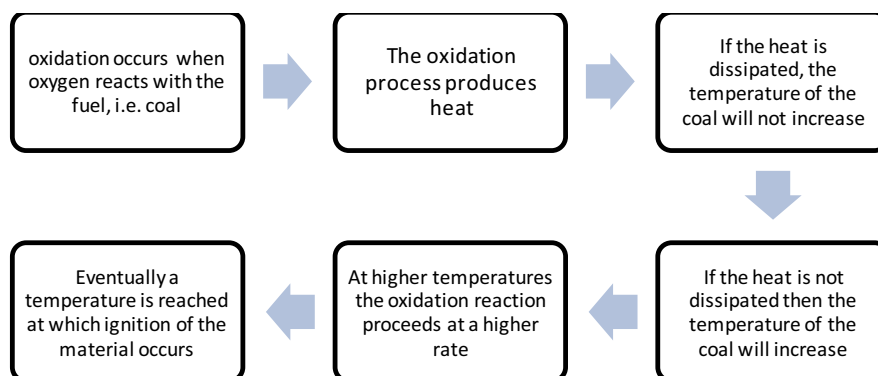

Figure-3. Process of self-burning of coal

Heat dissipation depends on the thermal conductivity of coal and the surrounding rock, on convection processes caused by wind and barometric changes in the atmosphere and on the minor and major fracture density in the rock mass. The tendency of coal to self-heat is a function of both intrinsic factors (coal type, geological setting and environmental conditions) and extrinsic factors (mining related).Combustible matter can interact with the oxygen in the air at ambient temperature releasing heat. Favorable conditions for spontaneous heating would be the accumulation of heat

caused by a rise in temperature and hence an increase in the reaction rate. Although, at ambient temperature, the reaction can be so slow that it is unnoticed, when heat accumulates the temperature is raised and, according to the Arrhenius law, the reaction rate increases exponentially:

$$v = c_r c_0 \, Ae^{\frac{E_a}{RT}} \tag{1}$$

Where:
v = reaction (mol g−1 s−1)
c_r= combustible concentration (kg/m3)
c_o= Oxygen concentration
A= Arrhenius Frequency Factor (s^{-1} or $s^{-1}C^{1-n}$)
E_a= Activation Energy (kJ/mole)
R= Universal gas constant = 8.314 J moleK^{-1}
T= Temperature (K)

3. Factors Affecting the Spontaneous Heating of Coal

Davis and Reynolds did one of the earliest classifications of the factors affecting spontaneous combustion (figure 4). The factors were grouped under chemical and physical headings as shown below.
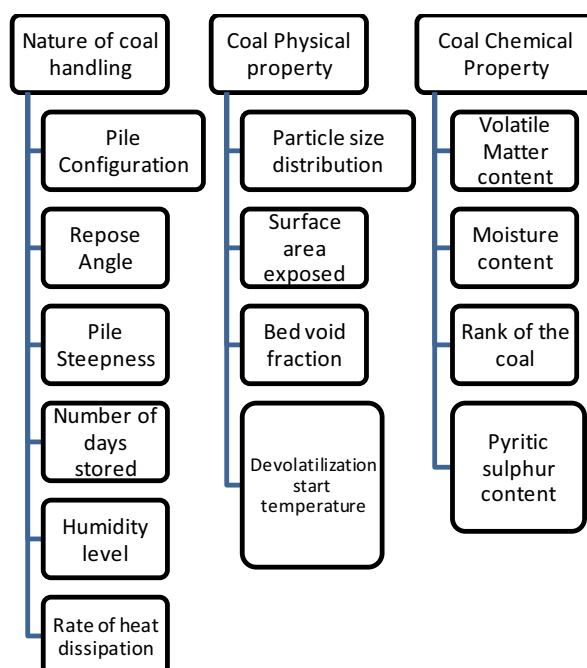

Figure 4. Various factors responsible for spontaneous combustion

4. Role of Quality of Coal

A coal molecule constitutes two parts: The condensed aromatic structure which is resistant to decomposition and the hydro-aromatic structure or the aliphatic (open chain) part that is susceptible to dissociation. The low rank coals have lower structural stability and degree of aromatization in it. On heating, low rank coals produces volatile matters mainly formed from aliphatic present in it. The higher rank coals have structure towards graphitic which helps it in formation of aromatic groups rather than aliphatic. For example a boiler grade coal of around 0.3 reflectance value might have

higher porosity, lower aromaticity and lower thermal instability. There might be greater loss of hydrocarbon vapor from coal surface which in turn might induce faster self ignition. Boiler Coal having around 0.65 reflectance values, will have better aromaticity with better thermal stability. This will lead to less dissociation and less formation of hydrocarbon vapor from coal surface.

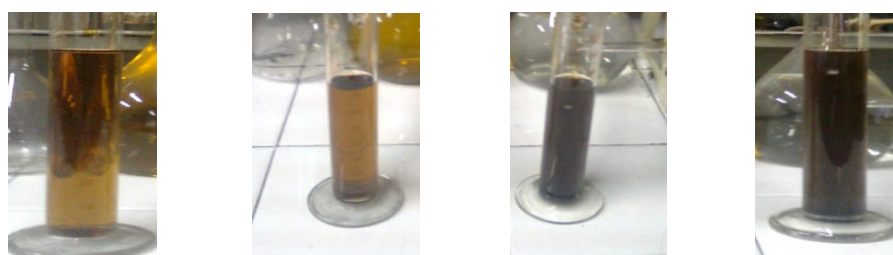## 5. Assessment of Propensity towards Self Ignition

A number of methods have been developed by various workers to predict self-ignition. Though some of these methods are very efficient in dealing with the problem, they only apply to specific geo-mining conditions. Their performance rate also varies from case to case. The methods which are more popular listed as follows:

1. Feng et al(1973) – methodized a composite Liability Index by using various results of CPT(Crossing Point Temperature), called FCC Index
2. Banerjee and Chakraborty (1967)- suggested DTA(Differential Thermal Analysis) for the study of spontaneous combustion of coal, generally in classifying coal depending upon their susceptibility to self heating
3. CPT (Cross Point Temperature): It refers to the minimum temperature at which the coal temperature coincides with that of the bath temperature. This method is primarily used in India for determination of liability of coal samples towards spontaneous heating.
4. AHR (Average Heating Rate)
5. Critical Self Heating Temperature ($CSHT_{Vol}$)
6. Wet Oxidation Potential Analysis(Estimation of Relative Degree of Oxidation)

Among several methods, RINL adopts three methods i.e., 1) Estimation of relative degree of oxidation 2) Test on initial devolatilization temperature 3) Critical Self Heating Temperature (CSHT), to assess the tendency of spontaneous combustion of coal.

6. Estimation of Relative Degree of Oxidation

The alkali extraction of humic acid content of coal and measurement of transmittance (Method as per ASTM D 5263) gives an indication of structural complexity. Higher transmittance value is indicator of better structural order. To differentiate the degree of structural looseness of two boiler coal sources i.e., BC-2 andBC-3, used at RINL, were subjected oxidation test as per ASTM D 5263.

Test-1:BC-2 (%T=45.5)Test-2: BC-2 (%T= 55)Test-3: BC-3(%T= 33)Test-4: BC-3(%T=21)

Figure5. Transmittance of humic acid extracts of coal

It can be observed from the figure (figure 5) that % transmittance (%T) value of BC-3 is lower with dark extracted material indicating higher amount of oxidizing material present than that of BC-2. In actual practice BC-3 exhibits higher self-burning tendency compared to BC-2.

7. Test on Initial Devolatilization Temperature

It is believed that low rank coal due to its unstable molecular structure will lose volatiles gases such as methane and other hydrocarbons at comparatively lower temperature than that of the high rank. Due to this early release of hydrocarbon gases which may be entrapped deep inside piles, initiates' fire when they reach their ignition point. Several tests conducted at laboratory of RINL, with different sources of boiler coal using TGA (Themo-Gravimetry Analyzer, TGA-700, Leco), where the rate of devolatilization at 300 ^{O}C is observed. The result is shown at figure 7(a).The devolatilization also start temperatures were noted for different coal sources. Lower devolatilization start temperature coupled with higher rate of devolatilization at 300 ^{O}C is the indication of higher thermal instability leading self-ignition (figure 6).
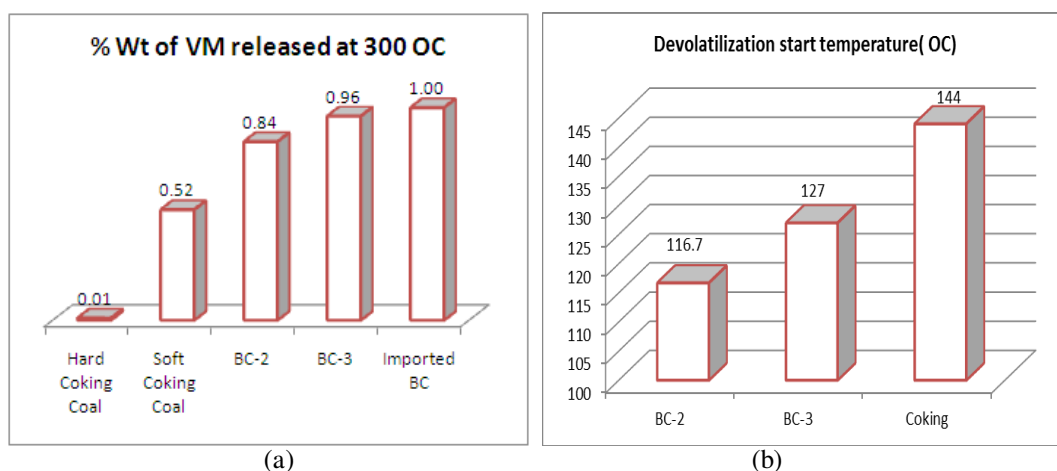

(a)	(b)

Figure6. (a). % De-volatilization at 300 ^{O}C and devolatilization start temperature, (b). Start of devolatilization

8. Critical Self Heating Temperature (CSHT$_{Vol}$)

The CSHT due to the moist fuel ratio is based upon an empirical equation proposed by Litton and page [3], who in turn, based their equation on data and results from Smith and Lazzara. This equation was given as:

$$\text{CHVT}_{VOLUME} = 117(1 - e^{-2.6x}) \qquad (2)$$

Where:

CSHT$_{VOLUME}$= critical self-heating temperature in °C based upon carbon, volatiles, and moisture adsorption.

x= "moist fuel ratio" and is defined as;

$$x = \frac{\frac{\%FixedCarbon}{\%Volatile\ Matter}}{\%Moisture} \qquad (3)$$

Smith and Lazzara proposed that for CSHT values less than 70°C, the coal should be classified as having a high potential for spontaneous ignition. Coals having a CSHT factor above 70°C, but less than 100°C, should be considered as having a moderate potential for spontaneous ignition. For coals having a CSHT equal to or greater than100°C, the potential for spontaneous ignition should be considered low. The CSHT value of various boiler coal sources used at RINL, along with the Medium coking coal is determined and shown in below figure (figure 7).
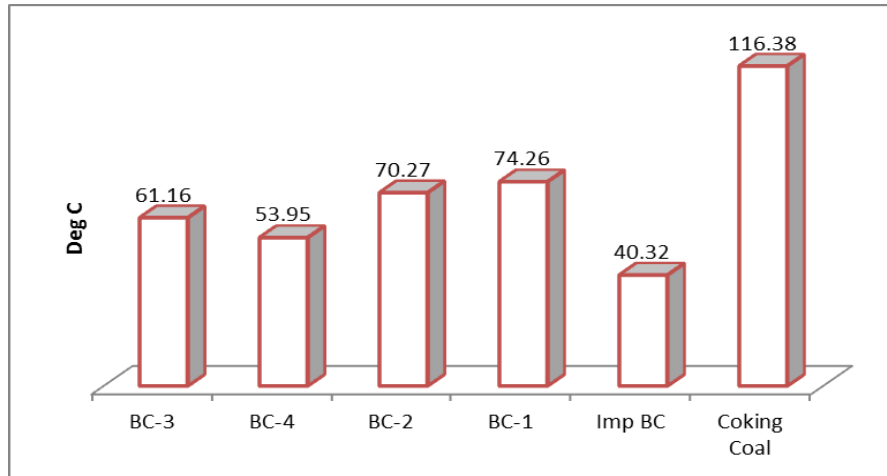
Figure7. Critical self-heating temperature of coals of RINL

9. Boiler Coal Handling at RINL

Raw Material Handling Plant (RMHP) of RINL handles approx. 2.7 lakh tones of boiler coals with storage capacity 30 days in the boiler stock yards named as; CC-31, CC-32, CC-33 (Figure -8). Boiler grade coal having different physical & chemical properties normally come under grades G11 to G14.The property of boiler coal used at RINL is presented below in table 1.

Table 1. Various Boiler coal sources used at RINL

Parameter	BC-1	BC-2	BC-3	BC-4	BC-5
Inherent Moisture, %	2.8	3.6	3.9	3.2	6.5
Volatile matter, %	18.2	24.9	21.1	24.9	41.1
Ash, %	59.2	40.3	54.6	56.0	8.8
Fixed carbon, %	19.8	31.3	20.5	15.9	43.6
Carbon, %	28.2	46.7	31.2	28.2	61.8
Hydrogen, %	2.3	3.3	2.3	2.1	5.0
Sulphur, %	0.23	0.6	0.30	0.67	0.3
Nitrogen, %	0.20	0.6	0.23	0.59	0.7
G. C. V (kcal/kg)	2764	3224.0	2678	2390	5900

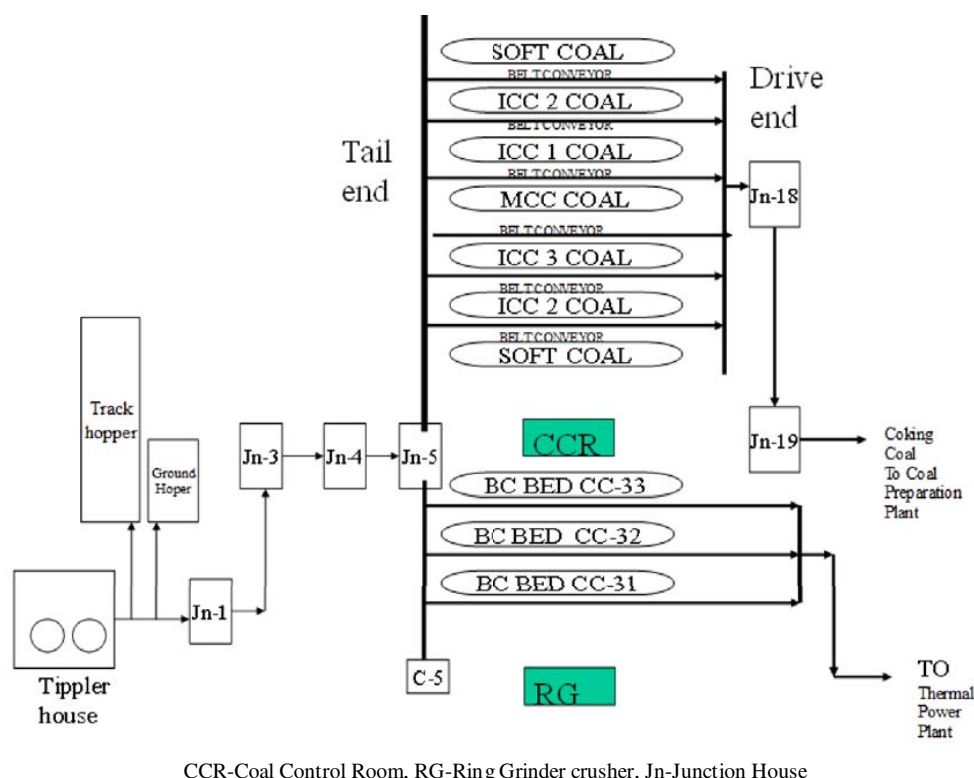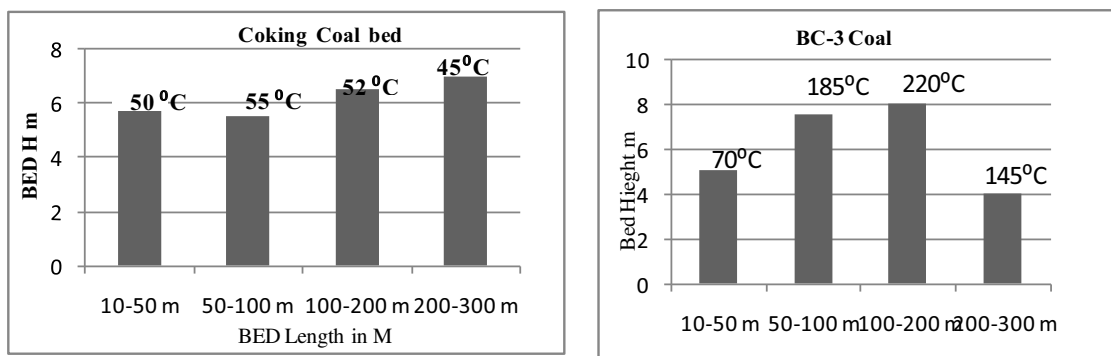CCR-Coal Control Room, RG-Ring Grinder crusher, Jn-Junction House

Figure – 8. RMHP Coking coal and Boiler Coal yard

10. Operational Aspects of Coal Handling Responsible For Spontaneous Combustion At RINL

Raw Material Handling Plant (RMHP) of RINL is having a long operational experience of handling various grades of boiler coal produced nationally and internationally. The flow-sheet of the plant is shown in figure above (figure 8). Some important aspects having influence on self-burning of coal were identified and are discussed below in details.

10.1 Temperature pile and its measurement

Physical observation of the pile surface temperature is a vital indication about the magnitude of self-ignition occurred. The temperatures indicated in below figures (figure 9) are measured by inserting the thermometer rod up to a depth of approximately 1 meter. This temperature e is an indication of the average temperature of the bed surface. It can be seen from the above figures that boiler coal bed surface temperature is significantly more than that of the coking coal bed. It indicates that there is some amount of self-burning inside the pile. It is also observed that higher bed height leads to higher surface temperature due to more surface area.
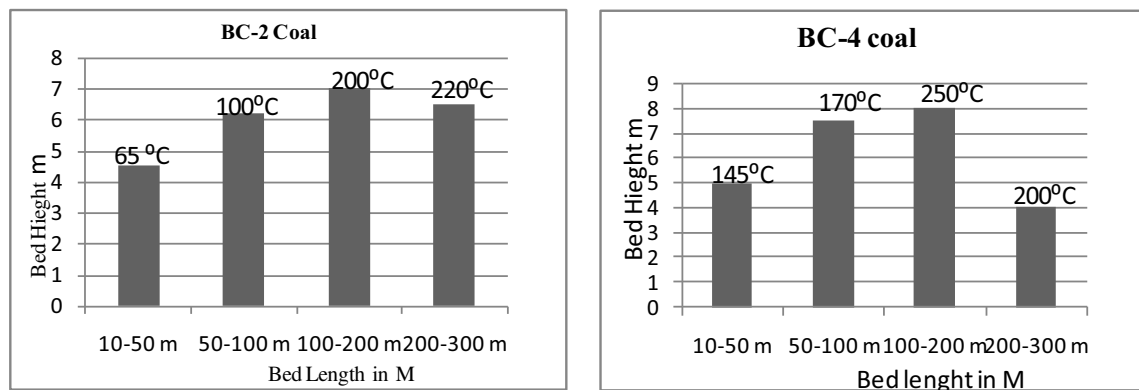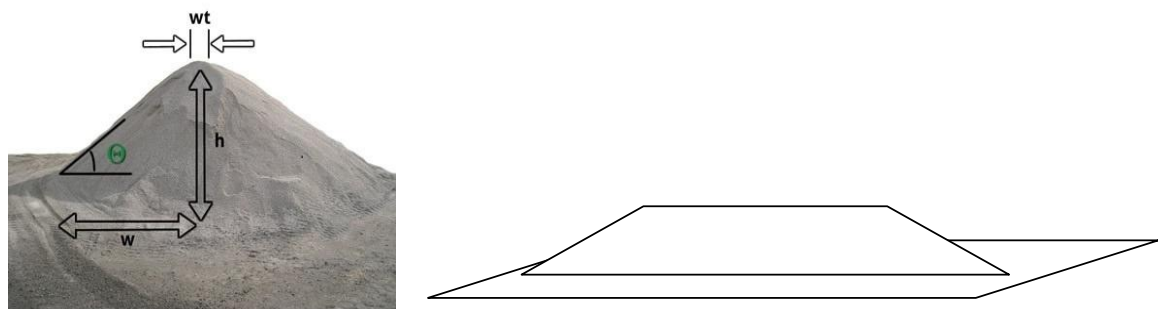
Figure 9. Bed temperature across length and height, Coal temperature in ^0C recorded during inspection of boiler coal beds by using an inserted thermometer

10.2 Dimensions and shape of the bed:

During stacking, coal piles are normally conical in shape and likely to be permeable & porous in nature. Such types of coal piles provide maximum surface area and absorb more amounts of O_2 & moisture from its space around. If the coal piles having excessive fines, the adsorption of oxygen & moisture will also be more. Hence self-ignition of coal will occur.

Un-compacted pile after compaction by Dozer

Figure10. Role bed profile on spontaneous combustion

Coal piles should be packed in horizontal layers through leveling & compaction by Dozers along with water spraying. It helps evenly distribution of coal and can avoid segregation of coal fines. It minimizes angle of repose, reduce bed permeability & porosity of the pile (Figure - 10), and minimize Surface to volume ratio and finally minimize absorption rate of oxygen & moisture.

10.3 Granulometry of coal in bed

Coal particle size has considerable influence on the self-heating character of coal in the bed. Oxidation increase with decreasing the particle size, because smaller or fines material provides large surface area and adsorbs high content of oxygen and moisture. Activation energy for self-burning of the coals reduces with decreasing particle size because the coal fines have high content of ash and other non-combustible minerals such as Alkalis & Pyrite (FeS_2) than coarse size. Coal fines accumulate between coarse particles creating sites for hot-spot and self-ignition.

To avoid the size effect on spontaneous combustion, compaction should be done by Dozers along with water spraying. If excessive fines are present then Excavator, Dozer & water spraying should be

put together. It helps in avoiding channels, voids, segregation of fines between coal particles and in increasing bed compactness. It will reduce air and moisture penetration and better distribution of particle. Recommended coal size in the coal bed (Stacking) is +10 to -100mm.
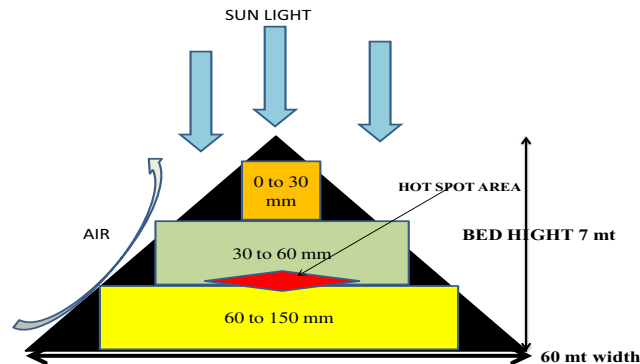

Figure 11. The size segregation in pile, hot spot area in Stacking Bed

10.4 Stacking Pattern &Reclamation

Stacking and reclamation if done arbitrarily will increase the possibility of mix-up between old and new arrival of coal stock promoting the self-ignition. Fresh coal stacking on the top of the old pile always has a boundary area where hotspot will occur.

The data shown in above figure (Figure-11) indicates that coal is stacked from 8.0 m height from the stacker. Coal size varies from 60 to 200 mm are accumulated at bottom portion of the bed, coal size 25 to 60 mm at middle of the bed and coal size 0 to 25 mm at top of the bed.

10.5 Recommendation Patterns of stacking

To ensure better control on self- burning following recommended practices are found to be helpful in RINL coal storage beds (figure 12).

- LT stacking (Boom Swing 90^0 to 70^0) is to be done.
- Coal piles compaction by Dozers and water spraying should be joined forces along with stacker movement.
- Bed height (A in figure-12) should not be above 8 meters.
- Distance (B in figure-12) from track wall should be maintained 3-4 meters.
- Thought total bed stacking should be avoided and gap (C in Figure-12) between two piles should be maintained around 10-15 meters.
- Different sources of coal should be planned for stacking either separate pile in same bed or in separate bed.

10.5.1 Reclamation Pattern: In addition to proper stacking the reclamation of the coal also should follow a proper pattern. Following practices at RINL coal yard are found to be quite sensitive to spontaneous combustion.
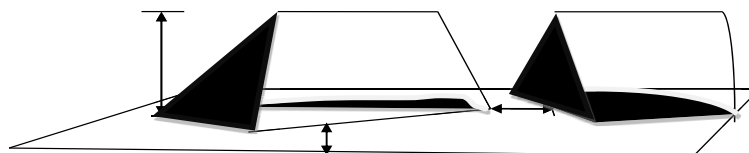
Figure 12-. Recommended pattern of stacking

- Fresh pile or bed reclamation should be completed up to ground level.
- Old bed or pile should be stared first and finish in same.
- Heavy equipment like HM Loader & dozers should be engaged after final cutting at ground level.
- Avoid direct feeding to plant and also avoid attachment with reclamation & Stacking. This type of operation increases resident time of coal in the bed,

10.5.2 Handling procedure: Different sources of coal should not be mixed each other and coal should be stacked in one chosen bed. Different sources of coal have different chemical properties even if same coal in different geographical distribution. Thus, to eliminate segregation and mix-up of categories within themselves an earmarked coal source-wise storage and reclaiming plan was embarked. The shit-wise monitoring system on stockpile was also introduced.

Table 2: Coal stacking in specifically earmarked beds.

Coal Brand	Storage Yard No.
BC-1	CC 31/CC 32
BC-2	CC 32/CC 33
BC-3	CC 31/CC 32
BC-4	CC 31/RG
MCC	CC 33/CCR-SIDE

10.6 Aspects of coal handling

Following coal handling aspects are recommended to mitigate spontaneous combustion issue as per the operational experiences at yard management of RINL is concerned.

- Coal piles area should be kept away from foreign materials, conveyor cleaning or belt cleaning materials, scrapes
- Large volume of water should be sprayed along with excavator.
- Excavator and dozers should be joined forces. (Because of excavator helps in cutting off steam and oxygen to hot coal)
- With help of HM loader extinguished fire coal should be spread to progressively cool and a gap of 1or 2 days, reclamation should be done.
- Fired-coal should be removed from ground level with help of HM loader, Dozers and should be cleared with reclamation.
- After clearing ground level work again water should be sprayed.
- Extinguished fire coal should not be mixed with fresh coal.
- Old fired coal should not be leveled on the bed.
- BF slag or sand should be evenly laired on vacant bed after water spraying, because it helps reduce the ground emission heat after removing the coal.

11. Coal Combustion Index (Boiler Furnace)

In order to assess, that the coal under consideration is having the desired amenability towards smooth combustion in the boiler furnace, parameters such as; Fuel Ratio (FC/VM) and Ignitability Index (II) can be considered. The Fuel Index and Ignitability Index are expressed as follow.

$$\text{Fuel Index} = \frac{\%FC}{\%VM} \qquad (4)$$

$$\text{Ignitabiliy Index(I.I)} = \frac{CV*81.9*\%FC}{\%VM+\%Moiature} \qquad (5)$$

The Ignitability Index (I.I) should be 35 and the Fuel Ratio below 1.5 is believed to provide better combustibility to the coal. Ignitability Index is below 35, blending of higher ignitability coal can be done. Fuel Ratio above 1.5 is going to create problem in combustion hence this also is to be addressed by proper blending. Below at Table-3, values related to ignitability for the coal used at RINL is presented.

Table -3. Combustible propensity of various coals used at RINL for power generation

Coal source	AM Analytical moisture%	VM Volatile matter %	ASH %	FC Fixed carbon %	I.I Ignition Index	Fuel ratio %FC/%VM
BC-1	2.8	18.2	59.2	19.76	55.35	1.08
BC-2	3.56	24.89	40.28	31.28	24.28	1.26
BC-3	3.35	24.5	48.8	23.35	28.25	0.95
BC-4	3.6	25	50	21.4	22.96	0.86
BC-5	6.53	41.1	8.76	43.61	41.31	1.06
BC-6	1.5	18	29	51.5	16.85	2.86

12. Incorporation of Selfignition and Combustibility Index in Boiler Grade Coal Specification

A normal specification of boiler grade coal is focused around heating value, and ash content which are the major requirement to address the efficiency of a power plant. It may be noted that in addition to these primary requirements, self- burning during handling and amenability to combustion at boiler furnace also should be given adequate attention. This issue is addressed by quantitatively measurable parameters which indicate self- burning and amenability to combustion aspects. We can use critical self-heating temperature ($CSHT_{vol}$) for self- burning and Fuel Ratio (% Fixed Carbon/%Volatile Matter) to indicate the ignitability aspect of the coal under consideration. Below a typical specification of boiler grade coal, which incorporate the ignitability and spontaneous combustion aspects in addition to the conventional parameters such as; GCV, Ash content Moisture content and Volatile matter content is shown in table below (table 4 and table 5). The aim is to provide an opinion outside the conventional approach.

Table 4. The conventional specification of the boiler grade coal

Sl. No.	Parameter	Guaranteed	Absolute
1	Gross Calorific Value(GCV) (Kcal/Kg)	4100 Min	3865-7324
2	Total Moisture % Max	12	15
3	% (Ash + Inherent Moisture)	43	40-47
4	Total Sulfur %	0.4 max	0.5 max
5	Hardgrove Grindability Index (HGI)	55 Min	50 Min
6	Ash Fusion Temperature in Deg C	1200 Min	1100 Min
7	Volatile Matter %	27 Max	25-30

Table 5. Revised specification og boiler grade coal which includes Spontaneous combustibility index and fuel ignibility index

Sl.No.	Parameter	Guaranteed	Absolute
1	Gross Calorific Value(GCV)	4100	3865-7324
2	Total Moisture % Max	12	15
3	Ash %	32	34
4	% Fixed Carbon /Volatile Matter	2.2	2
5	Mean Maximum Reflectance (MMR)	0.5 Min	0.5 Min
6	% Total Sulfur	0.4 Max	0.5 max
7	Hardgrove Grindability Index (HGI)	55 Min	50 Min
8	Ash Fusion Temperature Deg C	1200 Min	1100 Min
9	$CSHT_{Vol}$	70 Min	70 mln

13. Technoeconomics in Power Generation and Optimization of Boiler Coal Sources

Based on the GCV value and chemical properties of each boiler grade coal source the theoretical cost of the fuel for generation of one MWH is calculated which is shown below (table 6).

Table 6. Chemical property and fuel cost for Boiler Coal (BC) used at RINL

Coal source	AM Analytical moisture%	VM Volatile matter %	ASH %	FC Fixed carbon %	Fuel Cost (Rs/Mega Watt Hour)
BC-1	3.5	18.2	59.2	19.8	3672
BC-2	3.5	24.9	40.3	31.3	2242
BC-3	3.9	24.5	48.8	23.4	2383
BC-4	3.2	25.0	50.0	21.4	2383
BC-5	7.3	41.1	8.8	43.6	2517
BC-6	1.5	18.0	29.0	51.5	2404

The linear plus nonlinear programming technique is used to arrive at an optimum tonnage distribution giving minimum cost of fuel per MWH subjected to the operational, logistic and legal /environmental conditionality. The situation be formulated mathematically as follow and the optimal solution arrived is discussed.

Minimize C= $C1 * X1 + C2 * X2 + C3 * X3$ (6)

Subjected to the constraints as depicted below in table 7..

Where, $C_1, C_2, C_3, \ldots \ldots C_n$ are the cost of fuel /MWH for individual coal sources;
$X_1, X_2, X_3 \ldots X_n$ are annual consumption of individual coal sources respectively.

Table-7: Conditionality (considering only the technical parameters) for optimization calculation of minimum fuel cost per annum at RINL

Sl no	Constraint parameters	Value	Remark

1	The GCV of boiler kcal/kg	2800-3500	Operational Constraint
2	Ash content	<34 %	Government Guideline to pollution
3	Fuel ratio (% FC/%VM)	<1.2	To address proper burning inside boiler furnace

Mathematically the above constraint condition can be designated by the following equation having slack and surplus variable.

$$\sum_{i=0}^{n} aij\, Xi + Si + Sj = bi \text{-------------------- (3)} \;(i= 1,2,\ldots\ldots\ldots k\,)\;;(\,j= 1,2,\ldots\ldots\ldots.n\,)$$

And $Xi \geq 0$, $S_i \geq 0$, $J = 1,2,\ldots\ldots n$
$C_1, C_2, C_3, \ldots\ldots C_n \geq 0$, to satisfy the non-negativity restriction

Where, $C_1, C_2, C_3, \ldots\ldots\ldots\ldots C_n$ are the cost of individual coal sources

a_{ij} is the positive coefficient defined in the constraint equation for the ith parameter of the jth component.

b_i is the constraint conditionality for the parameter i^{th}

Si and Sj are the slack and surplus variable added to the constraint conditionality for equality.

Under above considered logistics and techno-economic boundary lines optimized blending options were worked out by performing the calculations as depicted above. The outputs of the optimized options are presented below.

RINL procures boiler grade coal every year for its captive power plant from different indigenous and imported sources. The total quantity of each source is dependent on mostly logistic and commercial constraints. Column-2 to column-5 depicts optimized and the constraints are shown in Table -7; feed blend composition which renders a minimum fuel cost (Rupees/MWH) to the power plant under various logistic. The data shown in Table-8, first column indicates the % distribution of various sources used in year the 2016-17. The calculated cost (Rupees) of fuel to produce one MWH is indicated. All the options indicate the saving against the existing composition. It can be seen from the above analysis that the use of BC-2 along with BC-5 (as shown in fifth column) provides the maximum savings. However, if we anticipate a limitation in the supply of this source in future option-1 (as indicated in second column) works out to be better. of approximately rupees 26crores can be achieved if the blend is implemented continuously for the whole year against the exiting usage pattern.

Table -8: The result of optimization analysis

Source	Present Distribution (% Consumed 2016-17)	Optimal Distribution -1	Optimal Distribution -2	Optimal Distribution - 3	Optimal Distribution – 4
BC-1	17	0	10	10	0
BC-2	36	20	20	63	72
BC-3	38	29	22	0	0
BC-4	6	0	0	0	0
BC-5	3	17	15	27	28
BC-6	0	34	33	0	0
Blend Property					
%AM	3.7	3.6	3.5	4.5	4.6
%VM	24.0	24.6	24.6	28.8	28.9
%ASH	44.7	35.0	35.0	35.0	35.0
%FC	27.5	36.9	36.9	31.6	31.5
GCV(Kcal/kg)	2942	4148	4075	3658	3728

CSHTVol	65	76	77	60	59
Cost of power (Rs/MWH)	2467	2385	2513	2461	2320
Fuel Ratio (FC/VM)	1.14	1.50	1.50	1.10	1.09
Approximate Quantity of boiler coal consumed (TPY)	1744594	1744594	1744594	1744594	
Savings due to optimal usage (crore/Annum)	14	-8	1	26	

1) Ash % = 35
2) GCV is between 2800 -3500 Kcal/Kg
3) Ignitability index is < 1.2
The logistic constraints consider during optimization:
1)BC-2 = 20%   1) BC-2=20%   1)BC-1=10%   No supply source constraint
2) BC-4 = 10%   2) BC-4=10%
                       3) BC-1=10%

The above calculation is intended to provide an idea (theoretically) regarding what can be a minimum cost feed to power plant of RINL within the constraint of boiler (GCV between 2800-3500 kcal/kg), ash content of maximum 34% and good Ignitability Index if the coals of different qualities are blended in different proportion. The above exercise doesn't purport towards actual implementable blend proportion.

14. Conclusion

Phenomenon of spontaneous combustion in boiler grade coal is quite common in industry which is responsible for huge loss of property. Even though the phenomena of spontaneous combustion are common, the approach to mitigate it basically plant specific. The success of the approach depends on true identification of the factors which are responsible for the spontaneous combustion for the plant in question. Most of the time it has been a group of factors which includes coal property and operational aspects. At RINL the issue of spontaneous combustion was addressed in comprehensive manner as listed below.

1. All coal quality parameters are examined for its criticality towards self-burning of coal in bed. Finally, they are grouped in to three vital assessment criteria. They are amounts of transmittance of humic acid extract, Rank of coal (MMR), Rate of devolatilization at 300 $^{\circ}$C and an index derived from volatile matter, fixed carbon and moisture content.
2. Other than coal quality parameters several operation aspects were examined and practices of coal handling were standardized to eliminate self-burning in stock yard.
3. In order to make the approach more system driven several coals quality-based indexes were estimated and incorporated in coal specification to address the issue of spontaneous combustion & ignitability at boiler end.
4. Finally, optimization model was developed in order to establish a methodology for selecting various boilers feed coal alternates under different logistic, environment and economic constraints.

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