Slagging Behavior of Coal Ash Under Gasifier Environment

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Abstract

For the six different bituminous coals, the fusion temperature and chemical composition of coal ashes are determined. The slagging behavior of each coal ash is estimated by calculating two different slagging parameters. Accurate prediction of slagging behavior with calculated slagging parameters is difficult because of complex ash melting pehavior in the high temperature gasifier environment. It will be suggested that the optimum slagging condition for gasifier operation should be determined by measuring strength and deposition rate of slag in the specially-designed DTF(drop tube furnace) which is simulating 3 T/D BSU entrained-bed gasifier condition.

INTRODUCTION

Recently, thermal power plants in Korea are utilized large amounts of imported bituminous coal for their energy source. Because of different characteristics of imported coal, standard ASTM ash composition measurements are used to predict slagging behavior of coal ash in the power plant. However, the estimation of ASTM method doesn't show actual slagging/fouling behavior of coal ash because of complex ash melting behavior in the high temperature [1].

The objective of this study is to predict slagging behavior of coal ash from its physical and chemical properties and to construct a fundamental database by investigating the relationship of chemical composition, fusion characteractics and deposition strength of coal ash. The experimental results are obtained by utilizing ASTM method as well as DTF(drop tube furnace) which simulating an entrained-bed gasifier's temperature and residence time. The results will be used in determining optimum operating condition of slagging gasifier which is the major part of Integrated Gasification Combined Cycle(IGCC). Another objective of the study is intended to prevent clogging phenomena of gasifier slag at gasfier outlet which occurs due to solidification of melted slag. The result of this study can also contribute to the selection of candidate coal in the 3 T/D BSU(Bench Scale Unit) gasifier which is in the construction stage in Korea.

EXPERIMENTAL METHOD

In the systematic investigation, proximate and ultimate analysis of six different coals are conducted and the results are shown in Table 1. All the coal samples are presently used as fuel in Korean thermal power plant. Rank of the coal samples show wide range between sub-bituminous to bituminous.

Analysis of coal ash characteractics, such as chemical composition and fusion temperature, is performed in order to predict slagging behavior of coal ash. Initially, coal ash samples were made using ASTM standard ashing method [2]. Coals are heated from room temperature to 500℃ during 1 hour, then to 750℃ during 2 hour and leave for no more mass change at 750℃. Chemical composition data of each coal ash is shown in Table 2. The acidic oxide constituents, such as SiO_2, Al_2O_3 and TiO_2 are generaly considered to produce high melting temperatures. Whereas, ash melting temperatures will be lowered proportionally with relative amounts of basic oxides of Fe_2O_3, CaO, MgO, Na_2O and K_2O. Coal ash samples are shown wide range of oxides composition as in Table 2. Counting the fact that coal with low fusion temperature of coal ash has a higher propensity of slagging, it can be predicted that Alaska coal with low contents of acidic oxide consistents and ROTO coal with high contents of Fe_2O_3 will have a higher slagging behavior than others.

The fusion temperature of each coal ash was also measured by using ash fusion determinator (LECO-600). The cones were manufactured to pyramidal shape, height 19mm, base 6.5mm. The experiment was done with reducing and oxidizing conditions, with preheating temperature of 390℃, start temperature of 538℃, final temperature of 1600℃ and heating rate of 8 ℃/min. The surrouding gases were used of H_2 and CO_2 mixture (50/50) in reducing condition and air is used in oxidizing condition. The result of ash fusion temperature measurement is shown in Table 3. The result of fusion temperature experiments represents same ash fusion behavior as determined by chemical composition data.

RESULTS AND DISCUSSION

Prediction of slagging behavior of coal ash was determined two different methods. Base/acid ratio is to be used as one of the indicators to predict slagging propensity of coal ash, which is defined as follows [3].

$$B/A = \frac{Fe_2O_3 + CaO + MgO + Na_2O + K_2O}{SiO_2 + Al_2O_3 + TiO_2} \quad \text{......... (1)}$$

The calculation of slagging indicators (R_s) using B/A ratio is as follows.

$$R_s = B/A \times \text{Total sulfur} \quad \text{................... (2)}$$

If the R_s value is less than 0.5, the possibility of slagging is low, more than 0.7, the slagging possibility is high and above one, the slagging propensity is severe. The R_s values of the coal ashes used in the experiment are shown in Fig. 1.

The slagging index(F_s) suggested by Gray & Moore is calculated as follows [4].

$$F_s = \frac{4(IDT) + HT}{5} \quad \text{.......................... (3)}$$

Comparing F_s value with slagging behavior, if F_s value is from 1505℃ to 1615℃, slagging possibility is low, from 1325℃ to 1505℃, slagging possibility is high and less than 1325℃, the slagging possibility is severe level. The F_s values of the sampled coal ashes are shown in Fig. 2. The slagging behavior of Alaska coal and ROTO coal is quite high from the result of F_s value calculation of the candidate coal. For case of NOVA coal, an accurate fusion temperature can't be measured due to fusion temperature exceeds maximum temperature range of ash fusion determinator. But from the result of F_s value calculation, it is thought that NOVA ash sample deosn't show slagging characteristic in gasifier. Furthermore, result of R_s value calculation of the six coals doesn't represent any slagging behavior. But compared with the measurement of fusion temperature, Fs value and chemical composion data show slagging behavior in several coal samples. As a result, Rs values determined by Eqn. (2) and Fs values by Eqn. (3) illustrated somewhat different results of slagging behavior of coal ash.

Up to the present, coal ashes are manufactured by ASTM method and the slagging behavior of the coal ash is predicted by measuring its chemical composion and fusion temperature. But it is expected that the slag produced in actual gasifier is quite different from that by ASTM method. Because of complex processes in gasifier such as, higher heating rate and the volatilization of low melting ash component, precise prediction of slagging should be determined by measuring chemical composition, particle size, deposition rate of the slag produced by DTF, which represents simulated condition of an actual gasifier's temperature, gas compositioin and heating rate. With this finding in mind, a specially designed DTF is constructed to determine actual slagging behavior of coal ash. It can get a heating rate of 10^4K/sec and maximum temperature of 1900K close to real furnace. The schematic diagram of the DTF system is shown in Fig. 3. Steam generator was added to simulate gasifier condition. Deposit probe is also installed to get slag from main reactor tube. In the DTF, the ash transformation process of original coal is determined by analyzing ash produced with different residence time in DTF experiment. Distribution of inorganic materials in coal and thermal, chemical, physical characteractics of ash is also considered by analyizing molten ash produced by DTF. With deposition probe at the low part of DTF, deposition rate of molten slag is measured and composition, structure and strength of deposited ash on the probe is analyzed. All of the experimental data will be used to establish the ash slagging mechanism in coal gaifier condition.

CONCLUSION

Chemical compositions and ash fusion temperatures were determined for different coals which is presently used in Korean power plant. Relationship between measured value and slagging behavior was evaluated by calculating two different slagging parameters, Rs and Fs. Slagging indicator (Rs) and Fs (slagging index) evaluation result show somewhat contradictory behavior of ash slagging behavior due to standard ASTM ashing method doesn't represent actual gasifier slagging conditon. As a result, precise slagging prediction of coal ash should be done with simulating gasifier condition such as one in DTF.

REFERENCE

1. *The Research of Combustion Characteristics in Domestic Thermal Power Plant*, Korea Institute of Energy Researce, Report, 1993.
2. Clarence Karr, *Analytical Method for Coal and Coal Products*, Academic Press, 1978.
3. J. G. Singer, *Combustion Fossil Power Systems*, Combustion Engineering Inc., 1981.
4. Gray, R.J. and Moore, G.F, *Burning the sub-bituminous coals of Montana and Wyoming in langc uitility boilers*, ASME paper 74-WA/FV-1, 1974.

Table 1. Proximate & Ultimate Analysis of coal Ash samples

Coal	Proximate Analysis				Ultimate Analysis				
	M.	V.M.	F.C	Ash	C	H	O	N	S
ULAN	2.4	30.6	51.3	15.8	81.1	5.0	10.8	1.78	0.86
Palmco	2.6	18.7	63.8	15.4	86.3	4.3	8.2	0.47	0.32
NOVA	2.4	26.6	55.9	15.1	82.8	3.9	9.7	1.88	0.71
C&A	2.4	31.7	51.7	14.0	80.0	5.0	12.6	1.74	0.62
Alaska	16.67	35.1	35.1	8.7	60.5	5.9	30.8	2.19	0.24
ROTO	5.61	46.71	51.76	1.5	69.3	4.7	24.4	1.32	0.27

Table 2. Chemical Composition of coal Ash samples

#	Caol	SiO_2	Al_2O_3	TiO_2	P_2O_5	Fe_2O_3	CaO	MgO	Na_2O	K_2O
1	ULAN	74.2	15.78	0.8	0.13	3.45	1.69	0.5	0.28	0.66
2	Palmco	66.9	20.52	0.92	0.26	4.56	1.49	0.51	0.25	0.72
3	Alaska	49.23	18.13	0.82	0.35	6.08	12.17	2.28	0.47	1.32
4	NOVA	62.53	28.64	1.21	0.29	1.19	0.25	0.26	0.07	1.88
5	C&A	57.75	23.00	1.02	0.44	4.1	2.23	0.94	0.41	1.52
6	ROTO	32.58	27.49	0.25	0.24	21.23	4.11	1.85	0.24	0.87

Table 3. Ash Fusion Temperature of coal Ash samples

	ULAN		Palmco		Alaska		NOVA		C&A		ROTO	
	Ox	Re	Ox	Re	Ox	Re	Ox	Re	Ox	Re	Ox	Re
IDT	1423	1423	1446	1414	1199	1154	>1600	>1600	1452	1373	1395	1204
ST	1478	1457	1494	1478	1222	1197	>1600	>1600	1489	1474	1424	1236
HT	1517	1476	1520	1499	1249	1217	>1600	>1600	1520	1498	1430	1257
FT	1566	1502	1538	1516	1283	1243	>1600	>1600	1541	1523	1437	1271

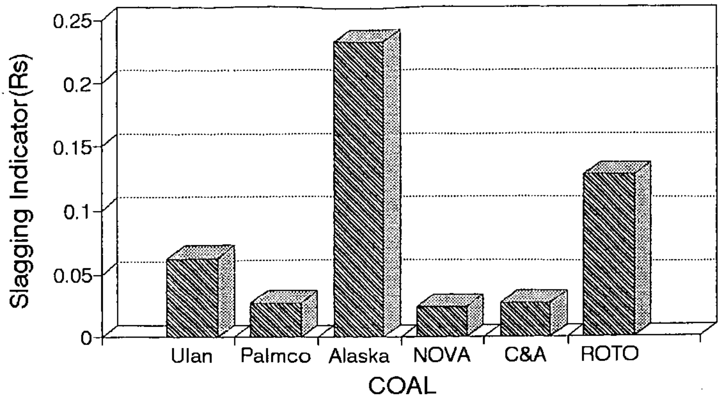

Fig. 1. Slagging Indicator (Rs) values of Six Different Coal Samples

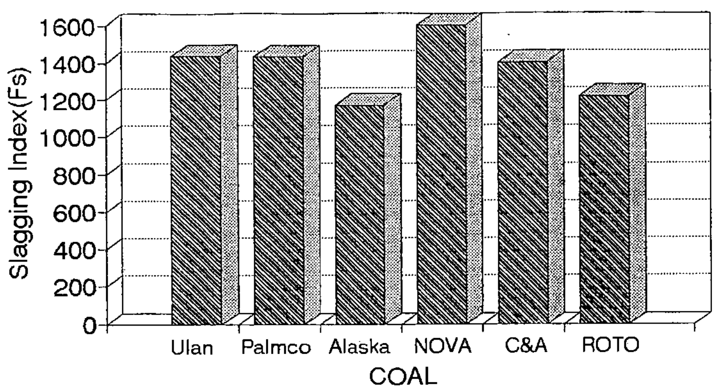

Fig. 2. Slagging Index (Fs) values of Six Different Coal Samples

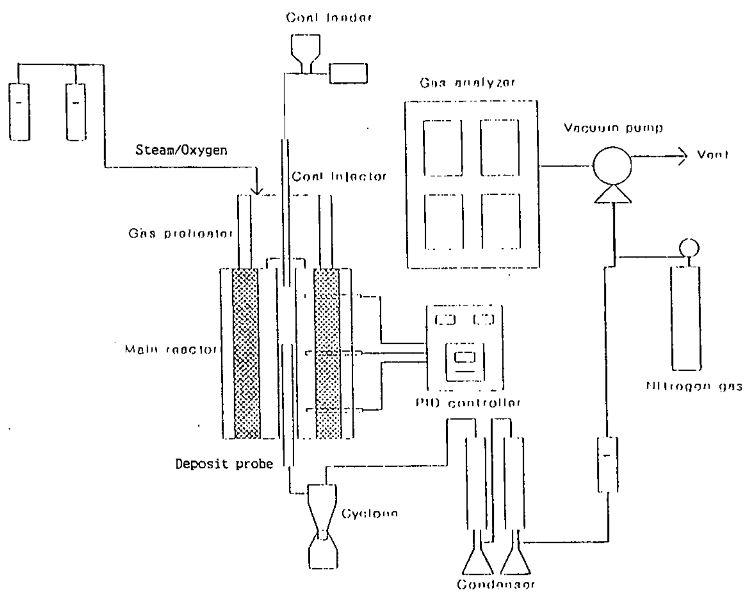

Fig. 3. Schematic Diagram of DTF