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CO-COMBUSTION OF KOREAN ANTHRACITE WITH VARIOUS FUELS IN A COMMERCIAL CIRCULATING FLUIDIZED BED BOILER

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ABSTRACT

The effect of co-combustion of various fuels such as bituminous coal, imported anthracite, RDF and wood pellet with Korean anthracite on the combustion and environmental performance was observed in the commercial CFB boiler. The temperatures in the furnace and cyclones exits decreased with increasing the co-combustion ratio of the bituminous coal, which could achieve more stable operation of the CFB boiler. During Co-combustion of the RDF and wood pellets, the temperature of the furnace exit increased slightly with due to volatiles re-combustion which could restrict to increase the co-combustion ratio of the RDF and wood pellets in the CFB boiler. It was limited for the electrostatic precipitator (EP) to maintain the stable operation above 5% of the RDF co-combustion ratio according to decrease of the output voltages of the EP collecting plate. High content of CaO in the RDF and the wood pellet made the required limestone flow rates decrease. The emissions NOx, HCl and dioxin during co-combustion of the RDF and wood pellets did not change appreciably when compared with firing only Korean anthracite, which were also low enough to meet Korean regulation limits. On the other hand, chlorine content in the ashes emitted from the boiler increased gradually with increasing the RDF co-combustion ratio because of absorption by limestone. The co-combustion of various fuels with Korean anthracite in the commercial CFB boiler was found to be of great use up to a certain co-combustion ratio of each fuel without the technical and environmental problems.

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INTRODUCTION

Recently, interest in the efficient fuel utilization for the electric power generation has been increased since almost energy consumption in Korea is dependent on imported energy resources. Moreover, due to the increase of oil and gas prices, the fuel utilization technology is more important. One of the successful technologies of the fuel utilization is a circulating fluidized bed combustion because it is capable of burning various fuels such as refuse derived fuel (RDF), biomass, sludge and municipal waste as well as low quality coals. Besides, the reduction of CO_2 emission during the combustion of biomass and wastes resources as well as the ease control of SO_2 and NOx without additional facilities is an attractive environmental performance of the CFB technology [1-2].

Korea East West Power Company which is one of the subsidiaries of Korea Electric Power Corporation (KEPCO) have two units of the CFB boilers (2 x 200MWe) which have been operated successfully since 1998 in spite of using low quality Korean anthracite. However, the utilization of the CFB boiler has been gradually restricted because of the insufficient production and supply of the anthracite. Therefore, the fuel diversification in the CFB boiler is expected to improve the utilization factor and the environmental performance [3-4].

A large number of researches have been accomplished to understand and analyze the effect of co-combustion of various fuels on the combustion stability, the operational performance, the qualities of the ash and the emission of pollutants etc in the CFB and FB combustors [5-9]. In according to these results, the potential problems of co-firing of various fuels in the CFB boiler could be found to be the corrosion of heat transfer tubes, the qualities of the ash, and the emission of pollutants. However, the factors such as flue gas emission, fouling or bed sintering tendency were seldom simple linear functions of the fuel mixture. This may be the difference of the properties among fuels as well as the difference of each CFB system and operation condition.

Therefore, in this study, the effect of the co-combustion of various fuels such as bituminous coal, imported anthracite, RDF and wood pellet with the anthracite on the commercial CFB performance, the qualities of the ash and the emission of pollutants was investigated.

EXPERIMENT

The CFB boiler used in this study was shown in Fig. 1 in which commercial scale co-combustion tests were carried out. The CFB boiler consists of a furnace (19m-W x 8m-L x 32m-H), three cyclones and loopseals, three fluidized bed heat exchangers and a fluidized bed ash cooler (FBAC). As all fuel feed points were aligned on the furnace front wall, the rectangular geometry was chosen to allow for good fuel mixing. Limestone was injected with the fuel in the fuel feed chutes and was also introduced in two injection ports along the rear wall. Bottom ash was removed from the furnace via two ash control valves (ACV) and then was introduced into the FBAC which contains economizer and cooling water heat transfer tubes. Most entrained and elutriated particles were captured by three cyclones and were returned to the furnace, passed through the loopseals. Fly ash was captured by an electrostatic precipitator (EP) which consists of 2-channels and 5-stages collecting

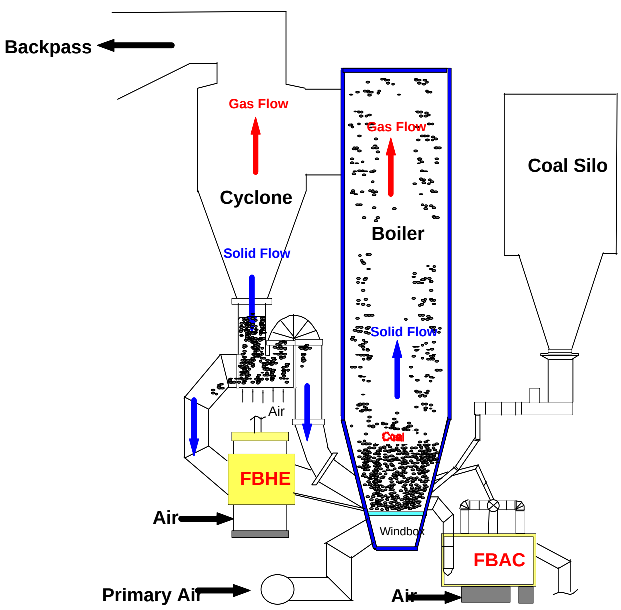


Fig. 1. CFB boiler feature

plates.

For the transfer of the RDF and wood pellets to fuel silos without passing through coal crusher which made them spread out and consequently deposited to a coal screen, a separate hopper and a conveyor belt bypassing the crusher were installed.

The analyses of various fuels and the co-combustion conditions used in this study are shown in Table 1 and Table 2 respectively.

Table 1. Analyses of various fuels used for co-combustion experiments.

Property	Korean Anthracite	Bituminous Coal	Imported Anthracite	RDF	Wood Pellet
Proximate analysis (wt.%)					
Moisture	4.1	2.37	1.7	1.58	8.39
VM	7.3	30.17	9.92	62.28	72.68
Fixed carbon	56.16	52.06	51.35	5.11	16.90
Ash	32.44	15.40	37.03	31.03	2.03
Ultimate analysis (wt.%, dry basis), HHV (as received basis)					
Carbon	63.15	71.33	57.47	39.15	48.90
Hydrogen	0.73	4.54	2.45	5.13	6.27
Oxygen	1.45	5.94	0.97	24.01	42.28
Nitrogen	0.28	1.57	0.79	0.11	0.21
Sulfur	0.57	0.65	0.45	0.08	0.16
Ash	33.82	15.97	37.87	31.52	2.18
Chlorine	-	-	-	0.79	-
HHV(kcal/kg)	4,599	6,844	4,918	4,182	4,226
Ash analysis (wt.%)					
SiO_2	53.31	54.89	56.70	67.08	27.89
Al_2O_3	31.72	24.46	28.74	7.44	12.15
Fe_2O_3	4.79	9.65	4.95	1.58	6.06
CaO	0.76	2.57	0.50	10.71	32.02
MgO	0.61	1.40	1.08	1.90	3.21
Na_2O	0.27	0.61	0.31	8.50	1.12
K_2O	3.63	2.15	5.24	1.27	12.01
SO_3	0.27	1.50	0.31	0.19	1.55
TiO_2	1.65	0.94	0.88	0.74	0.61
etc	2.99	1.83	1.29	0.59	3.80
Ash IDT (^oC)	1,450	1,314	1,455	1,025	1,257
Size (mm)	<6mm	<6mm	<6mm	<50mm	<50mm

Table 2. Experimental Conditions for co-combustion of various fuels.

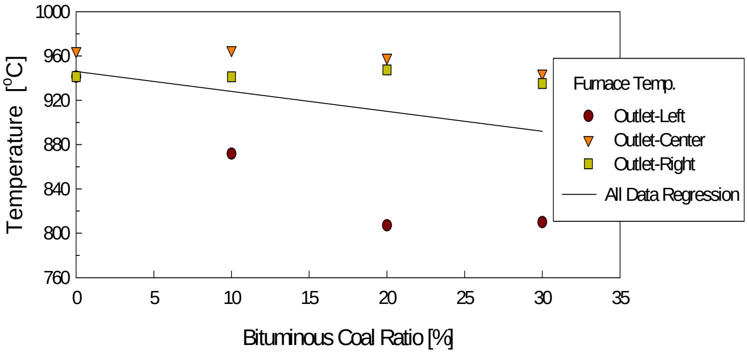
Conditions	Based on Korean Anthracite			
	Bituminous Coal	Imported Anthracite	RDF	Wood Pellet
Power Generation [MWe]	200	140, 180	200	200
Co-Combustion Ratio [%]	0~60	0~75	0~5	0~5
Coal Flow Rate [t/h]	84~86	71~89	98~104	103~107
Limestone Flow Rate [t/h]	5.8~6.2	3.9~6.9	4.7~7.6	5.3~6.5
Total Pressure Difference [mmH_2O]	1,560	1,500 1,600	1,500	1,500

RESULTS

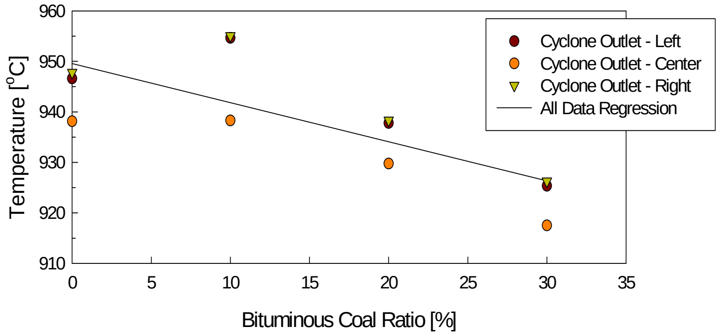
Effect on the CFB boiler performance

The change of the temperature in the commercial CFB boiler makes it possible to analyze the stability and combustibility of the co-combustion of the various fuels. Moreover, the operation of this CFB boiler can be restricted by the increase of the temperatures of the furnace and cyclone exits because of low combustion reactivity of the Korean anthracite [4,10].

The effects of the co-combustion ratio of the bituminous coal on the temperatures of the furnace and cyclone exits are shown in Fig. 2 (a) and (b). It can be observed that the temperatures of the furnace and cyclone exits decreased with increasing the bituminous coal ratio. This is why the combustion reactivity of the bituminous coal is better than that of the anthracite due to higher content of volatile matter. Therefore, it could be found for the operation stability of the CFB boiler to increase with increasing the co-combustion ratio of the bituminous coal.



(a) furnace



(b) cyclones

Fig. 2. Effect of co-combustion ratio of bituminous coal on the furnace and cyclone exits temperatures

However, as shown in Fig. 3, the temperature of the cyclone exit did not change appreciably and the temperature of the furnace exit increased rather than decreased with increasing the co-combustion ratio of the wood pellet which contains much higher volatile matter than that of the bituminous coal. This trend could be also observed when the RDF was co-fired with the anthracite. It seems that the combustion of the volatile matter occurred in the freeboard of the furnace because of low density of the RDF and wood pellets and because of easy fragmentation of the pellets although the size of them was larger than anthracite. Therefore, the temperature increase during co-combustion of the RDF and wood pellets makes it possible to restrict the increase of the co-combustion ratio of them for stable operation of the CFB boiler.

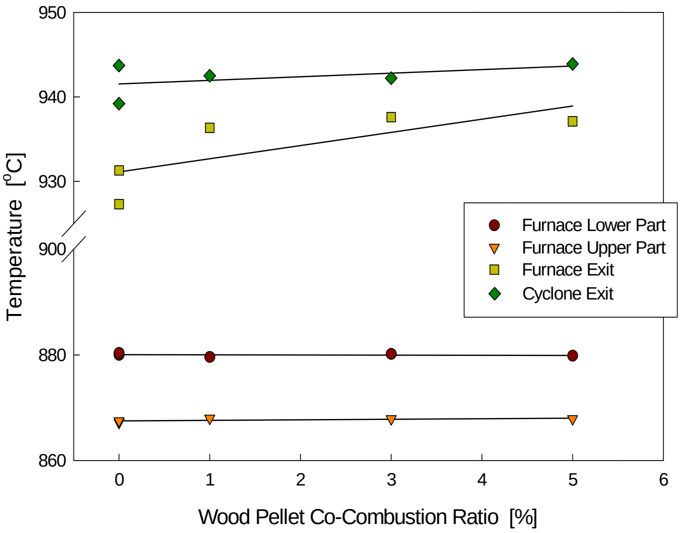


Fig. 3. Effect of co-combustion ratio of wood pellet on temperature profiles

On the other hand, the pressures along the CFB combustor during the co-combustion of the various fuels were measured at 0.9m (P1), 5.2m (P2) and 28.5m (P3) above the distributor and in the windbox (P0) [Ref]. Upper part pressure drop was a difference between P2 and P3, and the differences between P1 and P3 and between P0 and P1 were middle and lower part pressure drops, respectively. Total pressure drop (P0-P3) including distributor pressure drop was kept at a constant value via controlling the ACV of the furnace. The differential pressures along the furnace did not change appreciably when the imported anthracite and the bituminous coal were co-fired with Korean anthracite due to the similar size distribution. However, the differential pressures of the middle and lower parts changed during the co-combustion of the RDF and wood pellets with Korean anthracite. The pressure drop of the lower part decreased and the pressure drop of the middle part increased with increasing the co-combustion ratio of the RDF and wood pellets. This means that the RDF and wood pellets of which sizes are larger than that of Korean anthracite contributed to play a role in the fluidizing bed media of the middle part of the furnace rather than lower part of the furnace, because not only the pellets have lower density than the anthracite, but also the pellets were fragmented and cracked as soon as fed to the furnace due to high volatile content.

In the case of the RDF co-combustion, the performance of the EP was changed as shown in Fig. 4. As the RDF co-combustion ratio was increased up to 5%, the output voltages of 1, 2 stages of the EP decreased significantly to the EP trip condition. The decrease of the output voltages of 1, 2 stages could be derived from changing the dust resistivity and the composition of flue gas due to high content of SiO_2, CaO and MgO and low moisture content in the RDF. Therefore, the increase of the RDF co-combustion ratio should be restricted up to 5% for the stable operation of the CFB boiler. However, in spite of the output voltages drop, as the co-combustion ratio of the RDF increased to 5%, there was no problem of the overall performance on the EP according to keeping up the dust emission from the stack of the CFB boiler with an usual operation range (3.3 ~ 4.3 mg/m^3).

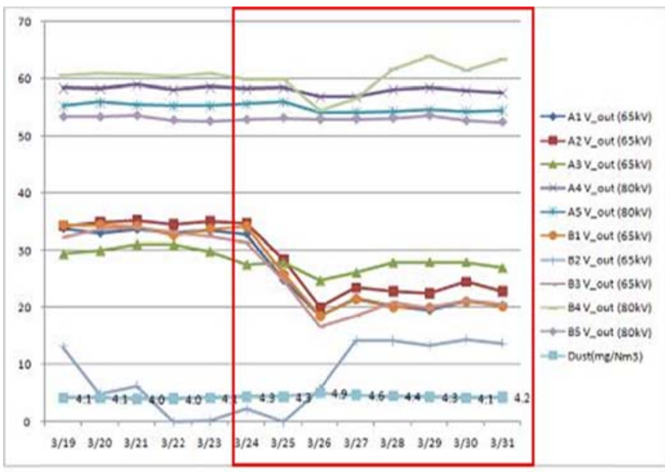


Fig. 4. Effect of co-combustion ratio of RDF on EP performance of the CFB boiler

Effect on the environmental performance

To analyze the environmental influence, the emissions of HCl and dioxin as well as SO_2 and NOx were measured during the co-combustion of the various fuels. The effect of the co-combustion ratio of the wood pellet on the emissions of SO_2 and NOx was shown in Fig. 5. In the operation of this CFB boiler, to meet a certain desired emission value of SO_2 (80ppm), the feeding rate of the limestone was controlled automatically. So, the emission of SO_2 was not changed appreciably. Instead, the limestone feeding rate was somewhat decreased with increasing the co-combustion ratio of the woo pellet. This may be caused by low fraction of S and also by high fraction of CaO in the wood pellet when compared to the anthracite. In the case of NOx emission, its concentration in the flue gas did not change in spite of low fraction of N in the wood pellet. It may be the reason that O_2 and volatile matter concentrations of the wood pellet was so high that N in the fuel could react easily with O_2. However, NOx emission could not affect the environmental performance of the CFB boiler with increasing the wood pellet co-combustion ratio. The similar trend could be also observed in the emissions of SO_2 and NOx during the co-combustion of the RDF. On the other hand, the emission of NOx increased with increasing the bituminous coal ratio, which seemed that NOx emission would restrict to increase the co-combustion ratio of the bituminous coal.

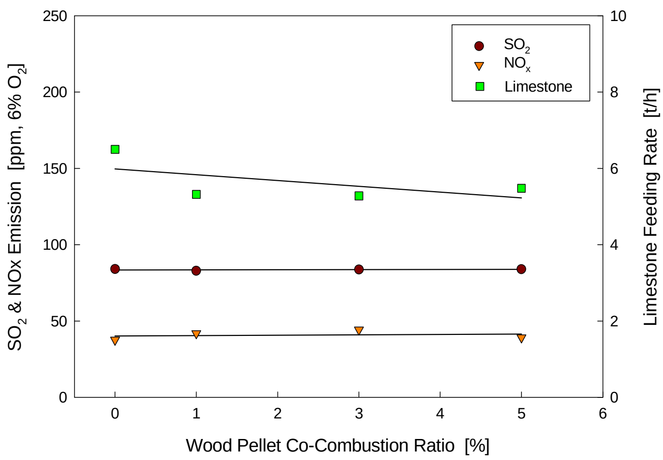


Fig. 5. Effect of co-combustion ratio of the wood pellet on SO_2 and NOx emissions

Chlorine compounds in the RDF are very important factors for HCl generation as well as dioxin synthesis. It is known that HCl causes corrosion of the boiler equipments as well as air pollution. HCl formation is a complex process, involving the availability of chlorine, the source of hydrogen, and the competitive affinity of heavy metals. Generally, the reactive affinity between hydrogen and chlorine is stronger than that between the heavy metals and chlorine [11]. The emission of HCl in the flue gas which was measured at the air preheater and was analyzed by ion chromatogram (IC), increased slightly. However, it was small enough to neglect the influence of the RDF co-combustion ratio. On the other hand, as the amount of chlorine in the RDF increased, the amount of chlorine of the ash from the CFB also increased. This is the reason of the absorption of HCl with the limestone which was fed into the CFB boiler for SO_2 capture. This indicates that the limestone did

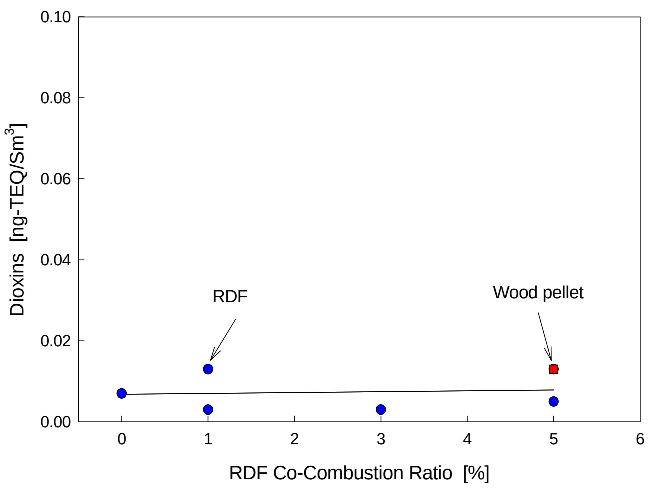


Fig. 6. Effect of co-combustion ratio of RDF and wood pellet on dioxin emission

play an important role in the capture of HCl emitted by organic chlorine from the RDF. However, the overall mass balance of chlorine could not be achieved exactly, because not only HCl removal by limestone is a complex process affected by flue gas temperature, absorbent quality, particle size and gas atmosphere but also HCl in the flue gas can react with heavy metals and corrode the boiler tubes [12].

Dioxin emission during the co-combustion of the RDF and wood pellets was measured at the stack of the CFB boiler, and was shown in Fig. 6. The dioxin concentrations with increasing the RDF and wood pellet co-combustion ratios up to 5 % were far below Korean regulation limit (0.1 ng-TEQ/Sm^3) although chlorine in the RDF was so high. It was also no correlation with the RDF and wood pellet co-combustion ratio. The chlorine could not be found to affect the formation of a dioxin precursor with increasing the RDF co-combustion ratio because most chlorine was absorbed by limestone in the CFB furnace.

The eluted amount of heavy metals in the fly and bottom ashes during the co-combustion of the RDF and wood pellets was analyzed. Because the quality of the RDF and wood pellet was regulated when they were produced, the eluted amount of heavy metals in the fly and bottom ashes was low enough to meet Korean permissible concentration level. Therefore, as the co-combustion ratio of the RDF and wood pellet was no more than 5%, the influence of heavy metals in the ashes could be neglected.

In the viewpoint of the efficiency improvement, the power generation per coal flow rate based on heating value of the coal fed is smaller than that of actual power generation per coal flow rate with increasing the bituminous coal ratio during co-combustion. It means that the actual power generation is bigger than that of theoretical power generation. This may be from improvement of the combustion reactivity of Korean anthracite through the co-combustion with the bituminous coal [3]. Also, this efficiency improvement could be observed during the co-combustion of the wood pellet. Therefore, the co-combustion of the high volatile fuels with Korean anthracite in the CFB boiler can improve the combustion efficiency through improvement of the combustion reactivity of Korean anthracite.

CONCLUSIONS

Co-combustion tests were carried out with various fuels in the commercial CFB boiler firing Korean anthracite. The effects of the co-combustion ratio of the fuels on the CFB boiler performance and on the environmental performance were investigated. The main conclusions drawn from the present work can be given as follows:

- The temperatures in the furnace and cyclone exits decreased with increasing the bituminous coal ratio, which could achieve more stable operation of the CFB boiler, whereas the temperature in the furnace exit increased slightly with increasing the co-combustion ratio of the RDF and wood pellets due to volatiles re-combustion which could restrict to increase the co-combustion ratio of the RDF and wood pellets.
- The operation of the electrostatic precipitator could be restricted at more than 5% of the RDF co-combustion ratio according to decrease of the output voltages of the EP collecting plates.
- The limestone flow rate decreased gradually at the constant emission of SO_2 due to high content of CaO in the RDF and wood pellets, and NOx emission did change appreciable with increasing the co-combustion ratio of the RDF and

wood pellets.

◆ The eluted amount of heavy metals of the ashes was far below Korean maximum permissible concentration level during the co-combustion of the RDF and wood pellets. Also, the emissions of HCl and dioxin were low enough to meet Korean regulation limits as the co-combustion ratios of the RDF and wood pellets are no more than 5%. This may be the reason that most chlorine was absorbed by limestone in the furnace.

◆ The co-combustion of various fuels with Korean anthracite in the commercial CFB boiler was found to be of great use up to a certain co-combustion ratio of each fuel without the technical and environmental problems.

REFERENCES

[1] Koornneef J, Junginger M, Faaij A. Development of fluidized bed combustion-an overview trends, performance and cost. Progress in Energy and Combustion Science 2007; 33: 19-55.

[2] Hupa M. Interaction of fuels in co-firing in FBC. Fuel 2005; 84: 1312-1319.

[3] Kim DW, Lee JM, Kim JS, Kim JJ. Co-combustion of Korean anthracite with bituminous coal in two circulating fluidized bed combustors. KJChE 2007; 24: 461-465.

[4] Lee JM, Kim JS, Kim JJ. Evaluation of the 200MWe Tonghae CFB boiler performance with cyclone modification. Energy 2003; 28: 111-118.

[5] Pandelova M, Lenoir D, Schramm KW. Correlation between PCDD/F, PCB and PCBz in coal/waste combustion. Chemosphere 2006; 62:1196-1205.

[6] Gulyurtlu I, Crujeira AT, Abelha P, Cabrita I. Measurements of dioxin emissions during co-firing in a fluidized bed. Fuel 2007; 86: 2090-2100.

[7] Stanmore BR. The formation of dioxins in combustion systems. Combustion and Flame 2004; 136: 398-427.

[8] Hernandez, FD, Ryu CK, Sharifi VN, Swithenbank J. Combustion of refuse-derived fuel in a fluidized bed. Chem. Eng. Sci.2007; 62: 627-635.

[9] Kupka T, Mancini M, Irmer M, Weber R. Investigation of ash deposit formation during co-firing of coal with sewage sludge, saw-dust and refuse derived fuel. Fuel 2008; 87: 2824-2837.

[10] Lee SH, Lee JM., Kim JS, Choi JH, Kim SD. Combustion characteristics of anthracite coal in the Tonghae CFB boiler. Hwahak konghak 2000; 38: 516-522.

[11] Chiang KY, Jih JC, Lin KL. The effects of calcium hydroxide on hydrogen chloride emission characteristics during a simulated densified refuse-derive fuel combustion process. J. of Hazardous Materials 2008; 157: 170-178.

[12] Lee JM, Kim DW, Kim JS, Na JG, Lee SH. Pollutant generation on RDF/coal co-combustion ratio in a commercial circulating fluidized bed boiler. J. of Korean Soc. of Waste Management 2009; 26: 596-601.

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