Comparison of Circulating Fluidized Bed Boiler (CFB) and Pulverized Coal-fired Boiler (PCB) Technologies

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ABSTRACT

After the accident of nuclear power plants in Fukushima, Japan, globally coal power plants has growing demand and number of new-built coal power plants has established. CO2 emissions are increased with the increasing of new coal power plants. The United States, which has 1,100 coal ash sites, produces 140 million tons of coal ash from coal-fired power plants every year. To reduce the landfill of coal ash, many countries have undertaken recycling of coal ash as key resources for recovery valuable critical rare earth elements and utilize the coal ash as construction material. One of our objectives was to evaluate the characteristics of hazardous heavy metals particularly mercury, arsenic, chromium and lead presented in coal combustion products (coal fly ash and bottom ash) from coal-fired power plants. The aim of this research was to identify and compare the technologies between Circulating Fluidized Bed Boiler (CFB) and Pulverized Coal-fired Boiler (PCB). In this study, coal and coal ash samples from different areas (Indonesia, Japan and Korea) are used for the evaluation of heavy metals concentration.

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KEYWORDS: Toxic Hazardous Heavy Metals, Heavy Metals Origin with Coal, Removal of Heavy Metals from Coal Ash

INTRODUCTION

Global energy demand is expecting to grow by 37% by 2040 and energy consumption will increase 56% by 2040.[1] The global distribution of energy demand changes more dramatically, with energy use essentially flat in much of Europe, Japan, Korea and North America, and rising consumption concentrated in the rest of Asia (60% of the global total), Africa, the Middle East and Latin America (Fig 1). By 2040, the world energy consumption and supply mix and divides into four almost equal parts: oil, gas, coal and other low carbon sources. Combined with increased electricity demand and advancements in electrical generation technology, the abundant supply of coal reserves and its low cost have led to a rise in coal demand.[2] Looking at total global coal production by year, coal consumption rose from 4677Mt in 1990 to 7608 Mt in 2011, and to 7830Mt in 2012.[3]

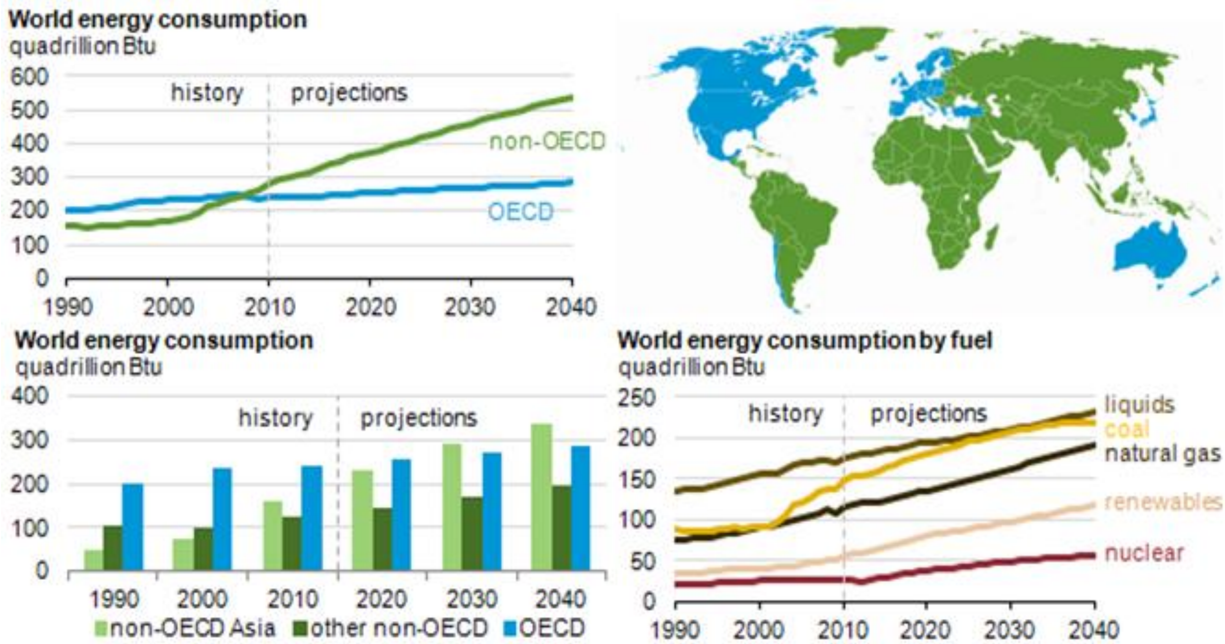

Fig 1. EIA Projects World Energy Consumption

In order to address the above problems, countries around the world are working to develop technologies for environmentally friend coal-fired power generation. Examples of such environmentally friendly and highly efficient coal-fired power generation technologies include ultra supercritical pulverized coal-fired power generation (USC-PC), integrated gasification combined cycle (IGCC), and pressurized fluidized bed combustion (PFBC) (Fig 2).[4]

Highly efficient, environmentally friendly and high capacity 600℃ grade ultra supercritical coal-fired power plants have been in commercial use in developed European countries and Japan since the 1990s, based on research and development going back to the 1980s. Current research in Korea is focused on the development of highly efficient, high capacity and environmentally friendly technologies.[5]

This study is carried out in the context of the growing use of low rank coal alongside the development of environmentally friendly coal-fired power generation technologies in Korea. It provides an overview of the current situation of power generation in Korea. As Korean researchers are working to develop fluidized bed boilers as a next generation technology with high efficiency, this study compares the characteristics of the fluidized bed boiler and the pulverized bed boiler in order to offer a better understanding of the developments in this field.

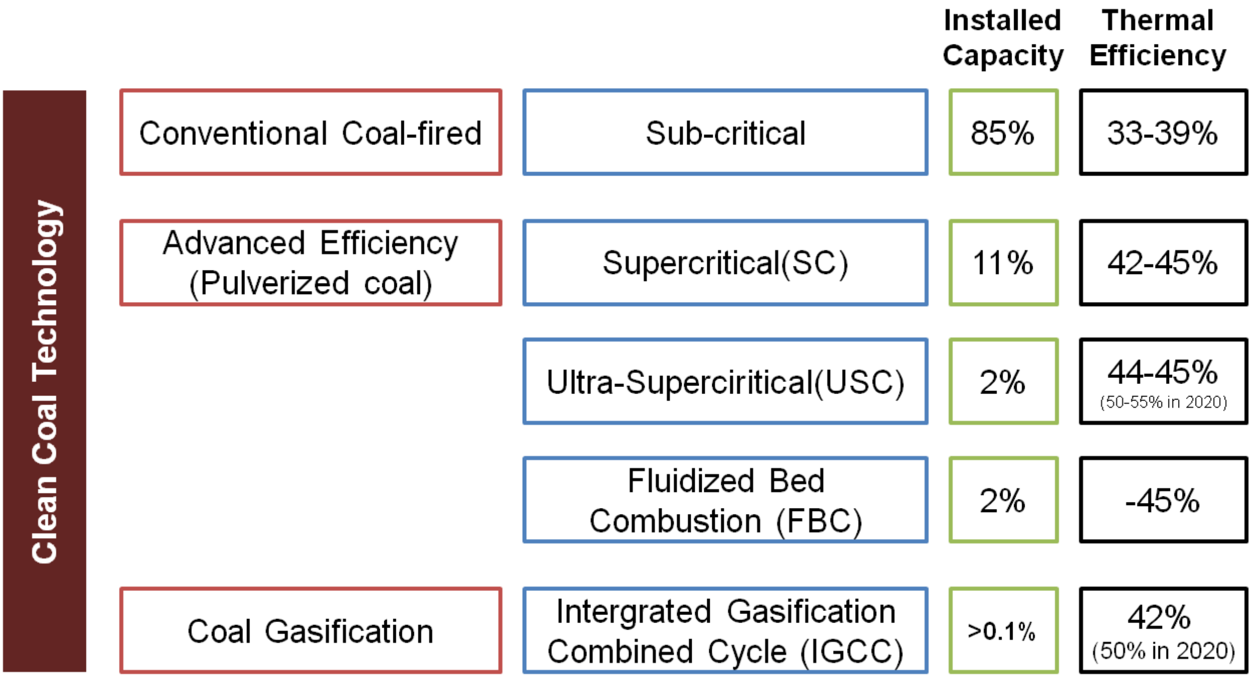

Fig 2. Clean coal technologies for Coal-fired power generation with installed capacity and thermal efficiency.

1. COAL-FIRED POWER PLANTS SITUATION IN SOUTH KOREA

Since the restructuring of the electricity market in 2001, power companies have been working to combat increased competition by reducing the cost of raw materials, which takes up the largest proportion of costs involved in coal-fired power generation.[6] Following fuel price fluctuations in 2007 and 2008, power companies greatly increased the proportion of low rank coal in fuel imports in order to lower costs and this has since been a continuing trend. Amid rising oil prices in the global energy economy, fluidized bed combustion is generally seen as the most appropriate technology to achieve environmentally friendly energy consumption and highly efficient combustion of the low rank anthracite used in domestic power plants.[7] In South Korea, the construction of coal fired power plants trends increased (Fig.3).

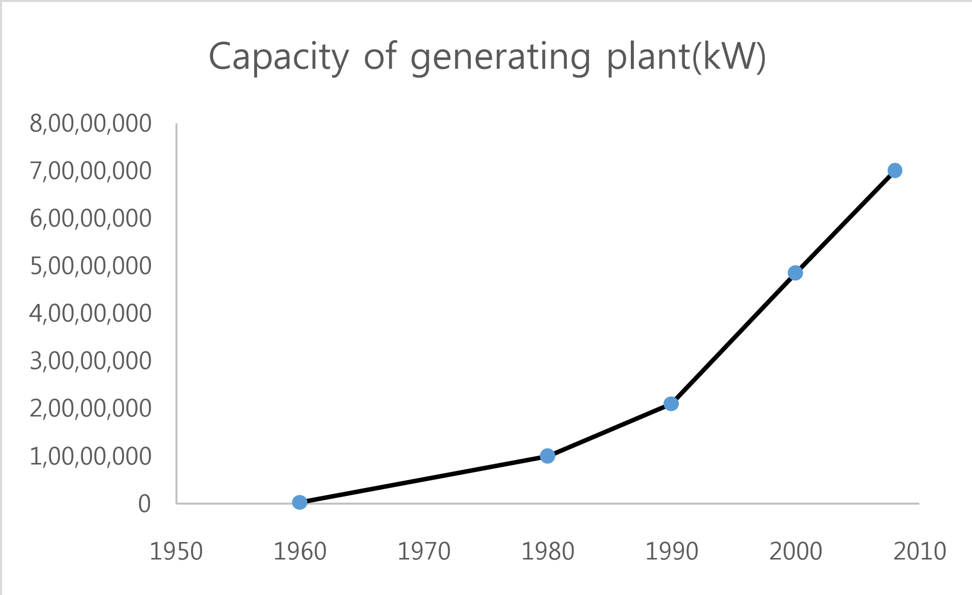

Fig 3. Increased trends of construction of Coal-fired power plants in South Korea

Demand for electric power in South Korea is increasing in line with the country's economic growth. Dmnd is seen continuing to grow going forward, and plans have been made for the construction of new power plants to increase the country's current 76 GW of total power generation capacity by 24 GW by 2020. South Korea aims to have enough renewable energy facilities to generate 32,020 MW, or 20% of overall power generation, by 2027. That's an increase from 11.4% target set in 2010 when the government mapped out its last energy supply plan.

2. THE TYPES OF COAL-FIRED POWER PLANTS AND THE CHARACTERISTICS OF COAL COMBUSTION PRODUCTS

2.1. COAL-FIRED POWER PLANTS: COMPOSITION OF PULVERIZED COAL COMBUSTION AND FLUIDIZED BED COMBUSTION

Pulverized coal combustion is the most widely-used technology in coal-fired power generation,[7] mostly found in high capacity thermal power plant boilers. The advantages of pulverized coal combustion boiler are that it operates at atmospheric pressure and materials travel through the plant via simplified routes.[8] However, pulverized coal combustion is inferior to fluidized bed combustion when it comes to efficiency and economy of operation. This is because the combustion constraints of low grade fuel necessitate the use of supplementary fuels (oil) to produce flames.

The unique combustion principle of fluidized bed combustion can better overcome the limitations of coal compared to traditional coal combustion technologies. The technology allows for a wider range of fossil fuels to be used with higher efficiency in power generation, thus reducing fuel consumption.

In fluidized bed combustion, jets of air are blown through the bottom of a layer made of inactive particulate materials such as lime, coal ash, and sand. This leads to the formation of a fluidized bed of particulate materials moving up and down. Flammable materials such as coal are combusted within this fluidized bed. Common types of fluidized bed boilers include the bubbling fluidized bed boiler, the circulating fluidized bed boiler, and the pressurized fluidized bed boiler. The speed of fluidization increases in the order of bubbling fluidized bed → circulating fluidized bed → air stream transfer.[9] The circulating fluidized bed boiler is composed of a circulating fluidized bed combustion chamber, a high temperature ash separation device (cyclone or impact separator, etc), a device to return particles back to base (loop seal, L-valve, etc), and depending on the boiler type, an external fluidized bed heat exchanger and fuel feeder (Fig 4).

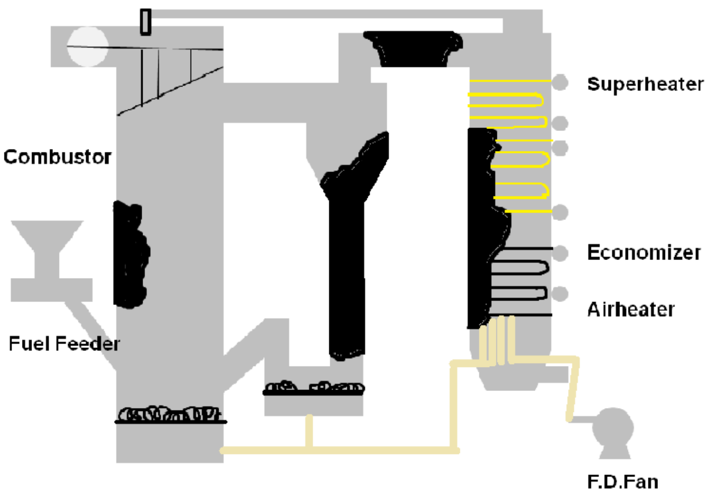

Fig 4. Conceptual Diagram of Fluidized Bed Boiler, Ref: Korea Institute of Energy Research

The main advantages of the fluidized bed boiler are listed in the table below.

- As fuel is surrounded by inactive materials (coal ash, limestone, sand, etc), combustion is not affected by changes in fuel type, water content, and ash content. Thus lower rank fuels unsuitable for existing combustion boilers can be used.
- Temperatures within the combustion chamber remain relatively low at 750~950℃ compared to existing combustion boilers, thus producing lower NOx emissions.

- The fluidization of solid particles minimizes obstruction from slagging, allowing the heating surface to remain clean and eliminating localized thermal stress.
- When using high sulfur content fuels, limestone can be introduced in the combustion process to eliminate 90% of SOx emissions.

2.2. THE PRODUCTION PROCESS AND THE CHARACTERISTICS OF COMBUSTION PRODUCTS FROM COAL-FIRED POWER PLANTS

The process of coal combustion in coal-fired power plants can be divided into three stages (Fig 5). The first step consists of applying heat to coal and the emission of volatile materials. The second and third steps consist of burning the emitted volatile materials and the remaining char. Thus, coal combustion products such as fly ash, bottom ash, boiler slag, fluidized bed combustion (FBC) ash, or flue gas desulphurisation (FGD) material are produced from coal-fired power plants.

Major minerals in coal consist of four mineral groups – aluminosilicates (mainly Kaolinite), oxides (quartz SiO_2 and hematite Fe_2O_3), carbonates (calcite $CaCO_3$, syderyt $FeCO_3$, and dolomite $CaCO_3MgCO_3$), and sulphur compounds (pyrite FeS_2, gypsum $CaSO_42HeO$). Major elements in coal combustion products are SiO_2, Al_2O_3, Fe_2O_3, and CaO [9], which correspond to the mineral composition of coal. Thus it can be seen that the composition and properties of coal ash originate from raw coal.[10]

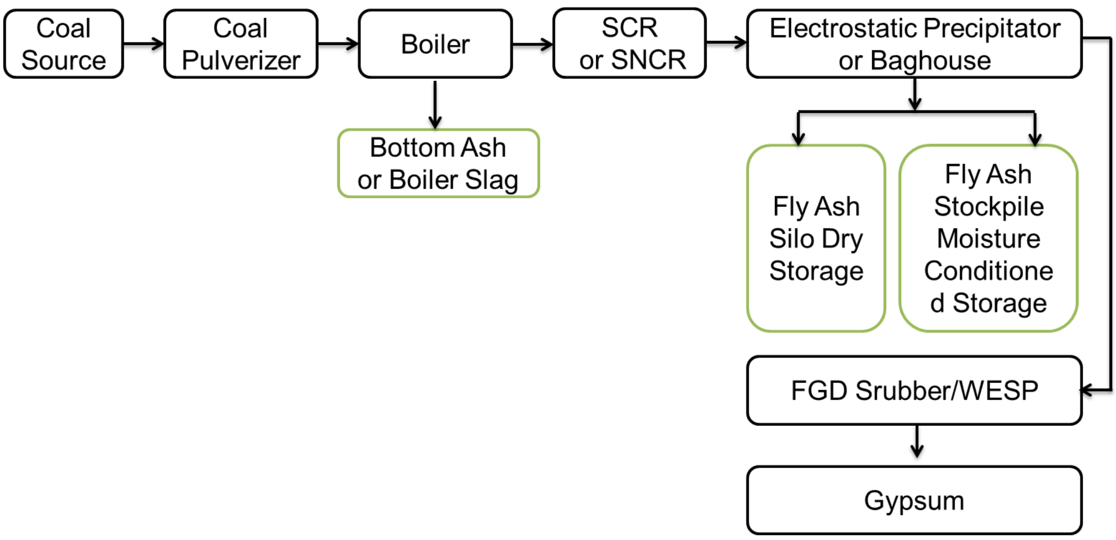

Fig 5. General Ash Generation Process in a Coal fired power plant

3. THE OCCURRENCE AND BEHAVIOR CHARACTERISTICS OF HAZARDOUS METALS IN COAL ASH

There are five major parameters that influence collected ash composition in coal-fired power plant waste products. Ruud Meij and Henk te Winkel (2007) identified the five primary parameters and secondary parameters of influencing factors. For the first primary parameter of fuel, the secondary parameters are type and origin of coal, ash content of coal, the stages of peat, industrial and domestic waste, etc. The secondary parameters of the combustion technique are grate boilers, pulverized coal boilers with dry ash removal, pulverized coal boilers with wet ash removal, cyclone boilers, gasification, fluidized bed combustion, fluidized bed gasification, etc. The third primary parameter is temperature and period of residence, with the secondary parameters being during combustion and in the flue gas. The fourth is the type of particle filter, with the secondary parameters of ESPs (high-temperature, low temperature, dry and wet systems), cyclones, baghouses, wet systems, and filter efficiency. The last primary parameter is other flue gas clean-up systems with secondary parameters of deNOx, carbon injection, etc. Among the above parameters, the parameters that have the greater impact on the heavy metal concentration in coal-fired power plant products is the type and origin of coal and the stage of peat, while the other parameters have supplementary effects. Thus, there is a direct relationship between the concentration of heavy metals in atmospheric power plant ash emissions and heavy metal content in raw coal.

With the passing of the Clean Air Act of 1990, the U.S. Environmental Protection Agency (USEPA) conducted a study on 15 elements out of the 120 elements of coal (Be, K, Cr, Mn, Co, Ni, As, Se, Cl, Cd, Sb, Hg, Pb, Th, U) as potential Hazardous Air Pollutants (HAPs), drawing the conclusion that out of the 15, Hg and As are causes of human health problems. Trace elements within coal are emitted during the combustion process in bottom ash, fly ash, and flue gas.

Most heavy metals have high boiling points and thus are emitted as solid particles in bottom ash or fly ash, being easily eliminated in air pollution prevention facilities for particulate materials.[11] However, mercury has high volatility and a low boiling point, and thus exists in a gas form within gaseous emissions.

4. CONCLUSION

Pulverized coal combustion (PCC) has maintained a dominant role in power generation from coal, and currently represents over 90% of global capacity. Circulating fluidized bed combustion (CFBC) is a more recent boiler technology whose higher tolerance to fuel quality has favored niche application in small-scale and industrial power generation, often firing unconventional fuels such as waste coal and biomass. Countries all over the world endeavor to find the solution by recycling the waste or developing technologies for eco-friendly coal-fired power generation including USC-PC, IGCC, and PFBC. In particular, fluidized bed boiler has shed new light recently with several advantages from the viewpoint of the possibility to use lower rank fuels, operating at low temperature, economic and environmental feasibilities.

With overviewing the current situation of power generation in South Korea, this study identified and compared two major boiler technologies.

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