Performance Analysis of Supercritical Coal Fired Power Plant Using gCCS Simulator

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ABSTRACT

Capturing the carbon dioxide emitted from coal-fired power plants will be necessary if targeted reduction in carbon emissions is to be achieved. Modelling and simulation are the base for optimal operation and control in thermal power plant and also play an important role in energy savings. This study aims to analyze the performance of supercritical coal fired power plant through steady and dynamic simulation using a commercial software gCCS. A whole power plant has been modeled and validated with design data of 500 MWe power plant, base and part load operations of the plant were also evaluated, consequently it had been proven that the simulated result had a good agreement with actual operating data. In addition, the effect of co-firng on the plant efficiency and flue gases were investigated using gCCS simulator.

Key words: Plant efficiency, Dynamic simulation, Base and Part load operation, gCCS

Conventional and unconventional fossil fuel will continue to be a source for forseable future. It is also considered that the low carbon resources are increasing as a source of energy now a days. According to IEA analysis, long-term global average temperature increases are limited to significantly less than 4℃ particularly, around 2 ℃ scenarios[1]. Even if there is a slight decrease in use of fossil fuel within last decade, fossil fuel will continue its share as it is. On the other hand, the demand of co-firing obligation ratio will increase from the 3% to 10 % up to 2022 [3]. In general the commitment of the 30% green house gas (GHG) reduction below business as usual (BAU) by 2020 [2] is based on renewable energy resource such as biomass as a partial replacement of fossil fuel and reducing the emission gases. Biomass co-firing biomass with fossil fuels in exiting boiler is a feasible technology which can significantly reduce the CO_2 emissions but there are some limitation during biomass milling in terms of energy consumption. There is extensive literatures dealing with integration of power plant and capture process. A range of power plant is considered specifically in the development of expression to quantify specific energy penalty imposed up on the power plant by the capture plant and pulverizer mill energy consumption [4]. In this contribution we perform the steady and dynamic operation of a coal fired power plant with 500 MWe power generation integrated with co-firing of different biomasses using a commercial software(gCCS). Validation of simulation and design data is performed. The effect of ramping the power plant from maximum stable generation to the part load operation on the varies operating parameter was investigated which is very important analysis in the carbon dioxide capture. In addition the flue gas produced and plant efficiency on co-firing of selected five kinds of biomasses have been investigated. The unit of 500 MWe supercritical power plant is selected for the modelling study. The schematic view of gCCS model on coal fired power plant is shown in Fig 1. Feed water from the last heater in water/steam side is heated in the economizer before entering the superheating stages through the water wall.

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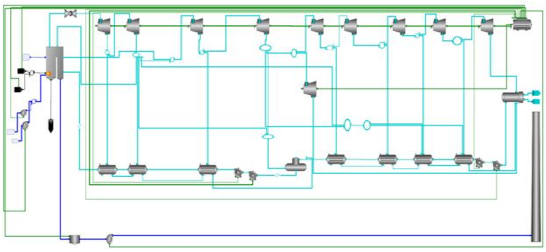

Fig. 1 The schematic gCCS model coal fired power plant process flow diagram.

The super heater consists of three sections: Primary super heater, secondary super heater and platen super heater. The main steam outlet is about 541 ℃ at steady state and the a pressure is 24.91 MPa. There are two reheating sections (primary reheater and secondary reheater) in the boiler for reheating the reduced thermal energy steam exhausted from high pressure turbine stages. The inlet and outlet temperature of the reheater is 279 ℃ and 541 ℃, respectively. The outlet pressure is also around 3.6 MPa. Finally, the power is generated through multi-stage turbines. The plant consists of primary air draft fan (PA), secondary air draft fan (FD) and induced draft fan(ID). An electrostatic precipitator is used to collect particulate material. The power consumption of each auxiliary unit is helpful to determine net plant efficiency of the plant. The water/steam side consists (2 high pressure, 2 intermediate pressure and 5 low pressure) turbines, a deaerator to deaerate the condensate steam, feed water heaters to preheat the boiler feed water by means of condensing steam, condenser to condense all the steam from the turbines and the four pumps (condensate pump, condensate booster pump, boiler feed pump and booster pump). To evaluate the performance of the plant is modeled and validated using the powerful simulator gCCS (general carbon capture system software).

It is a new product developed for power plant simulation, carbon capture and storage, compression, transportation, injection and storage. It is equation oriented resulting on a numerical solution of all the equation in a model or a flow sheet system. The main equipments included in the model are boiler, turbines, deaerator governor valve, feed water heater, steam condensor and electrostatic precipitator. The auxiliary models were: pumps, blowers (PA, FD and ID), generator, recycle breaker, source coal, source air, source utility (water), sink utility, sink waste (ash), stuck and the junction models. All the models can operate at design and operational mode. In this process simulation for utility fluid (water/steam side) IAPWS-95 steam table is used where as for process fluid (air/gas side) the peng-robinson equation of state is used [4]. Pulverized fuel (design coal), adaro coal (AC) and other biomasses such as wood pellet (WP), Palm kernel shell (PKS), empty fruit Bunch (EFB), wall nut shell (WS) and torrefied biomass (TB) are used as a source of fuel to evaluate the performance of the plant in terms of energy consumption and flue gas production. DC is used for validation of simulation results. The proximate and ultimate analysis of the fuels are shown in Table 1.

Table 1 Proximate and Ultimate analysis of coal and biomasses. (wt % air dry basis)

Fuel	Coal		Biomass				
	DC	AC	WP	PKS	EFB	WS	TB
Moisture	10.3	17.2	8.3	9.8	7.7	9.3	3.1
Volatile matter	42.0	39.2	82.0	59.6	73.5	70.5	62.5
Fixed carbon	46.2	40.8	8.6	14.8	17.8	19.2	33.3
Ash	1.5	2.9	1.1	15.9	1.0	1.1	1.1
Carbon	64.4	57.7	46.8	48.4	47.0	48.5	71.2
Hydrogen	4.7	4.0	5.6	5.7	5.7	7.1	4.6
Nitrogen	0.89	0.98	0.10	1.04	0.28	1.33	0.01
Sulfur	0.088	0.083	0.010	0.014	0.004	0.029	0.010
Oxygen	18.1	17.2	40.7	39.1	46.3	37.2	22.3
Chloride	-	-	0.003	0.018	0.015	-	-
HHV (MJ/KG)	26.2	23.0	18.7	19.3	18.3	21.4	27.9

The power plant model developed in gCCS was validated on steady basis and dynamic basis. The steady state model results were compared with the plant design data is given in Table 2 shows satisfactory agreement.

Table 2 Simulation result of flue gas composition and Auxiliary power consumption.

Flue gas composition (Vol%)	Design data	Simulation
CO_2	14.23	14.2
H_2O	10.62	8.391
O_2	3.19	3.1
N_2	71.95	74.3
SO_2	0.01	0.009
Power consumption(MW)		
Feed water pumps	N.K	18.88
Pulverizer	1.53	2.09
PA fan	1.898	1.868
FD fan	1.11	1.074
ID fan	3.032	3.24
Key performance indicators		
Net Power (MW)		453.99
coal flow rate (kg/s)		52.2
flue gas flow rate rate(kg/s)		544
Net plant efficiency(%)		36.46

N.K: Not Known

The sensitivity analysis made on the model developed indicate that the power generated mainly depends on the boiler efficiency. For an increment of boiler efficiency the power generated varies as shown in the Fig 2. Similarly Coal flow varies from 52.1kg/s to 49.2 kg/s with in this efficiency range.

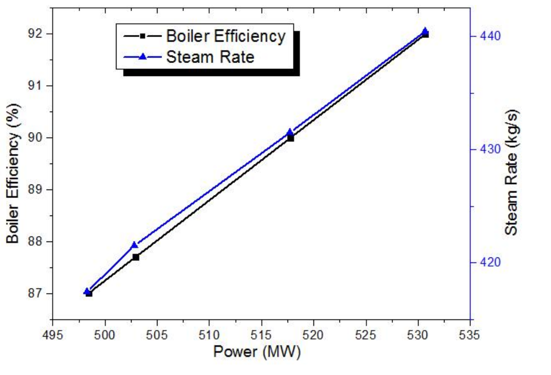

Fig. 2 Power generated and steam flow rate at different boiler efficiency.

As the power station reduces, its power output from a maximum stable generation of 500 MWe to a minimum stable generation (40 % load) set on the simulation study, the overall plant efficiency reduces from approximately 36.46 to 25.76 % in case of the steam flow not varied. As the fuel composition and excess air is assumed constant, the composition of the exhaust gas did not change as the power generated varied. A flue gas comprised of (14.2 % CO_2, 8.39 % H_2O, 3.1 % O_2, and less than 1% SO_2 and the remaining exhausted gas accounted for nitrogen) in volume basis.

The co-firing ratio of each biomasses is based on thermal share input as shown in Table 3. The gross power produced is set to be constant for all co-firing cases, but the net power produced varied due to auxiliary power consumption variation. The net power generated by co-firing of all five selected biomasses are slightly lower than the main fuel (AC) due to the power consumed by the pulverizers in co-firing cases are higher than the power consumed by the pulverizer of the main fuel. This is mainly due to the bond work index of AC is lower than other co-firing cases. The net plant efficiency of TB co-firing case is relatively higher than other biomass co-firing cases of the same thermal share input for similar aforementioned reason.

Table 3 Effect of co firing of biomasses with low rank coal on the power produced.

Fuel	DC	AC	WP	EFB	PKS	WS	TB
Thermal input (MW)	1245 .2	1245 .2	1245 .2	1245 .2	1245. 2	1245 .2	1245 .2
Coal (%)	100	100	90	90	90	90	90
Biomass (%)			10	10	10	10	10
Coal feedrate (kg/s)	52.1	56	50.5	50.5	50.5	50.5	50.5
Biomass feedrate (kg/s)			7.3	7.9	11.5	6.5	4.7
Plant efficiency (%)	36.4 6	36.4 7	36.4 3	36.4 3	36.45	36.4 2	36.4 6

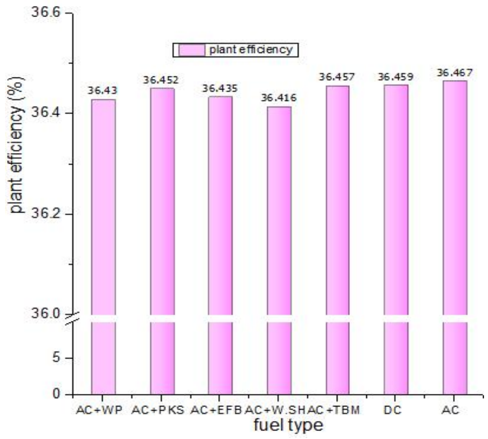

Fig. 3 Plant efficiency in case of co-combustion of different biomass with AC.

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