A Study on the Generation Cost with Carbon Emissions Reduction in Coal-fired Power Plant

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***Abstract* — The power industry is a centralized source of CO_2 emissions. Controlling and retarding of CO_2 emissions in electricity production have the important significance for addressing global warming. 300MW units and 600MW units with carbon emission reduction were taken as examples, and using normalized cost of electricity, carbon abatement costs and power efficiency as the evaluation parameters. The results show that 300MW units make more total capital cost growth, with the growth rate of normalized cost of electricity and carbon abatement costs, than 600MW units, as follows: i) the total capital cost growth of 300MW units is 24.11%, ii) the number of 600MW units is 17.66%, iii) power efficiency reduction of 300MW units is 13.74%, iv) the number of 600MW units is 13.65%, v) carbon abatement costs of 300MW units is $49.70/t, vi) the number of 600MW units is $45.55/t, vii) normalized cost of electricity of 300MW units $0.0285/kWh, and viii) the number of 600MW units is 0.0266/kWh.**

Keyword - Coal-fired power plants; Carbon capture; MEA absorption; Levelized cost of energy (LCOE); Carbon abatement cost(CAC)

I. INTRODUCTION

With the rapid development of society and economy, the requirement of global energy is increasing year by year, and fossil fuel consumption[1] is also rising each year which result in environmental problem becoming more and more serious. The major factor which leads to global warming is greenhouse gas emissions, CO_2 is to blame[2]. Therefore, it's important to control the greenhouse effect and slow down global warming[3].

Since the industrial revolution, the total emissions of CO_2 every year grew from 0 to 31.7Gt in 2012[4]. In 2012, the total global coal accounted for 29% of the world's total basic energy, CO_2 emissions resulting from burning coal is 44% of the total global CO_2 emissions. Compared to natural gas, the contribution of coal on CO_2 emissions is nearly two times more. The data revealed that the amount of CO_2 emissions from coal is gradually exceeding the amount which from natural gas and oil, leading the first one in amount. In 2012, the coal on the basis of CO_2 emissions in the 13.9Gt increased 1.3%. BaoYunqiao[5] et al. showed the data which the coal accounts for 70% of the primary energy, and he predicted that the CO_2 emissions from coal still accounts for more than 50% in 2050. In 2009, the amount of CO_2 emissions from China reached 6.2 billion tons, occupying the first place in the world, among them CO_2 emissions from the thermal power system is about 3.0194 billion tons which accounting for 48.7% of the total CO_2 emissions. Therefor China actively promised that carbon emissions of per GDP would be reduced by 40%~45% of it in 2005 by 2020. Therefore, the task of CO_2 emission reduction is very difficult for China[6].

In conclusion, targeting at the present situation of energy structure in China, and take traditional conventional coal-fired plant as research objects, we research cost problem and the change law of coal-fired power plants when add the CO_2 capture system after combustion, and analyze the influencing factors. With the continuous technological innovating, m*e*anwhile, carbon capture and storage(CCS) technology with higher efficiency[7-8] and lower consumption has important academic meaning and broad application prospect[9]. However, high energy consumption and cost of investment have prevented the CCS[10-12] from promoting and applying.

II. THE MAIN ECONOMIC EVALUATION PARAMETERS OF COAL-FIRED POWER PLANTS

Nowadays, most of conventional power plants do not have carbon capture device[13]. However, it is very promising that plant attach carbon capture system which using MEA as the absorbent. This article mainly take the carbon capture technology which adopt ethanolamine as absorbent to analyze. And its property is described in the following[14]: ethanolamine was also called monoethanolamine and be abbreviated as MEA whose Molecular formula is $HOC_2H_4NH_2(RNH_2)$. Many researchers and research institutions analyze the economics of carbon capture system from different types of power plants, and comparatively analyze all kinds of cost between conventional power plants and power plants which equipped with CO_2 removal system

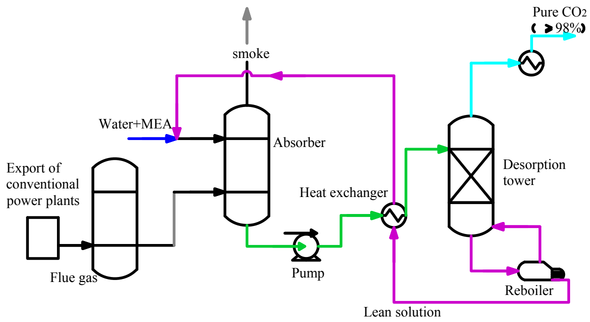

Figure 1. Flow chart of CO_2 capture using MEA method[15]

A. Levelized Cost of Electricity

The cost of power generation is calculated based on the basic principle of minimum annual income that income by selling electricity is equal to the sum of all the costs. So levelized cost of electricity model can be shown as:

$$LCOE=\frac{\sum_{k=0}^{n}\frac{D_k}{(1+i)^k}}{\sum_{k=0}^{n}\frac{Q_k}{(1+i)^k}} \tag{1}$$

LCOE—Levelized Cost Of Electricity,

D_k—the cost of the K^{th} year

Q_k—he generated energy of the K^{th} year

i —discount rate

n —project life cycle (concluding construction period and operating period , and when k is 0, it shows that this year is starting construction)

B. Carbon Abatement Cost

Carbon abatement cost model can be written as:

$$CAC=\frac{LCOE_{MEA}-LCOE}{m_{co_2}-m_{co_2-MEA}}=(LCOE_{MEA}-LCOE)/\left(\frac{M_{CO_2}}{W_{net}H}-\frac{M_{CO_2-MEA}}{W_{net-MEA}H}\right) \tag{2}$$

W_{net}—Net output power[16],

$LCOE_{MEA}$—Levelized Cost of Electricity of MEA,

m_{co2}—CO_2 emissions of unit capacity from conventional power plants,

Mco_2—CO_2 emissions of unit capacity from power plants with MEA-carbon capture,

Mco_2—CO_2 emissions of Conventional units,

Mco_{2-MEA}—CO_2 emissions of from power plants with MEA-carbon capture,

C. Efficiency of Power Supply

The efficiency of power supply in coal-fired power plant is the ratio of electricity output and heat input. A large number of energy consumption would lead to the decreasing of the efficiency of power supply in coal-fired power plant. So the efficiency of power supply model can be written as:

$$\eta=\frac{3600W_{net}}{H_i M_F} \tag{3}$$

η—the efficiency of power supply,

H_i—coal receive calorific,

M_F—the mount of coal-fired

III. RESULTS AND ANALYSIS

In the □, MEA carbon capture plant's economic assessment parameters has been established, the evaluation criteria is levelized cost of energy (LCOE), carbon abatement cost (CAC), power supply efficiency (η), 300MW subcritical units and 600MW supercritical units are chosen as the power plant units economic evaluation study.

A. Coal characteristics and economic evaluation analysis

In order to facilitate the comparison and analysis between 300MW units with 600MW units, MEA concentration of the absorbent is 80 percent is carbon capture rate, coal characteristics and economic evaluation parameters keep consistent. In this paper, Bohai Bay coal-fired thermal coal is chosen, current coal price, coal elemental composition and calorific received as shown in Table 1, the economic parameters were chosen based on the knowledge of economics and the actual data of power plants.

TABLE 1 COAL ELEMENTAL COMPOSITION

M_{ar} /%	A_{ar}/ %	C_{ar}/%	H_{ar}/ %	O_{ar}/ %	N_{ar}/ %	S_{ar}/ %	H_i (kJ/Kg)
6.5	19.6	66.59	2.69	2.93	0.94	0.75	24947.3

B. Economic Analysis for 300MW carbon capture plant operation

Taking a 300MW power plant in Guangdong as an example, the economic analysis of the MEA carbon-capturing units was conducted. The units' boiler is subcritical, reheat, direct-current boiler, boiler rated evaporation is 949.5t/h, the main steam parameters is 16.67MPa/537 □, reheat steam inlet parameters is 3.335MPa/296 □, reheat steam export parameters is 3.17MPa/537 □, water temperature is 275.7□, excess air ratio is 1.15, the exhaust gas temperature is 123□.

1) Economic Data of Conventional 300MW Units

TABLE 2 CONVENTIONAL 300MW UNITS

Parameters	Numerical
Plant-based investment(C_P)/Million dollar	193.32
Desulphurization investment(C_{FGD})/Million dollar	16.51
Denitration investment(C_{SCR})/Million dollar	113.95
Consumption of coal(M_F)/(t/h)	98.89
Consumption of electric power(W_{FEC})/MW	21.15
Oxidation rate of coal-fired κ/%	95
Efficiency of boiler $\eta_{B\text{-}air}$ /%	91.2

TABLE 3 ADDITIONAL INVESTMENT AND ENERGY CONSUMPTION OF 300MW CARBON CAPTURE UNITS

Parameters	Numerical
Investment of MEA absorb equipment(C_{MEA})/Million dollar	50.54[17]
Investment of CO_2 capture equipment(C_{CC})/Million dollar	3.41[17]
Energy Consumption of MEA absorb equipment (W_{MEA}) /MW	71.37
Energy Consumption of CO_2 capture equipment(W_{CC}) /MW	22.62

TABLE 4 ECONOMIC EVALUATION RESULTS OF 300MW UNITS

Parameters	Conventional units	MEA units
The total capital cost[18]C_I/Million dollar	223.78	277.74
Equal annual installments to repay the cost C_{AI}/Million dollar	27.20	33.75
Fuel costs C_F/Million dollar	57.35	57.35
Operation and maintenance costs C_M/Million dollar	8.95	11.11
Mount of each year CO_2 Emissions M_C/（Mt/y）	1.65	0.33
Mount of each year CO_2 capture M_B/（Mt/y）	0	1.32
Net output power W_{NET}/MW	278.85	184.86
Power Efficiency(η)/%	40.7	26.96
Levelized cost of energyLCOE/（dollar/kWh）	0.04865	0.0772
Carbon abatement costCAC/（dollar/t）		49.70

2) Investment and Energy Consumption of MEA Carbon Capture Systems Additional Equipment

When carbon capture rate of 80%, MEA absorbent concentration of 30%, additional investment and energy comsumption of 300MW carbon capture units as shown in Table 3.

3) Economic Evaluation Results of 300MW Units

Using data from □A, □B1), □B2) and the economic evaluations parameters to calculate, the result of 300MW units economic evaluation is shown in Table 4. From Table 4, it could be seen that compared with conventional units, carbon capture units increase in the total capital cost $53,956,336.95 an increase of 24.11%, net output declined 93.99MW, decreased by 33.71%; power supply efficiency fell by 13.74%, levelized cost of electricity increased by $0.0285/kWh, an increase of 58.6%; carbon abatement costs to $49.70/t.

C. Economic Analysis for 600MW carbon capture plant operation

Taking a 600MW power plant in Guangdong as an example, the economic analysis of the MEA carbon-capturing units was conducted. The units' boiler is supercritical, reheat, direct-current boiler, boiler rated evaporation is 1950t/h, the main steam parameters is 25.5MPa/571 □, reheat steam inlet parameters is 4.92MPa/327□, reheat steam export parameters is 4.73MPa/569□, water temperature is 296□, excess air ratio is 1.15, the exhaust gas temperature is 124□.

1) Economic Data of Conventional 600MW Units

Table 5 shows the investment and energy consumption of conventional 600MW units.

2) Investment and Energy Consumption of MEA Carbon Capture Systems Additional Equipment

When carbon capture rate of 80%, MEA absorbent concentration of 30%, additional investment and energy consumption of 600MW carbon capture units as shown in Table 6.

3) Economic Evaluation Results of 600MW Units

TABLE 5 CONVENTIONAL 600MW UNITS

Parameters	Numerical
Plant-based investment(CP)/Million dollar	405.33
Desulphurization investment(CFGD)/Million dollar	30.45
Denitration investment(CSCR)/Million dollar	27.31
Consumption of coal(M_F)/(t/h)	204.2
Consumption of electric power(W_{FEC})/MW	35.15
Oxidation rate of coal-fired κ/%	95
Efficiency of boiler $\eta_{B\text{-}air}$ /%	93

TABLE 6 ADDITIONAL INVESTMENT AND ENERGY CONSUMPTION OF 600MW CARBON CAPTURE UNITS

Parameters	Numerical
Investment of MEA absorb equipment(CMEA)/Million dollar	76.61
Investment of CO2 capture equipment(CCC)/Million dollar	5.18
Energy Consumption of MEA absorb equipment (W_{MEA}) /MW	146.43
Energy Consumption of CO_2 capture equipment(W_{CC}) /MW	46.74

TABLE 7 ECONOMIC EVALUATION RESULTS OF 600MW UNITS

Parameters	Conventional units	MEA units
The total capital cost[15]C_I/Million dollar	463.08	544.86
Equal annual installments to repay the cost C_{AI}/Million dollar	56.33	66.22
Fuel costs C_F/Million dollar	118.43	118.43
Operation and maintenance costs C_M/Million dollar	18.52	21.79
Mount of each year CO_2 Emissions M_C/ (Mt/y)	3.41	0.682
Mount of each year CO_2 capture M_B/ (Mt/y)	0	2.728
Net output power(W_{NET})/MW	564.85	371.68
Power Efficiency(η)/%	39.92	26.27
Levelized cost of energy LCOE/(dollar/kWh)	0.04962	0.0762
Carbon abatement cost CAC/(dollar/t)		45.5462

Table 7 shows, compared with conventional units: MEA carbon capture units increase in the total capital cost $81,777,662.55, an increase of 17.66%; net output declined 193.17MW, decreased by 34.20%, power supply efficiency fell by 13.65%, levelized cost of electricity increased by $0.02658/kWh, an increase of 53.57%; carbon abatement costs to $45.5462/t.

IV. CONCLUSION

In this paper, coal-fired power plants with CO_2 capture system as the object of study, and its energy consumption characteristics and the cost variation of the units after installation of CO_2 capture device were be analyzed, which was in order to get the CO_2 capture system-coal-fired plants' running economy clearer and more comprehensive understanding, to provide a reference for the promotion and application of CO_2 capture system. By using the economic assessment model, we can get the main conclusions which are as follows:

- For 300MW units, compared with conventional units, carbon capture units increase in the total capital cost $53,956,336.95, an increase of 24.11%; net output declined 93.99MW, decreased by 33.71%; power supply efficiency fell by 13.74%; levelized cost of electricity increased by $0.0285/kWh, an increase of 58.6%; carbon abatement costs to $49.70/t.
- For 600MW unit, compared with conventional units: MEA carbon capture units increase in the total capital cost $81,777,662.55, an increase of 17.66%; net output declined 193.17MW, decreased by 34.20%; power supply efficiency fell by 13.65% ; levelized cost of electricity increased by $0.02658/kWh, an increase of 53.57%; carbon abatement costs to $45.5462/t.
- After adding MEA carbon capture systems, 300MW units and 600MW units, the rate of decline of the net output power and power efficiency both are similar. 300MW units make more total capital cost growth, the growth rate of levelized cost of electricity and carbon abatement costs than 600MW unit, which meet the theory that the larger the group, the smaller the cost of change.

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