Theoretical Analysis and Research on CO_2 Emission of Thermal Power Plant

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Abstract—**The calculating model is the effective means to master know on CO_2 emission. By analysising the quantifying model of CO_2 emissions for thermal power plant, we propose the idea of capture,reduction and reusing CO_2 under the intravenous circulation economic model in development of low-carbon electricity production .**

Keywords- thermal power plant, IPCC CO_2 emission factor model, practical measurement method, material balance method, macro-model method, intravenous low-carbon model

Climate change is a significant global concerning issue. The large-scale exploitation and utilization of energy resources is one of the major causes of environmental pollution and climate change. As a new concept of energy development , low carbon economy becomes the world's energy production and development constraint. Increasing environmental pressure caused by the consumption of energy, mostly coal. Coal is the main energy consumed in China, The dominance of coal is not expected to fall significantly even as China's energy demand grows , the energy structure with coal playing the main role will remain unchanged for a long time, Coal consumption has been the main cause of smoke pollution[1], The environmental cost is maximum. as well as the main source of greenhouse gas. China with low accumulative emissions. is a developing country in the primary stage of industrialization, From 1950 to 2002, the aggregate amount of China's fossil fuel CO_2 emissions accounted for only 9.3 percent of the world's total in the same period. The amount of China's per-capita CO_2 emissions ranked 92nd in the world, and the elasticity coefficient of carbon dioxide emissions per-unit GDP was very small. International Energy Agency report shows that the world's carbon dioxide emissions will be incressed with a higher speed after 2010, China's CO_2 emissions, second only to the United States, are also a threat to the global environment.

It is said that the earth's climate in future depends largely on the degree of increasing concentration of atmospheric CO_2, which is closely related to the warming effect of CO_2 and the lifetime .

TABLE I.   GREENHOUSE GAS WARMING EFFECT AND THE LIFETIME [2,3]

Greenhouse gases	Temperature Effect,%	Lifetime,year
carbon dioxide CO_2	63	50-200
methane CH4	15	12-17
nitrous oxide N_2O	4	120
HFCs	11	13.3
PFCs		50000
SF6 and other	7	-

The effective calculating model is the mean to Master know on CO_2 emission.At present, Intergovernmental Panel on Climate Change (IPCC) recommended method , depands on national basic datas, using material balance, emission factors and decision tree to estimate, is mainly used to calculate the amount of carbon emission. Study of emission estimation method must take into account the type of carbon source, various uncertain factors, such as the combustion completeness of electricity and fuel and so on. There are many ways to determine the global carbon emissions, such as the macro-models, direct measurement and estimation. But it is currently used mainly statistical methods, which is uncertainty, rather than the detection methods in a specific country, particular enterprise or even an individual emissions. For specific businesses, based on specific data, direct calculation method is more reasonable. Emissions are usually calculated by an indirect approach, for example,calculated by the amount of burned coal, not captured amount directly in power plant.

I.   ANALYSIS OF APPLICABILITY ON CALCULATING METHOD IPCC RECOMMENDED OF CO_2 EMISSIONS

CO_2 emissions based on the IPCC, "Guidelines for National Greenhouse Gas Emissions Inventory" can be calculated.

Emissions GHG, fuel=Fuel Consumption fuel • Emission Factor GHG, fuel

The key of calculation is emission factor. For fossil fuels, it is IPCC default value. CO_2 emission factors which many countries estimated are different. It has reported [4]thatCO_2 emission factor , recommended by China Energy Research Institute of National Development and Reform Commission is 0.67, the reference factor from The Institute of Energy Economics of Japan is 0.68(Japan Energy and Economic Statistics Handbook, 2003), 0.69 from U.S. Department of Energy (DOE / EIA International Energy Outlook 2002),which is roughly equal with the recommended value (0.67) .

Equivalent to unit of coal equivalent of 29302KJ/Kg,CO_2 emission factors (carbon count) of coal, oil, natural gas, were 0.651-0.755, 0.5-0.585, 0.395-0.447, which measured by the Energy of China's State Development Planning Commission were 0.651, 0.543, 0.404 [5,6].

Comprehensive energy consumption of the macro-CO_2 emissions is converted from IPCC carbon emissions calculation formula to

$$E_\tau = \delta_\phi E_\phi + \delta_\mu E_\mu + \delta_\nu E_\nu \qquad .!(1)$$

Where, E_t is CO_2 emissions, E_f is the standard coal consumption quantity for coal, δ_f is carbon emissions conversion factor for coal consumption; E_m is the conversion standard coal consumption quantity for oil, δ_m is the carbon emissions conversion factor for oil consumption; E_n is the conversion standard coal consumption quantity for natural gas, δ_n is the carbon emissions conversion factor for natural gas.

Conversion factors derived by the researchers of china in Table II.

TABLE II. CONVERSION FACTORS[6,9,10]

Energy sources	Coal (t/t ce)	Oil (t/t ce)	Natural gas (t/t ce)
Carbon conversion factors δ	0.7476	0.5825	0.4435

IPCC emission factors are fit for macro-statistical calculation. It is provided for the two concepts of emission factor and oxidation factor in calculation of the iron and steel enterprises emission in Russia.The emission is the product of fuels energy content, emission factor and oxidation factor.

There will be more uncertain in the calculation process, statisticing respectively the fuel data and product data ,it is difficult to reflect the characteristics of centralized emission, CO_2 emissions is divided into fuel combustion emissions and technical process emissions in industrial production(IPCC method).The recommended IPCC factor obtained from coal to electricity conversion process in the laboratory is theoretical value.Therefore, it is certainly different from the reality.For example, in a thermal power plant, according to different combustion efficiencies depended on coal quality and the corresponding parameters of the boiler equipment and management, conversion factors are also different .

Emission factor is closely related to coal consumption in the thermal power plant. It decrease as coal consumption reduce. Thermal energy consumption is a dynamic number based on enterprise management level and the main devices.It is usually used Statistics figures of the NDRC and the National Bureau of Statistics in Macro-economic statistics. However, this figure is mutative, for the Chinese thermal power plant, coal consumption per unit of electricity is 0.392 kg ce in 2000, 0.36 kg now, maybe it could be reduced to 0.32 kg by 2020.

II. MEASURED METHOD

The monitoring instruments approved by the country or related departments is the prerequisite condition of measured approach, such as the Continuous Emission Monitoring System (CEMS), by using monitoring instruments or on-line facility continuously monitor the flow (velocity) of emissions, CO_2 concentration, directly calculate the instantaneous emissions with the both product, and then statistical calculate the total emissions. This method is accurate,but its cost is high. Currently , it is in the United States that CEMS running perfect ,not in China .

The recommended analysis method of CO_2 concentration in flue gas include the capacity titration, gas chromatography and non-dispersive infrared gas analyzer method.The last is used widely,but it can't eliminates interference of CO, hydrocarbons and water vapor.

III. MATERIAL BALANCE METHOD

A. Analysis of CO_2 emissions by material balance method

Based on the combustion reaction $C + O_2 = CO_2$,there will produce 44/12kg CO_2 for 1kg C. This analysis method is applicable to the carbon balance calculation established producing systems, processes, combustion equipment.

In order to compare the economy of boiler, it is should converse different heat value to 29307 kJ/kg ce(coal equivalent calorific value).The integrated thermal efficiency of power plant (η_0) is calculated as

$$\eta_0 = [(Q_r + 36 E_g) / (B \times 29.27)] \times 100\% \quad (2)$$

Where: Q_r - heat supply Consumption,GJ;E_g - Annual Electricity Consumption ,10,000kW· h; B - total standard coal consumption,t.

Known for the power supply and the heat supply, the standard coal consumption can be calculated.

$$B = (Q_r + 36 E_g) / 29.27\eta_0 \quad (3)$$

A is Actual coal consumption,then; Q_{coal} is actual heating value,MJ/kg.

$$A = B \times 29.27 / Q_{coal} \quad (4)$$

Using the carbon content(C)of the actual burned coal to calculate the emission of CO_2 ,then

$$
\begin{aligned}
M_{CO2} &= A \times C \times (44/12) \\
&= B \times 29.27 \times C \times (44/11) / Q_{coal} \\
&= [(Q_r + 36 E_g) / 29.27\eta_0] \times 29.27 \times C \times (44/11) / Q_{coal} \\
&= (44/12) C [(Q_r + 36 E_g) / \eta_0] / Q_{coal} \\
&= (44/12) C (Q_r + 36 E_g) / (\eta_0 Q_{coal}) \quad (5)
\end{aligned}
$$

B. Analysis and checked on Carbon content

The carbon content is different for different types of coal, so CO_2 emission is. Carbon content of coal is about 20% -70%. Depleted coal, bituminous coal, lignite are usually used in power plant of China, carbon content is about 55%.

The carbon content of coal include carbon content of received basis (C_{ar}), carbon content of air dried basis (C_{ad}), carbon content of dry basis (C_d) and carbon content of dry ash-free basis (C_{daf}). Actual heating value Q_{coal} can be used instead of Q_{ar} (heating value of received basis) , C_{ar} used instead of C,

$$M_{CO2} = (44/12) C_{ar} (Q_r + 36 E_g) / (\eta_0 Q_{ar}) \quad (6)$$

C. The check on net calorific value as received basis $Q_{net, ar}$

Coal'S Calorific Value including net calorific value and gross calorific value. Gross calorific value Q_{gr} stands for all given heat of 1 kg coal burned completely, including the heat as water vapor condensation released in flue gas; net calorific value Q_{net} defines as the heat used water vaporization, which has not been used. Q_{net} is usually used in China, while gross calorific value has adopted in some countries. So

$$Q_{ar,net} = Q_{ar,gr} - \gamma\left(\frac{900H_{ar}}{100} + \frac{M_{ar}}{100}\right) = Q_{ar,gr} - 25.1(9H_{ar} + M_{ar}) \quad (7)$$

r is the potential heat of water evaporation, taken as 2510 kJ / kg.

Therefore, CO_2 emissions should be expressed as

$$M_{CO2} = (44/12) C_{ar} (Q_r + 36 E_g) / (\eta_0 Q_{ar,net}) \quad (8)$$

D. The check on Incomplete Combustion of coal-burned Boiler

Burning 1kg C produce 44/12kg CO_2 for complete Combustion,it is only a qualitative value.Thermal effciency in boiler's operation is an imponant index for evaluating economy of coal-fired boiler,It heavily affecte the CO_2 emissions.Using the incomplete combustion of carbon balance method, it can be calculated equipment discharged ash, fly ash and the carbon sequestration rate in dust, which is an important data for calculation of CO_2 emissions. The calculation of CO_2 emissions must include oxidation efficiency.Knowing energy consumption, burning rate, carbon content and carbon oxidation efficiency, etc., we can directly calculate the CO_2 emissions.

Generally, if combustion equipment of coal is not advanced, and the oxidation efficiency is lower, the emission factor is low too.
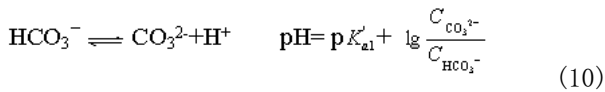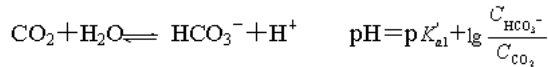
In the boiler, there is also a small amount of carbon of fuels to generate carbon monoxide in the incomplete combustion condition, and escape into the atmosphere with the flue gas. Considering that carbon monoxide will eventually oxidize to carbon dioxide, so this small amount of carbon is also included in the amount of carbon dioxide what the boiler combustion generat.

E. The check on CO_2 Emissions after desulfurization

Based on the complex process of thermodynamics, kinetics and micro-chemical balance, desulfurization equipment maybe effects CO_2 emissions positively, may be negatively. Lime-gypsum FGD process will generate a lot of carbon dioxide. It is said that removing 1 ton of sulfur dioxide will produce 0.7 tons of CO_2. There is acid-base balance reaction between wet desulfurization sorbent and CO_2, such as the alkaline ammonia desulfurization agents, lime and dual-alkali Na_2CO_3 or NaOH solution absorb the SO_2 in flue gas, absorb CO_2 at the same time.

At the same time, wet solutions effect the dissolution equilibrium of CO_2, following Henry's Law, CO_2 partial pressure (p (CO_2)) and water temperature (T) follow the relationship below (4 ~ 28 ℃):

$$p\ (CO_2) = 221.\ 03 + 6.\ 62 \times T\ (r^2 = 0.\ 96,\ n = 23) \quad (9)$$

$$CO_2 + H_2O \rightleftharpoons HCO_3^- + H^+ \qquad pH = pK'_{a1} + lg \frac{C_{HCO_3^-}}{C_{CO_2}}$$

$$HCO_3^- \rightleftharpoons CO_3^{2-} + H^+ \qquad pH = pK'_{a1} + lg \frac{C_{CO_3^{2-}}}{C_{HCO_3^-}} \quad (10)$$

Dissolution equilibrium depends on the pH of absorption fluid primarily. The carbonate compounds are changed with pH. The pH of Desulfurization fluid is usually controlled between 5.5-5.7, when free CO_2 and $HCO_3^-$is the main form of carbonic acid.

On the other hand, physical absorption and chemical absorption are subject to the vapor diffusion rate (or the gas film resistance) and the liquid diffusion rate (or the liquid film resistance). The way of enhancing disturbance of gas phase - liquid phase is used broadly to eliminate gas film and liquid film resistance in desulfurization projects. Dynamic balance factors affect the solubility. MA Li-Li [11] and other studies have the conclusion that the flow of fluid caused carbon dioxide system away from the original static dissolved water balance. At 25.5 ℃, about 6.55% of the carbon dioxide dissolved in original static water is desorpted. Henry coefficient can deviate 15% of original value.

IV. MACRO-MODEL APPROACH

The LEAP model (The Long-range Energy Alternatives Planning System) [12] developed by Lawrence Berkeley National Laboratory is an energy-environment scenario analysis model. Model forecast the long-term energy supply and demand in whole society which is effected by different driving factors in aspects of energy supply, energy processing, final energy demand.and calculate air pollutants and greenhouse gas emissions of the energy in the circulation and consumption process.

Wang Ke et al [13] make use of LEAP China long-term energy alternative planning system model simulating CO_2 emissions in 2000-2030 and the corresponding emission reduction potential in three different scenarios of China's steel industry,then according to assess the feasibility of reduction costs, to identify the key of reduction technology.

Zhu Chun-jie et al [14] use LMDI (logarithmic mean Divisia index) to decompose and analysis carbon dioxide emissions resulting from regional energy consumption in some provinces in China, broken down the change of carbon dioxide emissions into five major factors, namely, fossil fuel emission factor, energy consumption structure, energy intensity, per capita GDP and population size.

V. BUSINESS PRODUCTIVITY METHOD

Based on capacity of the enterprise and output, taking into account the integrated combustion factors of fuel and process factor, total emissions [15,16] can be calculated by aggregating the emissions source point, The amount CO_2 emission estimated per industry is the product of the composite emission factor in this enterprise and the production and the capacity utilization rate,and we must take the equipment average full load hours into account.

VI. ANALYSIS OF THE PROBLEMS ABOUT "LOW-CARBON BREAKTHROUGH"FOR A THERMAL POWER PLANT

Low-carbon development effect China's long-term construction of energy and environment significantly and multiplly. CO_2 emissions and emission reduction is a basic research work in thermal power plant, which needs to be improved in the following areas:

1) Emission factors research of thermal power plant is to be made perfect.

2) It is need to resolve the interference of various uncertain factors.

Coal sample analysis is the basis of determining the coal quality, so it is very important to analysis of coal before get into the factory and furnace for power plant. The sampling and analysis methods must be strict, otherwise its potential impact

for emission factor is immeasurable, forthermore the results on the estimation emissions, leading to the results uncertainty.

The value of electric power sector coal low-calorific is lower than Coal Institute study's in many reasons. That is to say, it is objective reality that there are different qualities of coal in China in all segments (production, distribution and consumption), and this fact makes the estimation of greenhouse gas emissions uncertain [17].

3) Coordinating the relationship between the CO_2 emissions sources and sinks is the key.

In the development of green energy, the CO_2 capture and storage(CCS)is a basic point for the traditional power plant to reduce CO_2 emissions. The CCS technology can make CO_2 isolated from the atmosphere for a long time. It capture CO_2 from industrial emission sources, then deliver to a selected geological structure to seal and store. CCS reduces 85% - 90%.carbon emissions per unit of electricity generated.How to make traditional thermal power enterprises reducing emissions as a profitable market needs study carefully. If making the CCS technology to a breakthrough in thermal power production process, the high-pollution power plant will become "carbon neutral" company. At the same time, we must emphasize the value of CO_2 resource utilization, CCU means CO_2 Capture and utilization,it is a real technological breakthrough. High-cost is a restricts for the development of CCS technology. it will take about 20-40 U.S for per tonne of CO_2 capture.CCU is a more practical way for developing countries to reduce emissions. Gaobeidian power plant is a good example of attempting product carbonated soft drinks resource for carbon dioxide, while the price per ton of dry ice is 1,200 yuan, the cost of food grade carbon dioxide production is 600 yuan / ton. Actively research on CCU technology is a effective way to reduce the capture cost. If looking the power producing progress as an artery economy, CO_2 capture and resource utilization are intravenous economy. It is a low-carbon economic model to a reasonable match between them for the thermal power plant.

REFERENCES

[1] HUANG Lei, ZHANG Cai-hong ,QIN Qin.Environmenta cost and generation by woody biomass. Power Demand Side Management, 2007 9(1):77-80

[2] Li Yu-Hui, Cheng Shi-cai, Shi Teng-fei et al. Greenhouse gases and greenhouse effect.

[3] Wu Dui. Greenhouse gases and greenhouse effect. METEOROLOGICAL, 2003

[4] 2006 IPCC Guidelines for National Greenhouse Gas Inventories, 1.1 introductions.

[5] National Bureau of Statistics, China Statistical Yearbook 2003, China Statistics Press, 2003 9

[6] China Energy Statistical Yearbook 2008, National Bureau of Statistics Division and the Bureau for Comprehensive National Energy Board。

[7] GAO Shuting ZHANG Huiqin YANG Liyong W ANG Qiuling. Forecast M ethod and Countermeasures for Greenhouse Gases in China.RESEARCH OF ENVIRONMENTAL SCIENCES 1994, 06:56-59

[8] XU Guo-quan, LIU Ze-yuan, JIANG Zhao-hua. Decomposition Model and Empirical Study of Carbon Emissions for China, 1995 - 2004. China Population Resources and Environment,2006,6:158-161

[9] SONG Tao, ZHENG Ting-Guo, TONG Lian-Jun. Theoretical Analysis and Econometric Testing on Relationship of Environmental Pollution and Economic Growth.Scientia Geographica Sinica,2007,02:156-162

[10] TAN Dan, HUANG Xian-jin, HU Chu-zhi. Analysis of the Relationship between Industrial Upgrading and Carbon Emission in China. Sichuan Environment,2007,27(2):74-77

[11] MA LiLi ZHANG ZhenZhen GUO Kai. Explorative research on the dynamic dissolution equilibrium in the carbon dioxide-water system. Journal of Beijing University of Chemical Technology,2009,6: 11-15.

[12] LEAP Developer and COMMEND Manager .An Introduction to LEAP. COMMEND net

[13] WANG Ke, WANG Can, LV Xuedu, CHEN Jining. Abatement potential of CO2 emissions from China's iron and steel industry based on LEAP. Journal of Tsinghua University(Science and Technology),2006,12:1982-1986.

[14] ZHU Chunjie, MA Zhongyu, WANG Can, LIU Zigang. Analysis of difference features of energy-related CO2 emission in China. Ecology and Environmnet,2006 15(05):1029-1034

[15] Hendriks C Sophie A Der WaartV et al. Building the cost curves for CO2 storage part 1 sources of CO2 [R]. [s. l.] [s. n.] 2002

[16] BAI Bing LI Xiaochun LIU Yanfeng ZHANG Yong . PRELIMINARY STUDY ON CO2 INDUSTRIAL POINT SOURCES AND THEIR DISTRIBUTION IN CHINA. Chinese Journal of Rock Mechanics and Engineering,2006, 25(supp.)1:2918-2922

[17] Hu Xiu-Lian. Summary of list of topics electricity and coal energy sub-symposium. National Climate Change Coordination Office of Energy list of thematic groups, 2003