

Evaluation of the Greenhouse Gas Emission from Combined Heat and Power Plant in Industrial Complex of Korea

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ABSTRACT: Evaluation of the greenhouse gas emission from combined heat and power plant (CHP) in industrial complex of Korea is conducted on the basis of the data surveyed from plants. The surveyed data is composed of kind and amount of consumed fuel, generation, sale and efficiency of heat and electricity, condensed enthalpy, and etc of the each CHP plant. The method for calculating the emission rate for heat and electricity generation in CHP plant is developed. Emission rate of CO₂ for generation of heat and electricity is calculated by using four kinds of evaluation method of foreign countries and that of developed in this study. The calculated emission rate is shown to be different with each other according to the applied evaluation method because the each evaluation method uses different efficiency values for heat and electricity generation.

Keywords: greenhouse gas, evaluation, CHP, emission rate

NOMENCLATURE

CO_{2H} : CO₂ emission amount by heat generation

CO_{2P} : CO₂ emission amount by electricity generation

CO_{2T} : total emission amount of CO₂

E_H : amount of steam sold to customer

E_P : amount of electricity sold to customer

E_{H,tot} : total amount of heat generated in plant

E_{H,plant con} : amount of heat generated and consumed in plant

E_{P,plant con} : amount of electricity generated consumed in plant

E_F : amount of fuel consumed in boiler

E_{F,H} : amount of fuel consumed for heat generation

E_{F,P} : amount of fuel consumed for electricity generation

E_{H,tur} : amount of steam enthalpy reduced in turbine

E_{H,con} : amount of steam enthalpy reduced in condensation process

E_{h sup} : heat supplied from other plant

E_{P sup} : electricity supplied from other plant

e_H : steam generation efficiency

e_P : electricity generation efficiency

1. INTRODUCTION

Greenhouse gas is emitted by combustion process of fuel in boiler, engine and turbine of CHP plant. The greenhouse gas is composed of CO₂, CH₄, N₂O, etc. Among those gases, occupying ratio of CO₂ is more than 99.5% and that of CH₄, N₂O is less than 0.5%.

There are two kinds of method for calculating the CO₂ emission amount. One is direct detection method and the other is

consumed fuel analysis method. The first one measures the emission amount by using the continuous emissions monitoring system. This method has a merit in that it measures emitted gas from CHP plant directly but has demerits in that it needs much detection time and can induce large error. The second one calculates CO₂ emission weight by analysing the carbon content amount and carbon oxidation ratio of the fuel. This method has merits that could calculate emission amount easily by considering kinds and amounts of fuel consumed in plant but has demerit that theoretical results could make difference with real phenomena.

This research calculates CO₂ emission rate for heat and electricity generation in CHP plants of industrial complex in Korea by using the fuel analysis method. There are several fuel analysis methods to calculate the CO₂ emission rate for heat and electricity generation in several advanced countries like U.S., U.K., and international organization like WRI/WBCSD [1], [2]. In this study, new method for calculating the emission rate is developed considering the operation characteristics of CHP plants in Korea. Surveys for gathering the operation data is conducted for all 22 CHP plants in industrial complex of Korea. Among them 6 plant's data is used in calculation considering accuracy. And emission rates of each plant are calculated by applying those data to the methods of developed and foreign countries.

2. CO₂ emission rate calculation methods

2.1 Method of foreign countries

IPCC (Intergovernmental Panel on Climate Change) developed and presented CO₂ emission factor data base for fuels used in combustion devices. The IPCC method calculates emission amount by using the equation (1).

$$\text{CO}_2 \text{ (kg)} = \text{Fuel (kg)} \times \text{Emission factor (1)}$$

WRI/WBCSD (World Resources Institute, /World Business Council for Sustainable Development) and EPA (Environmental Protection Agency) of U.S. [3], [4], [5] developed emission rate calculation methods which could be applied to CHP plant. Those methods calculate not only total amount of CO₂ emission weight but also emission rate for heat and electricity generation. In the first step of calculation procedure, the methods calculate total amount of CO₂ emitted in CHP plant. Then the methods allocate the emission amount for heat and electricity generation by using the efficiency values for heat and electricity generation. In allocation procedure heat and electricity efficiency values of 80%, 35% recommended ones by U.S. CHP plant association are used [6]. The allocation procedure is conducted by using the following two equations.

$$\text{CO}_{2\text{H}} = E_{\text{H}} / e_{\text{H}} / (E_{\text{H}} / e_{\text{H}} + E_{\text{P}} / e_{\text{P}}) \times \text{CO}_{2\text{T}} \quad (2)$$

$$\text{CO}_{2\text{P}} = \text{CO}_{2\text{T}} - \text{CO}_{2\text{H}} \quad (3)$$

The CO₂ emission rate for generation of heat and electricity is obtained by dividing the above emission amounts by generated amounts of heat and electricity. The methods of CCAR (California Climate Action Registry) of U.S. [7], [8] and DEFRA (Department for Environment Food & Rural Affairs) of U.K. [9], [10] have same calculation procedure like WRI/WBCSD and EPA but use different efficiency values. CCAR method assumes efficiency for generating heat and electricity is same. DEFRA method assumes efficiency for heat generation is twice much higher than that for electricity generation.

2.2 Development of emission rate calculation method

The developed method calculates CO₂ emission rate for heat and electricity generation by allocating the consumed fuel amount for producing heat and electricity. It

is not possible to allocate consumed fuel amounts exactly for heat and electricity generation in CHP plant theoretically. In this study, allocation procedure is conducted by using the approximate efficiency values of heat and electricity generation. These efficiency values are calculated by using the operation data which is surveyed in this study. Because all of the surveyed plants use steam turbine, fuel allocation process is conducted on the basis of the steam amount consumed for heat and electricity generation. Heat generation efficiency, e_H , is defined as ratio between subtraction of heat and electricity generated and consumed in plant from total amount of generated heat and sum of fuels consumed in boiler and heat and electricity supplied from other plant. The equation for calculating the above heat generation efficiency, e_H , is defined as

$$e_H = (E_{H,tot} - E_{H,plant\ con} - E_{P,plant\ con}) / (E_F + E_{h\ sup} + E_{P\ sup}) \quad (4)$$

The amount of steam used for heat generation is considered to be same with the amount of steam sold to customer. And the amount of steam used for electricity generation is considered to be same with sum of condensed enthalpy in condenser and removed enthalpy in turbine from which generated electricity consumed in plant is subtracted. Then amounts of fuel consumed to generate heat and electricity are calculated simply by dividing the heat generation efficiency from amount of steam used to generate each other. These are expressed as

$$E_{F,H} = E_H / e_H \quad (5)$$

$$E_{F,P} = (E_{H,tur} + E_{H,con} - E_{P,plant\ con}) / e_H \quad (6)$$

Finally, emission rate for heat and electricity generation is calculated by using emission factor of each fuel and amount of consumed fuel obtained by dividing steam consumption amount with heat generation efficiency, e_H .

3. Results

3.1 Operation data survey

The Survey is conducted for all of the 22 plants' data of 2005 ~ 2007 years. Surveys through direct visiting are conducted for 6 plants, and those through indirect visiting are conducted for all of the 22 plants. Among the datum, only those of 6 plants' surveyed by direct visiting are used in this calculation. Because the data surveyed by indirect visiting show low reliability.

Total amount of energy consumed in 22 CHP plants is shown to be 40,619Tcal as shown in Figure 1. This amount is same with 1.8% of total amount of fuel energy consumed in Korea during a 2005 year. The amount of CO₂ emitted from each CHP plant is shown in Figure 2 and the total emission weight is 13.8Mton in 2005 year. The share of B-C and bituminous coal from consumed fuel is shown to be higher than other fuels as shown in Figure 3.

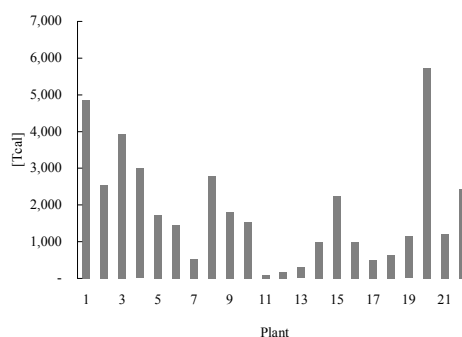


Figure 1: Fuel consumption amount of surveyed plants in 2005 year.

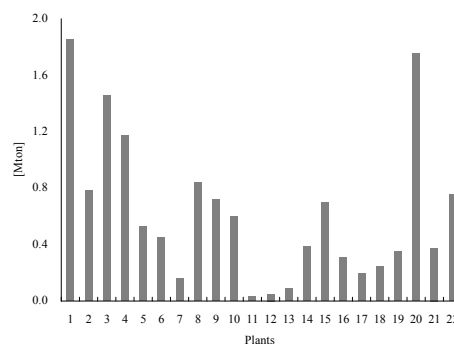


Figure 2: CO₂ emission amount of surveyed plants in 2005 year.

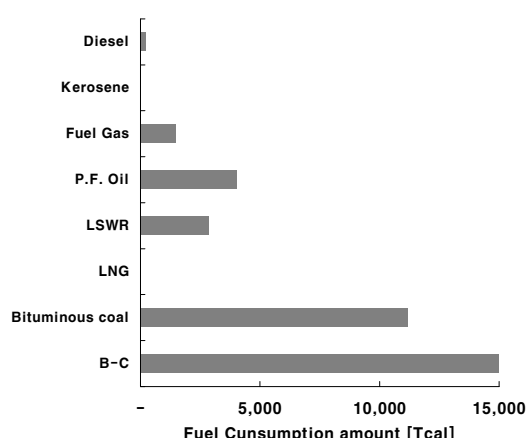


Figure 3: Kinds of fuels consumed in surveyed plants

3.2 Calculation of emission rate

The total weight of emitted CO₂ from each plant is calculated by using the IPCC emission factor tables. Table 1, 2 and figure 4, 5 show efficiency and emission factors calculated by using the method of developed and foreign countries. The calculated results of efficiency and emission rate for each plant are shown to be different. The difference of efficiency results between plants are owing to the difference of the operation characteristics (condensation ratio, heat and electricity generation ratio, etc), efficiency of main system like boiler and turbine, data accuracy. Table 3 shows factors influencing on the efficiency of heat and electricity generation. The values of influencing factor show large difference between each plant.

The efficiency results of plant B and D are shown to be unrealistically high. The reason for this phenomenon is owing to the surveyed data error that enthalpy reduction amount in turbine is too small compared to amount of electricity generation.

Figure 6 shows relation between electricity generation efficiency and steam condensation ratio. The electricity generation efficiency is decreased as the ratio of condensed steam enthalpy is increased. This is due to the fact that the condensed enthalpy is regarded as loss in electricity generation in developed method as shown in equation (6). Figure 7 shows

relation between emission rate and heat and electricity generation ratio. Generally, emission rate must be decreased as heat generation ratio increases because efficiency of heat generation is higher than that of electricity. But such tendency is not shown in this result and the reason for this is thought that various factors like condensation ratio, main facilities' efficiency and data accuracy affect to the efficiency simultaneously.

Figure 8 shows relation between emission rate and total efficiency of CHP plant. As total efficiency is increased, emission amount is decreased because fuel consumption amount is decreased also.

Table 1: Efficiency of heat and electricity generation

Method	efficiency	Results (%)					
		A	B	C	D	E	F
developed	e _H	61	89	74	87	65	84
	e _P	59	77	34	39	51	66
WRI, EPA	e _H	70	99	75	88	75	94
	e _P	31	43	33	39	33	41
DEFRA	e _H	68	96	72	84	72	92
	e _P	34	48	36	42	36	46
CCAR	e _H	60	89	61	66	62	81
	e _P	60	89	61	66	62	81

Table 2: CO₂ emission rate by heat and electricity generation

method		Results (kg/MWh)					
		A	B	C	D	E	F
develop	CO _{2 H}	541	324	417	387	407	315
	CO _{2 P}	569	369	919	856	525	403
WRI, EPA	CO _{2 H}	470	296	412	381	351	282
	CO _{2 P}	1,074	677	941	872	803	645
DEFRA	CO _{2 H}	485	303	430	404	366	291
	CO _{2 P}	969	605	861	808	731	582
CCAR	CO _{2 H}	544	328	511	509	427	325
	CO _{2 P}	544	328	511	509	427	325

Table 3: Factors influencing on efficiency

Factor	Unit	Results					
		A	B	C	D	E	F
Condensation ratio		0.0	1.2	13	17	5.5	0.0
Heat and electricity generation ratio	%	8.4	8.5	5.7	2.8	6.4	6.6
Boiler efficiency	%	83	94	95	89	90	92

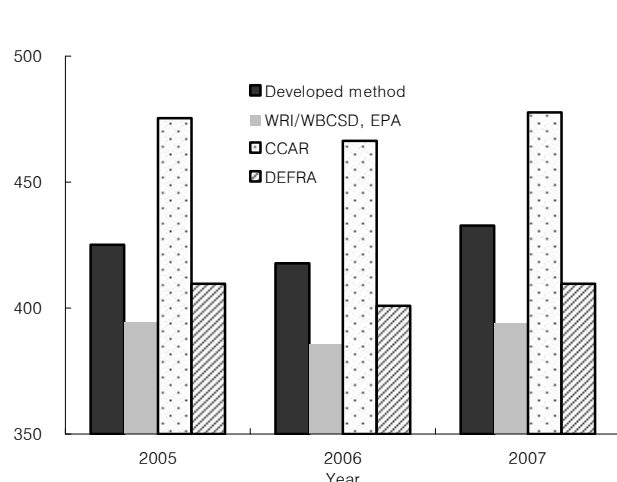


Figure 4: CO₂ emission factors for heat generation calculated (kg/MWh)

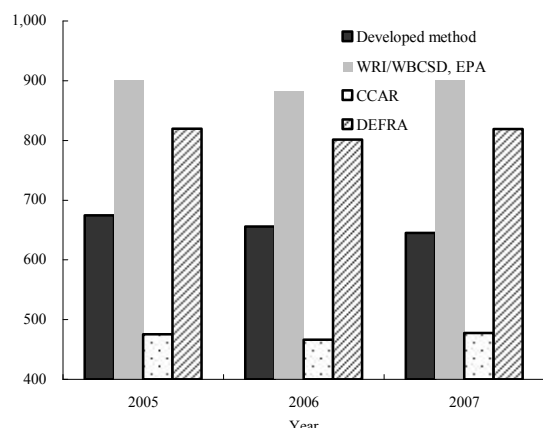


Figure 5: CO₂ emission factors for electricity generation (kg/MWh)

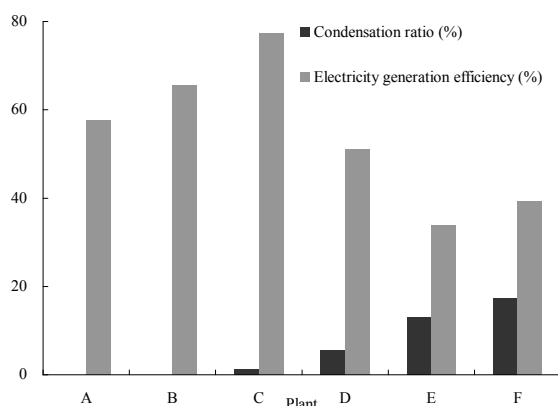


Figure 6: Electricity generation efficiency according to steam condensation amount

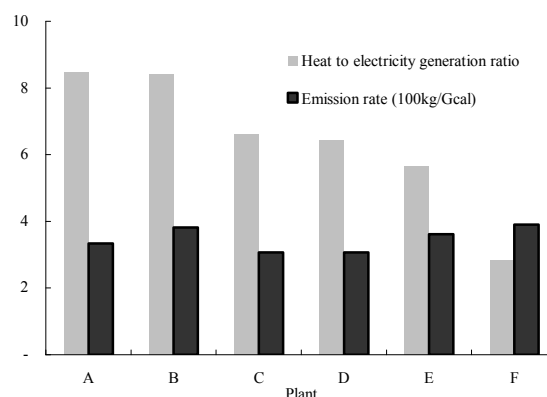


Figure 7: CO₂ emission rate according to heat and electricity generation ratio

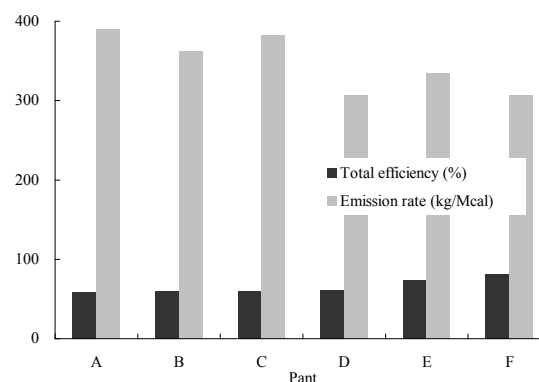


Figure 8: CO₂ emission rate according to total efficiency of CHP plant

4. Conclusion

The calculation method of CO₂ emission rate for heat and electricity generation in CHP plants is developed and applied to the plants in industrial complex of Korea. The calculated values of emission rate values are varied with influence of operation characteristics, efficiency of main facilities and data accuracy of each plant. The developed method seems to show more reliable results than other countries' ones. Because developed method using efficiency values derived from operation data can reflect operation characteristics of plants more exactly than other countries' method using arbitrary efficiency values.

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