Development and Cost Estimation of Green Gas Reduction Process for Power Plant

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ABSTRACT

The systematic and quantitative approach on the environmental pollution is a significant challenge in highly regulated industries, such as power plants, where a large amount of waste gas including greenhouse gas must be discharged. We simulated various CO_2 reduction processes and estimated the total cost of those. In this study, an environmental pollution impact is analyzed by the process operating conditions. First, this paper contains the simulation of the CO_2 reduction process for three absorbents(MEA (monoethanolamine), M-H amine solution, T-D amine solution) in the same operating condition. The simulation results include CO_2 recovery rate and CO_2 mole fraction in CO_2-rich gas of each absorbent. The T-D solution is inferior to others definitely. While the MEA solution and the M-H solution shows almost perfect CO_2 recovery rate, CO_2 recovery rate of the T-D solution is only 90%. However, all the operation conditions such as the inner temperature of the reboiler, the pressure of the stripper bottom, the temperature of the feed, the temperature of the absorbent and recycling rate of the absorbent are fitted for the MEA solution. The improved results of other absorbents can be expected as operation conditions are altered. For example, when the reboiler duty is changed 623MJ/h into 600MJ/h, about 2% in CO_2 recovery rate of the M-H solution is increased and the energy consumption is decreased simultaneously.

Second, cost estimation of the reduction process are performed for three absorbents considering investment cost, operating cost and raw material cost. As a result, the M-H solution is suitable with respect to operating cost and investment cost. The MEA solution seems to be better in accordance with raw material cost. In conclusion, the CO_2 recovery rate of the M-H solution is similar to CO_2 recovery rate of MEA solution, but total cost for M-H solution is lower than that for MEA solution. Based on this study, it is possible that an environment friendly design

and an environment friendly operation can be achieved simultaneously in some parts.

KEYWORD

CO_2 recovery process, Simulation, Cost estimation

INTRODUCTION

Since the beginning of industrial revolution, the ratio of fossil fuel used has been increased every year. The major energy sources come from coal, natural gas, and petroleum, all of which make air pollution problem. Fossil fuel combustion produces a large amount of CO_2. CO_2 is also one of causes of the global greenhouse effect. Owing to the emission of combustion gases, excess CO_2 accumulates around the atmosphere. The amount of CO_2 in the atmosphere increases globally about six billion tones per year. The combustion of fuel for power production is in most cases the largest contributor of greenhouse gas emissions from a process industry (H. Axelsson, 1999). Energy consumption and requirement increase quickly at present, but there is little clean type of energy available to use as a power source. Therefore, it is most important to recover CO_2 from the flue gases to avoid excessive CO_2 emission. The typical CO_2 reduction process does not remove contaminants perfectly but it just transfers those from one medium to another. And the technology leads to the cost required according to the change of social criteria and the strengthening of an emission regulation. Therefore, the introduction of the novel estimation system considering the optimal CO_2 emission and cost consumption is required.

SIMULATION for CASE STUDY

Figure 1 shows PFD of CO_2 reduction process to remove CO_2 of the waste gas for power plant. The waste gas goes into absorber and it meets absorbent with counter flow in absorber. The CO_2-lean gas is discharged into air and CO_2-rich solution is pumping into lean/rich-cross heat exchanger. In cross heat exchanger, the CO_2-rich solution is heating and the CO_2-lean solution is cooling. And then to regenerate solvent (absorbent), CO_2-rich solution is heating in the reboiler again and it enters regenerator. In generator, CO_2 and vapor go up to the condenser and absorbent is liquefied.

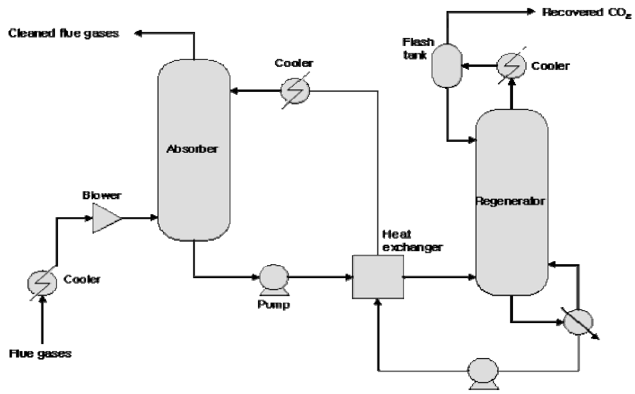

Figure 1. PFD of CO_2 reduction process

Table 1 shows the composition of the waste gas in a coal thermoelectric power plant; the net capacity of target plant is about 250MW.

Table 1. Composition of the waste gas in a 250MW power plant

Flow rate (m_N^3/s)		683.0
Pressure (kPa)		101.0
Composition (mol-%)	N_2	72.5
	CO_2	6.9
	H_2O	15.2
	O_2	5.4

Assumptions for this simulation are as follow; 1. CO_2 in feed gas is removed over 90%. 2. The temperature difference of heat exchanger is over than 10□. 3. When a stream flows in the condenser, the pressure drop is ignored. 4. The pressure drop is 5.0 kPa in the absorber and that of the regenerator is 30.0 kPa. 4. The flow rate of CO_2 in feed is 2.10 kgMol/hr. 5. The effect of other components in feed is ignored. 6. The reaction used in this study is as follow.

$$2H_2O \leftrightarrow H_3O^+ + OH^-$$

$$CO_2 + 2H_2O \leftrightarrow H_3O^+ + HCO_3^-$$

$$HCO_3^- + H_2O \leftrightarrow H_3O^+ + CO_3^-$$

$$R - NH^+{}_{x+2} + H_2O \leftrightarrow H_3O + NH_{x+1}$$

$$R - NH_xCOO^- + H_2O \quad \leftrightarrow \quad HCO_3^- + R - NH_{x+1}$$

$$\text{For MEA}: \quad R = -CH_2CH_2OH\ ; \quad x = 1$$

This study simulated the CO_2 reduction process about three absorbents (MEA (monoethanolamine), M-H amine solution, T-D amine solution) in the same condition with commercial simulator. The results of simulation are CO_2 recovery rate and CO_2 mole fraction in CO_2-rich gas of each absorbent. The results of simulation and the optimal operation condition of each absorbent are shown in Table 2.

Table 2. Comparison of Three absorbents

Operation Conditions	Solvent MEA (15%)	Solvent M (20%) – H (15%)	Solvent T (15%) – D (5%)
Reflux ratio	2.00	3.42	1.90
Reboiler duty [MJ/h]	**623.00**	**600.00**	**648.00**
No. of theoretical plates	24.00	20.00	24.00
Solvent flow rate [m^3/h]	3.22	3.22	3.22
Flue gas flow rate [kg/m^3]	848.00	848.00	848.00
Distillate flow rate [kmol/h]	2.00	2.16	2.16
CO2 mol-% in lean gas	**99.30**	**98.74**	**91.50**
CO2 recovery rate [%]	**99.85**	**99.71**	**90.16**

The MEA solution and the M-H solution are better than the T-D solution. While the CO_2 mole fraction in CO_2-rich gas of the MEA solution and the M-H solution is about 99%, that of the T-D solution is just 91.5%. Viewed in the CO_2 recovery rate, the difference between them becomes definite. The efficiency of the MEA solution and the M-H solution are over 99%. The T-D solution is inferior to others about 90%.

According to Table 1, the reboiler duty of the MEA solution is 623MJ/h(623MJ/h is reboiler duty of real pilot plant.) and that of the M-H solution is 600MJ/h. That is, the MEA solution and the M-H solution are almost equal in CO2 recovery rate, but the M-H solution process requires the less energy about 23MJ/h. It is because of the difference of the amount of water between the MEA solution and the M-H solution. The M-H solution has low water percentage is heated easily. In Figure 2, CO_2 recovery rate of M-H solution is shown according to the reboiler duty.

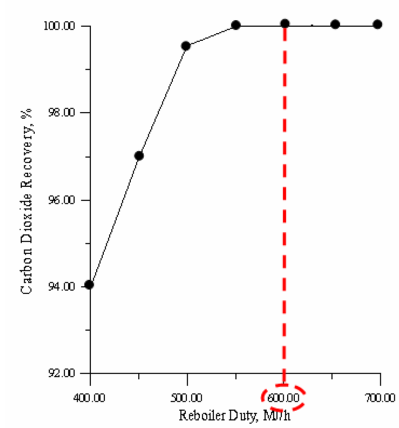

Figure 2. CO_2 recovery rate of M-H solution according to reboiler duty

COST ESTIMATION

The efficiency of the T-D solution is worse than the MEA solution and the price of T-D solution is more expensive than that of the MEA solution about 3 times(KEPRI 2002). This study therefore, estimates the cost of MEA solution and the M-H solution with the initial investment cost, the raw material cost and the operating cost. The processes of the MEA solution and T-D solution are just alike. The initial investment cost and maintenance cost of two processes are almost same. The initial investment cost including maintenance cost of the M-H solution process is higher than the MEA solution process about 5,500US$ just as the size of the regenerator. The cost of equipments for a CO_2 recovery process are calculated with *Econamine FG Process*(Mariz, 1991). Second, the operating cost of the M-H solution process is lower than the MEA solution process about 2,383US$. Because reboiler duty is changed 623MJ/h(the MEA solution) into 600MJ/h(the M-H solution), the energy consumption is decreased. This is shown in Table 3.

Table 3. Comparison of Operating cost

	Solvent MEA (15%)	Solvent M (20%) – H (15%)
Optimal reboiler duty	623 MJ/h	600 MJ/h
Power consumption	18 KW/h	11.6 KW/h
Cost	6,701 US$/yr	4,318 US$/yr

Finally, the raw material cost of the M-H solution process is higher than the MEA solution process about 1,052US$. Raw materials used in CO_2 recovery process is an absorbent and water. Because almost all water is recycled in CO_2 recovery process and supplementary water is supplied to power plant freely, this study does not mention water as the raw material. The cost of MEA is 2 US$/Kg and the cost of the M-H solution is 7.95 US$/Kg(KEPRI, 2002). The amount of the M-H solution used in CO_2 recovery process is 60 Kg/yr and the amount of the M-H solution used is assumed to 138 Kg/yr on the basis of the operation data of pilot plant.

Table 4. Comparison of Raw material cost

	Solvent MEA (15%)	Solvent M (20%) – H (15%)
Price	2 US$/Kg	7.95 US$/Kg
Amount used	60 Kg/yr	138 Kg/yr
Cost	120 US$/yr	1,097 US$/yr

The total cost of two processes is shown in Table 5. According to Table 5, the initial investment cost including maintenance cost of two processes is similar. Although the raw material cost of M-H solution is higher than that of MEA solution, the operating cost of the M-H solution is much lower than that of MEA solution. Therefore, if the M-H solution is replaced the MEA solution, about 1,602US$/yr is saved in CO_2 recovery process for 250MW power plant.

Table 5. Comparison of total cost

	Solvent MEA (15%)	Solvent M (20%) – H (15%)
Initial investment cost	825,000 US$ (33,000 US$/yr)*	820,500 US$ (32,820 US$/yr)*
Maintenance cost	2,970 US$/yr	2954 US$/yr
Operating cost	12,045 US$/yr	9,662 US$/yr
Raw material cost	120 US$/yr	1,097 US$/yr
Total	**15,135 US$/yr**	**13,713 US$/yr**

*: When the period to use of CO2 recovery process is 25 years.

CONCLUSIONS

Three types of CO_2 reduction process are explored in this study. As the result of simulation, the efficiency of the M-H solution is almost same with the MEA solution about 99% and the efficiency of the T-D amine solution is only 90%. Also, when the reboiler duty of the M-H solution is changed 623MJ/h into 600MJ/h, the CO_2 recovery rate is optimal and the energy consumption is decreased simultaneously. It leads that the total cost of the M-H solution process is lower than that of the MEA M-H solution process about 1,602 US$/yr. As the result of this study, the suitability of each CO_2 recovery process and the optimal operating conditions of CO_2 reduction processes for a power plant was evaluated.

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