Available online at www.sciencedirect.com

SciVerse ScienceDirect

Energy Procedia 37 (2013) 677 – 682

Energy Procedia

GHGT-11

Operating cost for CO_2 capture process using aqueous ammonia

Je Young Kim[a], Kunwoo Han[*], Chi Kyu Ahn, Man Su Lee, Chang Houn Rhee, Hee Dong Chun

CO_2 Project, Research Institute of Industrial Science & Technology, San 32 Hyoja-dong, Pohang 790-330, Republic of Korea
[a]Current address: Technnical Laboratories, AMT Pacific,152 Gajeong-ro, Yuseong-gu, Deajeon 305-343, Republic of Korea

Abstract

In the present paper, we report the result of cost analysis associated with the operation of CO_2 capture pilot facility using aqueous ammonia. The facility treating 1,000 Nm^3/hr of BFG (blast furnace gas) is in operation with the production capacity of 10 t-CO_2/d. From the pilot plant operation we found that the CO_2 recovery was 90% and the purity of product CO_2 was over 98%. Waste heat recovery system for steam generation was installed and integrated with the CO_2 capture facility successfully. Operating cost analysis based on the running data of the facility has been performed based on the consumptions of steam, electricity, water, and chemical. Since the process uses waste heat recovery system, the majority of operating cost is the electricity consumption. Excluding the steam cost generated by the waste heat recovery system, the operating cost for the process was estimated under \$20/t-CO_2.

Keywords: aqueous ammonia; CO2 capture; process economics; cost analysis

1. Introduction

As an attempt to mitigate the anthropogenic concentration of carbon dioxide (CO_2), absorption-based CO_2 capture technologies have been developed at large stationary point sources such as power generation and iron and steel-making plants. Two exemplary absorption solutions are the aqueous amines (advanced amine) and ammonia. Besides superior features such as low chemical cost and corrosiveness, the ammonia solution exhibits at relatively low regeneration temperature /energy rendering a competitive option for CO_2 capture, i.e, it is the most important factor when selecting the absorption solution for CO_2

* Corresponding author. Tel.: +82-54-279-6291; fax: +82-54-279-6729.
E-mail address: mdguru@rist.re.kr.

doi:10.1016/j.egypro.2013.05.156

capture. Due to the advantages of the above-mentioned characteristics, researchers have been developing ammonia-based CO_2 capture technologies [1-3].

Iron and steel industry is known to be one of the large CO_2 emitting industry, thus there is a strong need to mitigate the CO_2 emissions. Efforts have been made to develop steel-industry specific CO_2 capture technology removing CO_2 from blast furnace gas (BFG) [3,4]. Recalling the fact that ammonia solution can be regenerated at relatively low regeneration temperature, ammonia-based CO_2 capture technology can utilize low-grade steam which can be generated by recovering waste heat at low temperatures. Therefore, the ammonia-based CO_2 capture process can be very attractive in the iron and steel industry since there are lots of available waste heats at the low temperature range.

Depending on the calculation method, the application sector, location, and time, the operating cost of CO_2 capture facilities can vary considerably. For a pulverized coal-fired power plant, a cost analysis for CO_2 capture using monoethanolamine (MEA) has been performed and the CO_2 capture cost was estimated at \$50-75/t-CO_2 avoided using a process simulator [5]. More recently, a report was released dealing with the commercial & finance topics and the CO_2 avoidance cost range was €30-35/t-CO_2 [6].

In this paper, we report the test result of ammonia-based CO_2 capture technology at POSCO-Pohang Works. A rough estimation of the operating cost of the process has been made based on the pilot plant operation data together with a brief technical performance.

2. Method

2.1. Process Description

An aqueous ammonia-based CO_2 capture pilot facility has been constructed and in operation at POSCO-Pohang Works since mid-2011. The facility can process BFG at 1,000 Nm^3/hr resulting in the production of 10 t-CO_2/d. It is integrated with other sub-facility which comprises an exemplary CO_2 emissions reduction concept in iron and steel industry. After leaving the CO_2 capture facility, the captured CO_2 is converted into CO, a reducing agent, and then fed into BF to reduce the cokes consumption in iron-making process. In the meantime, the thermal energy or steam required for the regeneration of absorbent solution is provided by the waste heat recovery system.

The overall process concept for the CO_2 capture process combined with the waste heat recovery system is depicted in Fig. 1. BFG containing about 20% of CO_2 is processed by the rich solution and product CO2 is obtained at the top of regenerator or striper, while the waste heat from flue gas leaving a boiler stack has been recovered and used to generate steam for reboiling. The details of the ammonia-based CO_2 process can be found in the literature [3]. The ammonia-based CO_2 capture process is composed of three columns; absorber, stripper or regenerator, and concentrator. The basic concept for capturing CO_2 is similar to the typical amine-based CO_2 capture system. However, instead of a reclaimer unit for the decomposition of the heat stable salt, the process adopted a concentrator or recovery unit of ammonia. In the concentrator column, the partially carbonated aqueous ammonia from the tops of absorber and stripper is reboiled at ~ 105 ^{o}C so that theoretically all the ammonia molecules are vaporized and then fed into the stripper. Washing water is supplied to the tops of regenerator and absorber and to be recycled via concentration column.

CO_2 concentrations in the inlet and outlet of BFG and that in the product stream were measured by NDIR (non-dispersive infrared) CO_2 analyzer. Based on the concentration data, the CO_2 removal efficiency has been calculated.

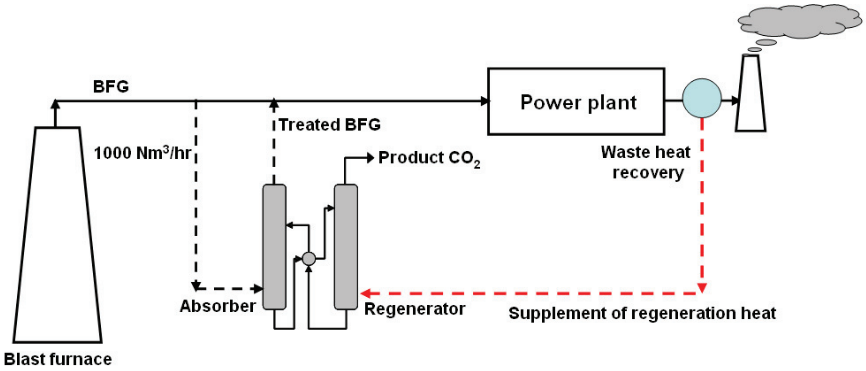

Fig. 1. Process schematic of an ammonia-based CO2 capture process at POSCO-Pohang Works [7].

2.2. Cost evaluation scheme

Total production cost for a chemical plant can be divided by the manufacturing costs and general expenses. The former contains direct production costs, fixed charges, and plant overheard costs, while the latter comprises of administrative expenses and distribution and marketing expenses [8]. The detailed cost analysis should be backed up by process simulation and long-term operation data at a larger scale facility. Moreover, more accurate financial and engineering data are mandatory. However, note that the scope of the work is not to thoroughly investigate the detailed analysis, but rather to provide a rule-thumb figure for process developers.

Accepting the limitations of this work, we can provide a rough estimate of an operating cost based on the current test results. While the operating cost of the CO_2 capture facility is affected by many parameters such as steam requirement, electricity consumption for pumps and cooling tower operation, process water consumption, and chemical loss (make-up cost of chemicals), etc., the majority of operating cost comes from the steam requirement for regeneration and concentration.

Thermal energy consumption (t-steam/t-CO_2) has been calculated by measuring the steam consumption. The quantity was obtained by the steam consumption flow rate (t-steam/hr) multiplied by 2.2 GJ/t-steam, the heat of vaporization of saturated steam at 1.0 kgf/cm^2_g. Typically, the electricity consumption has been measured at every two hours during the run.

3. Results and Discussion

3.1. Technical performance

The profile of CO_2 removal efficiency is shown in Fig.2. The steam generated by the waste heat recovery is designated as G steam. The efficiency of the CO_2 removal was about 90% and the concentration of CO_2 in the product stream is over 98% (figure not shown). The calorific value of BFG would be increased by 30% due to the selective removal of CO_2 from the supplied BFG. The increase in calorific value will increase the energy density; therefore, the process volume of BFG for combustion in the power plant could be significantly decreased, which, in turn, will lead to a cost benefit.

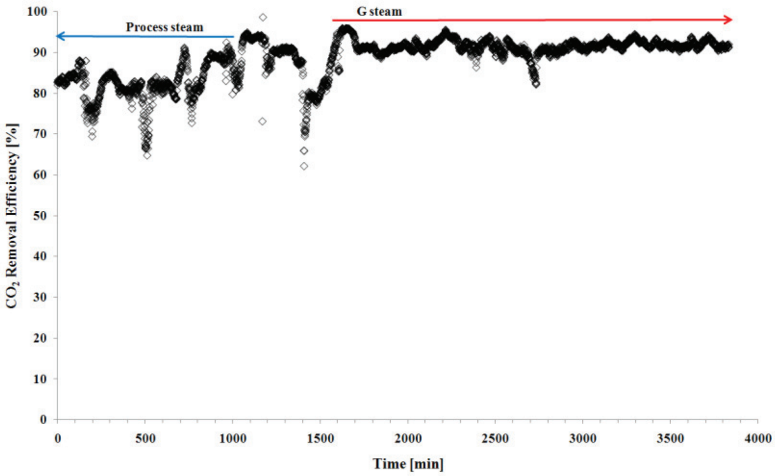

Fig. 2. Profile of CO_2 removal ratio during a test run of the pilot plant operation [7].

3.2. Cost analysis using field pilot operation results

Following the previous method for obtaining the operating cost of the process, we obtained the figures in the Table 1. For the process, the largest portion of the CO_2 capture cost was the electricity comprising 60-70%. The cost of electricity and make-up water to operate the waste heat recovery system comprises 20% of the cost. The cost for make-up water for the cooling tower and ammonia makeup due to ammonia loss was 10-15% of total CO_2 capture cost. Based on the pilot plant operation results, CO_2 capture cost was estimated under \$20/t-CO_2 because the process economics were greatly improved by using waste heat to provide the regeneration and concentration energy.

- Table 1. Operating cost of the ammonia-based CO_2 capture pilot plant from this work.

Cost components	Energy/Utility	Cost (\$)	Remark
Steam	~ 5 GJ/t-CO_2	0	For stripper and concentrator
			In case of the utilization waste heat
Electricity	~160 kWh/t-CO_2	~11	
Water	~3 m^3/t-CO_2	~1	
Ammonia	~2 kg/t-CO_2	~1	
Waste heat recovery		~3	Electricity and steam cost
Other expenses		~2	
Total operating cost		<20	

Considering the potential of electricity production by the waste heat, the opportunity cost is about \$ 10/t-CO_2. It was calculated by considering the sales of the electricity produced by using the Organic Rankine Cycle (ORC). The cycle is one of the efficient electric generation systems in low temperature range (70~350 ℃). The efficiency was assumed to be 10%. Therefore, it can be insisted that the total operating cost is lower than \$ 30/t-CO_2, even with the opportunity cost of the waste heat.

The steam requirement for the regeneration of aqueous ammonia is somewhat higher than that of amines [4]. However, recall that the steam for CO_2 production can be solely provided by the waste heat recovery system, which makes the process economically outstanding when there is available waste heat at mid and low temperatures.

3.3. Potentials to improve the process economics

From the results and discussion regarding the cost calculation of the CO_2 capture process, it should be stressed that even though the energy consumption is relatively larger than that of other competing technologies, the cost for the operation may not be; Available resources such as waste heat can drastically reduce the energy cost.

Suggestions can be made for the cost reduction of the ammonia-based CO_2 capture processes; ammonia slip prevention, heat integration within the system, process optimization and improvement, etc. Suppression of ammonia slip is of great importance for the commercialization of the ammonia-based CO_2 capture process. Replacing current structured packings with cheaper random packings in the column may be taken into consideration for the reduction of capital investment. Process improvement such as pressurized absorption/regeneration and recycle/reuse of waste stream is quite critical to the process economics. To reduce the operating cost, the process monitoring could be an effective tool. This can be done either by direct sensing of the process and control variables or by statistical and soft-sensing technology since the chemical process is quite complicated.

As discussed earlier, various factors determining the cost of CO_2 capture have to be taken into consideration to reasonably support the decision making process. Some of them are the following: time and duration, location(country) of the plant, fuel cost (for power generation sector) and other financial factors. Lots of financial factors including equipment, facility, utility, and human are affected by the choice of time and location. The following can be suggested for the cost analysis of CO_2 capture technology. Field operation data should be verified by another independent authorized organization. An economic analysis tool can be also applied to accurately deduce the cost analysis.

4. Conclusion

We have confirmed that the ammonia-based CO_2 capture technology can be successfully applied in the iron and steel industry. The CO_2 capture ratio was ~90% and the purity of product CO_2 was over 98%. Moreover, the CO_2 capture system can be successfully integrated with the waste heat recovery system. From a rough estimation on the process economics, we found that the majority of the energy consumption comes from the thermal energy or steam for absorbent regeneration and ammonia recovery. Although the energy consumption at current development status is relatively larger compared to the advanced amine system, the operating cost can be drastically lower than that If thermal energy could be supplied from the waste heat for stripping and concentration energy, the CO_2 capture cost from BFG can be reduced to less than \$ 20/t-CO_2. Conclusively, the ammonia-based CO_2 capture technology is extremely functional if there is unrecovered waste heat at low temperature like the iron and steel industry. The detailed process simulation data at larger scale, at least ~100,000 t-CO_2/yr basis and long-term operation data are pre-requisite to the more realistic estimate of the process economics.

Acknowledgements

This research was supported by POSCO and the Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Korea Government Ministry of Knowledge Economy (No. 20122010200040).

References

[1] Yeh AC, Bai H. Comparison of ammonia and monoethanolamine solvents to reduce CO_2 greenhouse gas emissions. *Sci Tot Env* 1999;228:121-33

[2] Kim JY, Han K, Chun HD. CO_2 absorption with low concentration ammonia liquor. *Energy Procedia* 2009;**1**:757-762.

[3] Rhee CH, Kim JY, Han K, Ahn CK, Chun HD. Process analysis for ammonia-based CO_2 capture in iron making industry. *Energy Procedia*. 2011;**4**:1486-1493.

[4] Mimura T, Murahashi K, Hayashi M. The long term performance of carbon dioxide capture from blast furnace gas by chemical absorption process. 2011. In: Presented at the 1st Post Combustion Capture Conference, Dubai, UAE .

[5] Plasynski SI, Cerfino JP. The cost of carbon dioxide capture and storage in geologic formations.Program Facts 2008.

[6] European Technology Platform for Zero Emission Fossil Fuel Power Plants. The costs of CO_2 capture, transport and storage: Post-demonstration CCS in EU. *ZEP Cost Report*. 2011.

[7] Kim JY, Han K, Ahn CK, Rhee CH, Park HS, Chun HD. Development of 1,000 Nm^3/hr CO_2 capture pilot plant from BFG based on aqueous ammonia. In: Presented at International Conference on Carbon Reduction Technologies. Polish Jurassic Highland, Poland, 2011.

[8] Peters MS, Timmerhaus, KD. *Plant design and economics for chemical engineers*. 4the ed. McGraw-Hill, Inc.1991