Advances in Mechanical Engineering and its Application (AMEA)
Vol. 3, No. 2, 2013, ISSN 2167-6380

www.worldsciencepublisher.org

ChemCAD Simulation of Benfield Process to Remove CO_2 from Natural Gas and Inspection of Temperature Profile of Key Units

[1]Niaz Bahar Chowdhury, [2]Nahin Bahar Chowdhury

[1]Chemical Engineering Department, Bangladesh University of Engineering and Technology, Dhaka, Bangladesh
[2]Mechanical Engineering Department, Chittagong University of Engineering and Technology, Chittagong, Bangladesh

Email: niazche@gmail.com

Abstract – Natural gas is one of the prime sources of fuel, industrial utility and raw material in the world. Due to the presence of unwanted substances (e. g. carbon dioxide, sulfur content) natural gas cannot be used directly without any kind of treatment. There are certain harmful components which must be brought under permissible limit to ensure safe operation. Sulfur, carbon dioxide and water are the components which need to be removed from the raw natural gas. Sulfur is corrosive and harmful to the environment. It also causes catalyst deactivation in processing plants. Carbon dioxide and water needs to be removed to ensure appropriate heating value of natural gas. There are many processes to remove carbon dioxide. Among them Benfield process is one of the widely used processes. The purpose of this is study is to study the carbon dioxide removal efficiency of Benfield process using well known process simulator ChemCAD. Also temperature profile of important unit operations will also be discussed in this study. This study will be very helpful for the proper operation of the carbon dioxide removal process.

Keywords – Natural Gas, Benfield Process, ChemCAD, Carbon Dioxide Removal efficiency, Temperature Profile

1. Introduction

The processes that have been developed to accomplish removal of carbon dioxide vary from a simple once-through wash operation to complex multiple step recycle system. In many cases, the process complexities arises from the need for recovery, in one form to another, of the impurity being removed or recover of the materials employed to remove it. Carbon dioxide removal processes are mainly of two types: Adsorption in a solid (dry process) and absorption into liquid (wet process). There are few processes that involve both processes like cellulose-acetate membrane process. Both adsorption and absorption may be of the physical or chemical type. Among the various processes, Benfield process is most frequently used process which falls into category of liquid absorption. The purpose of the study is to simulate a Benfield processing plant and to study the carbon dioxide removal efficiency. Temperature profile of various unit operations like contactor and regenerator will also be discussed in this study, as these two unit operations play an important role regarding effective operation of the process. [1]

2. Benfield Solution and Its Mechanism

Benfield solution is recognized as hot potassium carbonate solution used widely in the industry to remove carbon dioxide from feed stream.

Several reactions occur in the absorber that removes the carbon dioxide from our feed stream. Because many of these reactions are ionic reactions, this system can only be realistically modeled with the 'elec' option in Aspen. In addition to the reactions described below, the dissociation of water into hydrogen and hydroxide ions is also modeled. First of all in our system, our solvent, potassium carbonate, dissociates by the following reaction:

$$K_2CO_3 \ 2K^+ + CO_3^{2-}$$

This reaction sets up the carbonate system in the solution in the absorber. The carbonate system consists of the three equilibrium reactions of carbonic acid:

$$H_2CO_3 + H_20 \ H_3O^+ + HCO_3^-$$
$$HCO_3^- + H_2O \ H_3O^+ + CO_3^{2-}$$
$$CO_2 + 2H_2O \ H_3O^+ + HCO_3^-$$

The last reaction describes exactly how the carbon dioxide in the feed stream gets absorbed into the solution. This carbon dioxide reacts to form mostly bicarbonate ion which then exists in an equilibrium relationship with potassium bicarbonate as in the following reaction:

$$K^{+} + HCO_3^{-} \; KHCO_3$$

The bottoms stream coming out of the absorber consists of potassium bicarbonate, bicarbonate ion, carbonate ion, and carbonic acid along with slight impurities. In this way, all of the carbon dioxide in the feed stream is absorbed into the bottoms solution that then continues on to the stripper.

In the stripper, essentially, the reverse reactions occur. Equilibrium shifts to the left side of the above carbonate system equations. This shift in equilibrium occurs largely because of the huge difference in pressures between the absorber and the stripper. The stripper removes the carbon dioxide from the solvent and sends in on to be purified and sold. The regenerated solvent is then recycled back to the absorber to complete the cycle again. This solvent can be recycled indefinitely, and new solvent needs to be added to the system only to make up for small solvent losses in the stripper [2].

3. Why Benfield Solution?

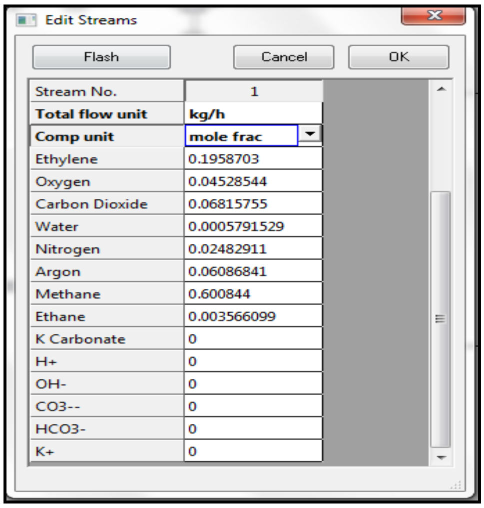
Many commercial processes for the removal of carbon dioxide from high-pressure gases use aqueous potassium carbonate systems promoted by secondary amines. This paper presents thermodynamic and kinetic data for aqueous potassium carbonate promoted by piperazine. Research has been performed at typical absorber conditions for the removal of CO2 from flue gas. Piperazine, used as an additive in 20–30wt% potassium carbonate, was investigated in a wetted-wall column using a concentration of 0.6m at 40–80°C. The addition of 0.6m piperazine to a 20wt% potassium carbonate system decreases the CO2 equilibrium partial pressure by approximately 85% at intermediate CO2 loading. The distribution of piperazine species in the solution was determined by proton NMR. Using the speciation data and relevant equilibrium constants, a model was developed to predict system speciation and equilibrium.The addition of 0.6m piperazine to 20wt% potassium carbonate increases the rate of CO2 absorption by an order of magnitude at 60°C. The rate of CO2 absorption in the promoted solution compares favorably to that of 5.0M MEA. The addition of 0.6m piperazine to 20wt% potassium carbonate increases the heat of absorption from 3.7 to 10kcal/mol. The capacity ranges from 0.4 to 0.8mol-CO2/kg-H2O for PZ/K2CO3 solutions, comparing favorably with other amines [3]

4. Advantage of using Benfield process

Although alkanolamine solvents, such as monoethanolamine (MEA), and solvent blends have been developed as commercially-viable options for the absorption of carbon dioxide from waste gases, natural gas, and hydrogen streams, further process improvements are required to cost-effectively capture CO_2 from natural gas processing plant. The promotion of potassium carbonate appears to be a particularly effective way to improve overall solvent performance. K_2CO_3 in solution with catalytic amounts of piperazine (PZ) has been shown to exhibit a fast absorption rate, comparable to 30 weight percent MEA. Equilibrium characteristics are also favorable, and the heat of absorption (10-15 kcal/mol CO_2) is significantly lower than that for aqueous amine systems. Studies also indicate that PZ has a significant rate of reaction advantage over other amines as additives [4].

5. Inlet Gas Composition

We considered the average composition of natural gas found from the various gas fields of Bangladesh. The composition can be changed according to the composition of an individual gas field. And depending on the composition, the unit operations used in this simulation may be changed partially.



Edit Streams

Flash Cancel OK

Stream No.	1
Total flow unit	kg/h
Comp unit	mole frac
Ethylene	0.1958703
Oxygen	0.04528544
Carbon Dioxide	0.06815755
Water	0.0005791529
Nitrogen	0.02482911
Argon	0.06086841
Methane	0.600844
Ethane	0.003566099
K Carbonate	0
H+	0
OH-	0
CO3--	0
HCO3-	0
K+	0

Figure1. Inlet Gas Composition

6. Key unit operation used

The unit operations used in this simulation is

1) Contactor or Absorber
2) Flash Separator
3) Regenerator
4) Cooler
5) Centrifugal Pump
6) Mixer

7) PID Controller

These unit operations may vary from one gas field to another. It depends on the composition of the natural gas and degree of separation required. Depending on the parameter, more than one flash separator/ cooler/ centrifugal pump/ mixer can be used. There are no reactions involved in this simulation. So, no unit process is required.

7. Process Description

Natural gas from the well head at a temperature 33°C and 22 bar pressure enters the contactor. It is also called absorber. Here the carbon dioxide from the natural gas is absorbed by the Benfield solution which enters the contactor at 83°C and 28.5 bar pressure. CO_2 is absorbed in Benfield solution and the sweet gas leaves the contactor for further processing if necessary. The rich Benfield solution enters a flash separator which is operating at 1.5 bar pressure and 86°C temperature. Due to reduction of pressure, a fraction of the volatile component flashes out from the flash separator and enters the separator at 1.5 bar pressure and 86°C temperature. Here Benfield solution is separated from the lean solution and the rest volatile hydrocarbon components are vented to the atmosphere. Now the lean Benfield solution is sent to a mixer using a centrifugal pump having 28.5 bar pressure and 83°C temperature. Here, makeup Benfield solution is added to the mixer. The reason of addition of makeup Benfield solution is, there is loss of Benfield solution during the operation. To makeup this loss additional amount of Benfield solution is added to the mixer. The outlet of the mixture is sent to the absorber having at temperature 83°C and 28.5 bar pressure. This solution is used in the contactor to separate carbon dioxide from well head natural gas. [5]

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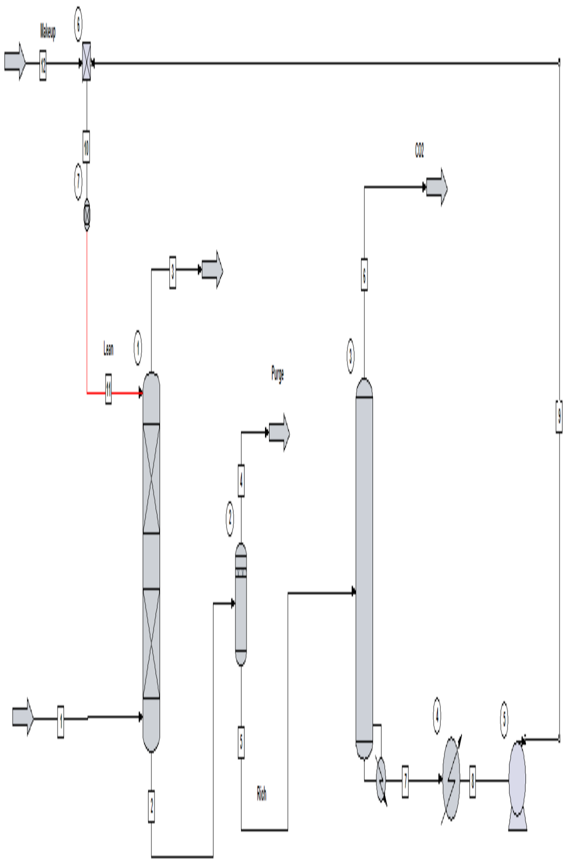

Figure2. Benfield Process

8. Temperature profile of Contactor and Regenerator

The temperature profile of the contactor is given below, which is generated using ChemCAD process simulator. This profile gives us a detail idea about the temperature profile in the contactor, which is a very important operational data need to be maintained at a constant value for safe operation. Form this graph we can find that, with the increase of stage in contactor temperature rises, which shows resembles to the real life situation also.

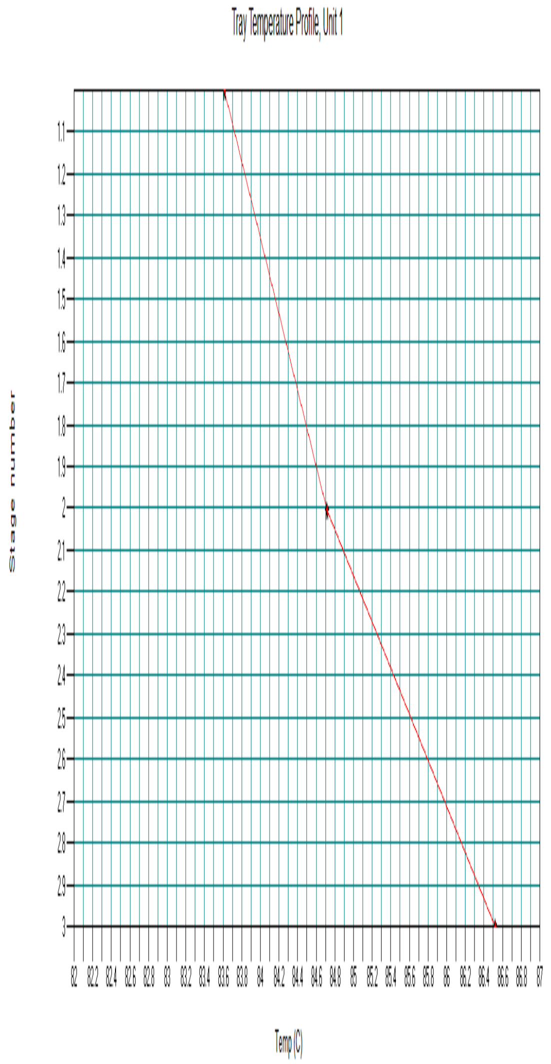

Figure3. Temperature profile of contactor

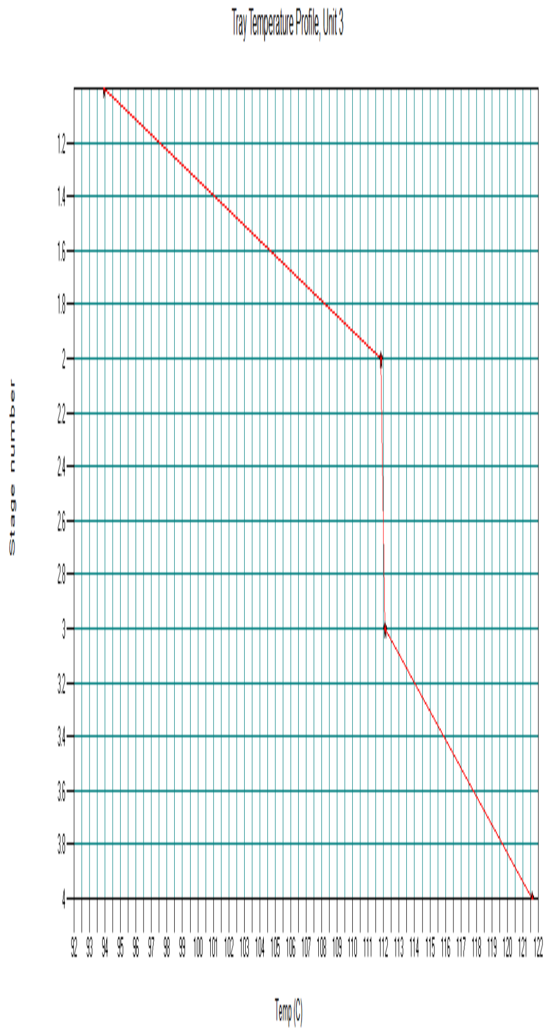

Figure4. Temperature profile of contactor

The temperature profile of regenerator is also given below. This temperature profile of regenerator is an important operational data and also very important parameter regarding effective separation of Benfield solution. The regeneration efficiency of Benfield solution largely depends on the operational temperature of the regenerator. So the temperature profile data of regenerator is of great use for operational purpose and also to maintain design efficiency of the regenerator. From the graph we can see that there are three distinct regions in the temperature profile of regenerator. With increase of stage number temperature also increases which shows resembles with real life situation. This complex behavior needs further research to explain properly.

9. Removal Efficiency

The mole fraction of carbon dioxide in inlet natural gas is 0.06815 and the mass flow rate is 5175 kg/hr. The mole fraction of carbon dioxide in the outlet gas is 0.0000428 and the mass flow rate is 3.0375 kg/hr. So the extent of removal of carbon dioxide using Benfield process is nearly 90.5%. So this process can be effectively and economically used to remove carbon dioxide from the raw natural gas. [6]

10. Result and Discussion

The output composition of natural gas using this process is given below. Here, 90.5% removal efficiency of carbon dioxide is achieved. This process is not very useful to remove sulfur component from the natural gas. Hence, if the natural gas contains significant amount of carbon dioxide, then this process is really helpful to remove carbon dioxide upto the sales gas condition. Modification can be made in this process by heating the raw natural gas by sales gas, using a shell and tube heat exchanger. This will reduce the heating load of the contactor and eventually results in a good separation. This practice is yet to implement in the industrial carbon dioxide removal process.

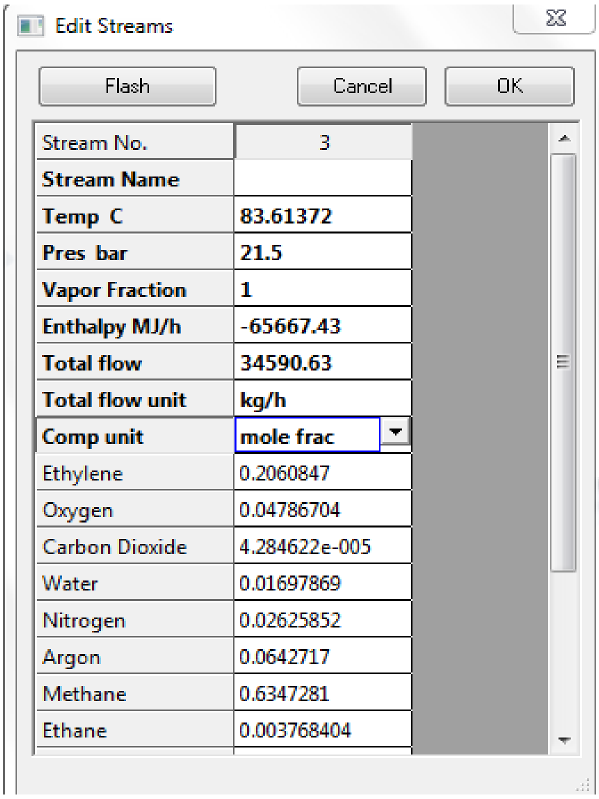

Figure5. Output composition of natural gas

11. Conclusion

This study will immensely help the industry people. The temperature profile of various unit operations is an important operational criterion. Hence, using this simulation one can easily predict the temperature of a certain stage of contactor and regenerator. This will ease the operational effort and also help to achieve sound and smooth operation of the Benfield process. Application of simulation study will also help the industry people to relate various parameters by changing the appropriate variables. So this study will be very useful for the people related to operation of Benfield process.

Acknowledgements

The sincere help of Md. Muniruz Zaman from Mechanical Engineering Department of Bangladesh University of Engineering and Technology is acknowledged. Without his help it would be really tough to study the Benfield process.

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Vitae

Mr. Niaz Bahar Chowdhury was born in Chittagong, Bangladesh. He obtained a B. Sc degree in 2012 in Chemical Engineering department from Bangladesh University of Engineering in Technology.

He worked as a Research Assistant in the above department. His research interest includes LPG, Process Engineering, Coal Gasification, and Thermal Engineering.