Engineering Press

Research Article

A Novel Global Warming Solution: Use of Flue Gas to Produce Urea

S. Rahman, S. Ajith, Z. Rashed Aldhaheri, S. Saeed[1], L. Owda[1] and O. Chaalal*

College of Engineering, Chemical Engineering Department, Abu Dhabi University, United Arab Emirates

***Corresponding author**
Omar Chaalal
College of Engineering
Chemical Engineering Department
Abu Dhabi University
United Arab Emirates
E-mail: Omar.chaalal@adu.ac.ae

***Received:** February 13th, 2018*
***Accepted:** April 30th, 2018*
***Published:** May 7th, 2018*

Citation
Rahman S, Ajith S, Rashed Aldhaheri Z, Saeed S, Owda L, Chaalal O. A Novel Global Warming Solution: Use of Flue Gas to Produce Urea. *Eng Press*. 2018; 2(1): 62-65. doi: 10.28964/EngPress-2-112

ABSTRACT

Urea is a nitrogenous organic compound which is widely used as a fertilizer and in the agricultural industry. On an industrial scale, urea can be manufactured from the reaction of carbon dioxide and ammonia. The goal of this research is to design a plant that produces 46.84 ton / hr. Urea from the raw materials carbon dioxide and ammonia. The quantities of carbon dioxide and ammonia consumed in the process were 37.32ton/hr and 28.84 ton/hr. respectively. The carbon dioxide is obtained using a sustainable approach from the waste products, the flue gas, of a nearby power plant. In the first step of the process, carbon dioxide is extracted in an absorption column that uses ammonia and stripping columns from the flue gases emitted from a power plant. This ensures that the whole production process is environmentally sustainable and contributes in the reduction of carbon dioxide that causes of global warming.

INTRODUCTION

Carbon dioxide is the main greenhouse gas that needs to be reduced from the atmosphere. There are various technologies used to separate CO_2 from flue gas. These include chemical solvent methods, physical absorption methods, cryogenic methods, membrane systems, biological fixation, and the O_2/CO_2 combustion process. Compared with the chemical plant, power plant has a large flue gas flow, different ingredients, relatively low CO_2 concentration and other characteristics. The chemical solvent techniques are generally recognized as the most effective technologies for CO_2 removal. This requires that the researchers developed a relatively low-cost, low-energy requirement CO_2 capture technology. Among the conventional CO_2 chemical removal processes, the monoethanolamine (MEA) process has been comprehensively studied and successfully used in chemical plants for CO_2 recovery in natural gas processing. Although the MEA process is a promising system for the control of CO_2 emissions from massive discharging plants, it is an expensive option since the cost of CO_2 separation may range from US$40 to 70/ton of CO_2 removed.[1] In addition, it has several major problems including a slow absorption rate, a small solvent capacity, etc.[2] Recently some studies shows that aqueous ammonia have a higher absorption capacity than that of monoethanolamine (MEA) at same temperatures and pressures. The CO_2 removal efficiency of aqueous ammonia can reach 95~99%, even 100%, and MEA is generally 90%.[3] An absorption capacity of aqueous ammonia can be higher than 1.0 kg CO_2/kg solvent, and MEA is only 0.36 kg CO_2/kg MEA.[4] The selection of ammonia in this process was based on its high capacity as mentioned in reference.[3]

Carbon dioxide affects global warming

Since 1988, the world's environmental scientists on the Intergovernmental Panel on Climate Change (IPCC, 2014) have provided multiple and clear scientific reports on the state of knowledge on climate change. Our planet is warming and the climate is changing. This sentence is a fact. No one can deny it. Because of the impact of global warming on our future, it is the most important environmental issue and a subject of actuality in the present. For instance, extreme weather disasters have partially or completely damaged crop production in many parts of the world.[5,6,7,8,9]

Global warming is the gradual noticeable increase in the earth's average overall temperature due to the atmosphere trapping the heat that's radiating from the earth. It is mainly caused by the greenhouse effect. One of the main gases that cause global warming is carbon dioxide. Carbon dioxide is either released into the atmosphere by natural processes like volcanic eruptions and naturally accruing fires or by human processes like the burning of fossil fuels leading to very drastic effects on the environment.[10] Power plants, oil refineries, and other factories make humungous amounts of CO_2 that is beyond the earth's capability to absorb and neutralize. Mainly in GCC Gulf countries, where the demand for desalinated water is too high, the emissions of carbon dioxide are increasing progressively. In order to decrease those environmental effects, the plant presented in this study will reuse the carbon dioxide from power plants in desalination plants into the process of the urea production. This way, the amount of carbon dioxide emitted into the atmosphere will decrease and the plant will save up costs of producing or extracting carbon dioxide in order to be used. Recent project was studied to reduce CO_2 from either natural gas or exhaust gases where the experimental results showed excellent removal of CO_2.[11,12,13] This means, there are possible ways to reduce carbon dioxide while making good use of it when dealing with reactions like the production of urea. Moreover, putting the environmental effects under consideration while making a plant will help to reduce the effects of global warming which vary from the increase of temperature and sea levels to rough heat waves and intense hurricanes.[14,15]

Theory of the process: Ammonia and CO_2 Reactions

The commercial synthesis of urea involves the combination of ammonia and carbon dioxide at high pressure to form ammonium carbamate which is subsequently dehydrated by the application of heat to form urea and water. One can say NH_3 and CO_2 are converted to urea via ammonium carbamate at a pressure of approximately 140 bar and a temperature of 180-185°C.

$$\underset{\text{Ammonia}}{2NH_3} + \underset{\text{Carbon Dioxide}}{CO_2} \overset{1}{\longleftrightarrow} \underset{\text{Ammonium Carbamate}}{NH_2COONH_4} \overset{2}{\longleftrightarrow} \underset{\text{Urea}}{CO(NH_2)_2} + \underset{\text{Water}}{H_2O}$$

Reaction 1 is fast and exothermic and essentially goes to completion under the reaction conditions used industrially. Reaction 2 is slower and endothermic and does not go to completion. The conversion (on a CO2 basis) is usually in the order of 50-80%. The conversion increases with increasing temperature and NH_3/CO_2 ratio and decreases with increasing H_2O/CO_2 ratio.

The total reaction of aqueous ammonia absorb carbon

dioxide can be described as the equation (1):

$$CO_2\,(g) + NH_3\,(aq) + H_2O\,(l) <=> NH_4HCO_3\,(aq) \qquad (3)$$

The actual process of the reaction is more complicated, that can be described as step-by-step reactions.

First of all, equation (2) occurs, and CO2 and NH_3 react to generate NH_2COONH_4, then NH_2COONH_4 hydrolyzes in solution instantaneous.

$$CO_2\,(g) + 2NH_3(aq) => NH_2COO^-(aq)+NH_4^+(aq) \qquad (4)$$

Then, NH_4^+ and NH_2COO^- have an irreversible reaction (3) in solution:

$$NH_2COO^-(aq) + NH_4^+\,(aq) + 2H_2O => NH_4HCO_3(aq) + NH_3(g) + H_2O(aq) \qquad (5).$$

At the same time, the complex balances of solute ionizing and ion reactions are happening in the solution, and the reaction equations are (4)-(8) as follows:

$$NH_3(aq) + H_2O(l) => NH_4^+(aq) + OH^-\,(aq) \qquad (6)$$

$$NH_4HCO_3(aq) => NH_4^+(aq) + HCO_3^-(aq) \qquad (7)$$

$$(NH4)_2\,CO_3(aq) => 2NH_4+(aq)+CO_3^{2+}(aq) \qquad (8)$$

$$OH^-(aq) + HCO_3^-(aq) => CO3^{2+}\,(aq) + H_2O \qquad (9)$$

$$CO_3^{2+}(aq) + CO_2\,(g) + H_2O(l) => 2HCO \qquad (10)$$

Presentation of the process:

The proposed process is done in two steps and the whole process is presented in (Figure 1).

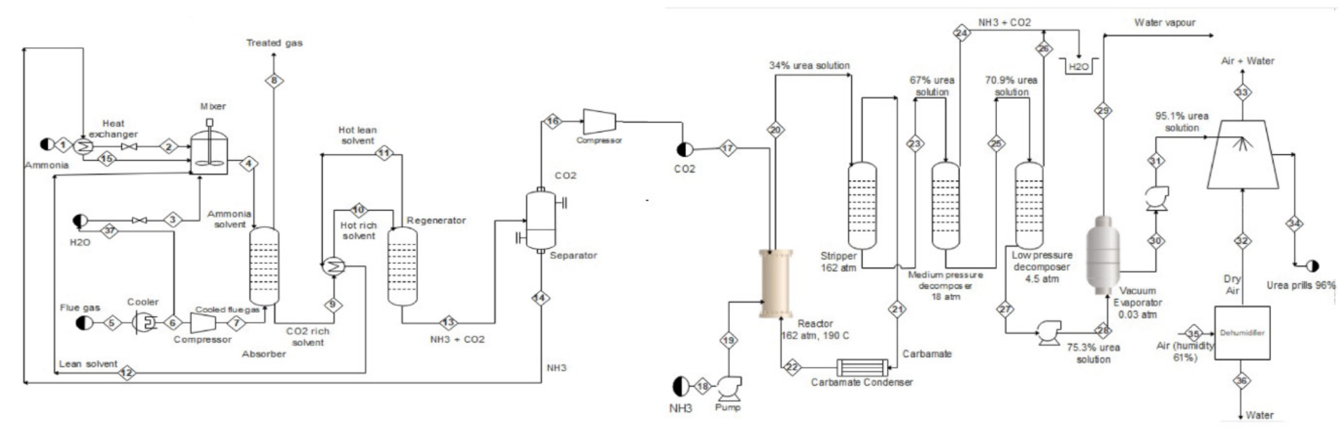

Figure 1: Overall Process Flow Diagram

Step 1: Carbon dioxide capture and separation

The first step of the process which is the sustainable approach in this project is to isolate carbon dioxide gas from the flue gases emitted from a nearby power plant. This is done by absorption using ammonia solvent. In order to prepare the ammonia solvent, liquid ammonia is purchased from a supplier and stored in the vicinity of the plant. A valve controls the flow of this liquid ammonia to a mixer where water is also added to make a 30% ammonia solution to be used as a solvent. Since the temperature of the stored ammonia is extremely low, it is made to pass through a heat exchanger initially where the temperature is raised to room temperature.

The hot flue gas obtained from the nearby power plant cannot be used at high temperatures. In order to bring down the temperature, it is passed through a cooler where the water vapor gets condensed and is recycled back to the water source to prepare the ammonia solution. Once the gasses are cooled, a blower push them to an absorption column that operates at atmospheric pressure and normal temperature.

In the absorption column, the flue gas enters from the bottom and the ammonia solvent enters from the top. The flow is countercurrent where the treated gas, mainly nitrogen, is left to the atmosphere while the carbon dioxide rich solvent is made to enter a heat exchanger. Once the carbon dioxide rich solvent gets heated, it is made to enter a regenerator where two outlet streams are obtained: hot lean solvent and another containing ammonia and carbon dioxide.

In order to obtain the carbon dioxide alone, the former outlet stream from the regenerator is sent to a liquid separator where the carbon dioxide rises to the top of the column and exits out. It is then directed to the second step of the process to be used for urea manufacture. The ammonia liquid which exits from the bottom of the separator gets recycled back to the mixer to make more of the ammonia solvent to be used for absorption. It is important be note that once the process reached steady state, the valve that controls flow of ammonia from the storage tank is closed so that the ammonia solvent keeps getting recycled in the closed loop. This ensures that the process is more profitable and sustainable.

Step 2: Production of urea

The second part of the process is to actually manufacture the urea. This occurs in a reactor which is at high temperature and high pressure ensuring maximum conversion of the reactants. The reactants used will be the carbon dioxide obtained from the previous process as well ammonia gas which is pumped into the reactor. The end of the reaction shows that 34% urea solution is produced along with other undesired products such as water, ammonia and carbamate. In order to purify the urea more, it sent to a stripping column where the carbamate separates out from overhead, The carbamate is then sent to a carbamate condenser where it is condensed back to liquid from and then recycled back to the reactor.

The rest of the 67% urea solution is sent to a decomposer at medium pressure. Here, 50% of the undesired ammonia and carbon dioxide gases are removed from the top while giving 70.9% pure urea solution. This is then sent to another decomposer at low pressure where the rest of the ammonia and carbon dioxide are removed and the only remaining solution 75.3% urea.

In order to remove the water from this solution, it is sent to an evaporator at vacuum conditions and low pressure, where water gets evaporated and is let into the atmosphere. The remaining 95.1% urea solution is sent to a prilling tower to further remove moisture content.

In the prilling tower, dry air is required to carry out the process. This dry air is obtained after passing humid air to a dehumidification unit. The urea solution is sprayed in the prilling tower where it counteracts with the dry air to form urea prills of 96% purity. This is the end product of the urea manufacture which can then later be stored and sold.

CONCLUSION

The research in this paper has been developed using the most practical but cost efficient and sustainable measures to produce urea. One of the main reactants needed for this production, carbon dioxide is obtained through an environment friendly approach. Being located next to a power plant, waste flue gases rich in carbon dioxide can easily be collected and used to produce urea. Using this innovative technique, carbon dioxide gas is obtained from the waste product which would have otherwise been emitted into the atmosphere to cause global warming. The flue gases undergo a series of absorption and regeneration processes with ammonia solvent to get the pure carbon dioxide. The urea is manufactured using this innovative process to get the final commercial product-solid urea prills. The whole process has been developed using the most efficient sustainable approach.

REFERENCES

1. Chakma A. Separation of CO_2 and SO_2 from Flue Gas Streams by Liquid Membranes. *Energy Convers. Manage*. 1995; 36(6-9): 405-10. doi: 10.1016/0196-8904(95)00031-8

2. Molburg JC, Thimmapuram P, Doctor RD. Comparison of Salient Features of Alternatives CO_2 Recovery Processes. A&WMA Annual Meeting, Cincinnati, June 1994.

3. Zhang Z, et al. Research on Physical Chemistry Characters and Production Increasing Mechanism of Long Effective Ammonium Bicarbonate. *China Science (B)*. 1996; 26: 453.

4. Bai HL, et al. Removal of CO_2 Greenhouse Gas by Ammonia Scrubbing. *Ind Eng Chem Res*. 1997; 36(6): 2490-93. doi: 10.1021/ie960748j

5. Battisti DS, Naylor RL. Historical warnings of future food insecurity with unprecedented seasonal heat. *Science*. 2009; 323(5911): 240-244. doi: 10.1126/science.1164363

6. World Food Program. Pakistan-Flood Impact Assessment. Website. http://documents.wfp.org/stellent/groups/public/documents/ena/wfp225987.pdf (2010) Accessed September, 2010.

7. Gu L, et al. The 2007 eastern US spring freeze: increased cold damage in a warming world. *Bioscience*. 2008; 58(3): 253-62. doi: 10.1641/B580311

8. Barriopedro D, Fischer EM, Luterbacher J, Trigo RM, García-Herrera R. The hot summer of 2010: redrawing the temperature record map of Europe. *Science*. 2011; 332(6026): 220-224. doi: 10.1126/science.1201224

9. Coumou D, Rahmstorf S. A decade of weather extremes. *Nature Clim. Change*. 2012; 2: 491-496. doi: 10.1038/nclimate1452

10. Cite a Website - Cite This For Me. Climate.nasa.gov, 2017. Website. https://climate.nasa.gov/effects/ Accessed October 22, 2017.

11. Chaalal O, Hossain M. A two-step process for removal of carbon dioxide and production of desalinated water using ammoniated saline water. *Environmental Progress & Sustainable Energy*. Website. http://www.wseas.us/e-library/conferences/2015/Seoul/ERG/ERG-11.pdf Accessed July, 2015.

12. Muhamad H, Chaalal O. Optimization Study for Carbon Dioxide in flue gas using liquid Membrane Permeator. International Conference: The 9th Dynamical Systems & Applications July 20-23, 2016 Antalya, Turkey. Website. http://at.yorku.ca/c/b/m/e/55.htm Accessed July, 2016.

13. Chaalal O, Muhamad H, Hossain MM, Hank D. A numerical study in a carbon dioxide membrane permeator. *Far East Journal of Mathematical Sciences*. 2016; 99(12): 1833-1847. doi: 10.17654/MS099121833

14. Global Warming Effects. Nationalgeographic.com. Website. https://www.nationalgeographic.com/environment/global-warming/global-warming-effects/. Accessed October, 2017.

15. Jackson R. Global Climate Change: Effects. Climate Change: Vital Signs of the Planet. Website. https://climate.nasa.gov/effects/. Accessed October, 2017.