NANOTECHNOLOGY CONVERTS CO_2 FROM POWER PLANTS FLUE GAS TO VALUABLE PRODUCTS (SODIUM BICARBONATE)

(US DOE DE-FE0031707)

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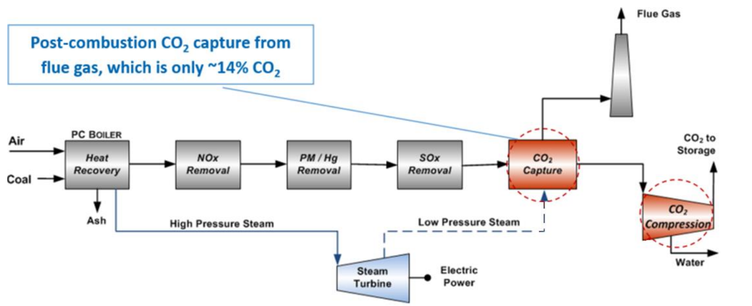
Postcombustion CO_2 Capture [1]



Objectives

To develop a continuous process using Amino Acids (AA) for CO_2 capture from a typical flue gas of post-combustion applications to obtain a high-value product (sodium bicarbonate nanoparticles). Gly will be used in the process.

Table 1. shows a typical flue gas composition [2]

Table 1. Typical Flue Gas Composition [2]

	Mol%
O_2	4.000
H_2O	7.000
CO_2	16.000
N_2	72.859
HCL	0.010
SO_2	0.080
SO_3	0.001
NO_2	0.025
NO	0.025

Previous Work

1. WVU (Li et al. 2017) experimentally proved that aqueous sodium glycinate solutions (Gly-NaOH-H_2O) convert CO_2 into nanofibers as shown in Fig. 1 [3].
2. Pitt developed and validated a five-components mathematical model in Matlab for CO_2 capture from a gas mixture (CO_2 + N_2) using 2M sodium glycinate (SG) aqueous solutions in an adiabatic countercurrent packed-bed absorber of 10-cm ID [4].
3. Pitt also developed a model in Aspen Plus v.10 for SG-(CO_2 + N_2) system. The Aspen Plus model predictions were compared with those of the Matlab model under the same operating conditions and a very good agreement was found [4].

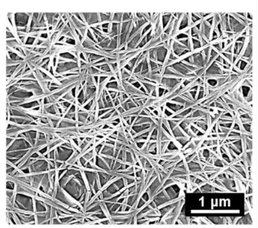


Figure 1. SEM image of nanofibers obtained [3]

Research Strategy

1. **Impurities (HCl, SO_2, SO_3, NO and NO_2) in a typical flue gas should be removed using an inexpensive fluid to ensure the production of pure sodium bicarbonate nanoparticles. Water will be used to wash the raw flue gas in a gas washing unit (GWU).**
2. **The impurities dissolved in the water will be removed using a reverse osmosis unit (ROU) and the clean water will be recycled back to the GWU. The wastewater will be disposed of or processed.**
3. **The impurities-free flue gas will be sent to a CO_2 absorption unit (CAU) to convert CO_2 to sodium bicarbonate nanoparticles.**
4. **The nanoparticles will be separated from the reaction products (aqueous glycine) in an ultrafiltration unit (UFU).**
5. **The nanoparticles will be collected, and the aqueous glycine will be mixed with makeup sodium hydroxide and recycled back to the CAU.**

Fig. 2 shows a schematic of the overall process.

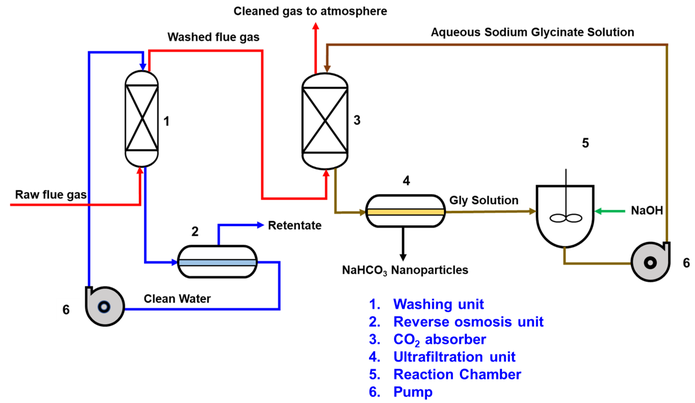
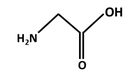
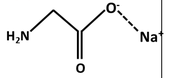


Figure 2. Schematic of a continuous process of CO_2 capture from flue gas and nanoparticle production

Reactions in the gas washing unit (GWU)	ΔH_r at 298.15 K (kJ/mol)
1. $SO_3 + H_2O \rightleftharpoons H_2SO_4(aq)$	- 227.72
2. $2SO_2 + O_2 \rightleftharpoons 2SO_3$	- 197.76
3. $SO_2 + NO_2 \rightleftharpoons SO_3 + NO$	- 41.81
4. $4NO + O_2 + 2H_2O \rightleftharpoons HNO_2(aq)$	51.66
5. $2NO_2 + H_2O \rightleftharpoons HNO_2(aq) + HNO_3(aq)$	- 107.09
Reactions in the CO_2 absorption unit (CAU) [5, 6]	
6. $NH_2CH_2COOH + OH^- \rightleftharpoons NH_2CH_2COO^- + H_2O$	- 11.636
7. $NH_2CH_2COO^- + H_2O + CO_2 \rightleftharpoons NH_2CH_2COOH + HCO_3^-$	- 56.85

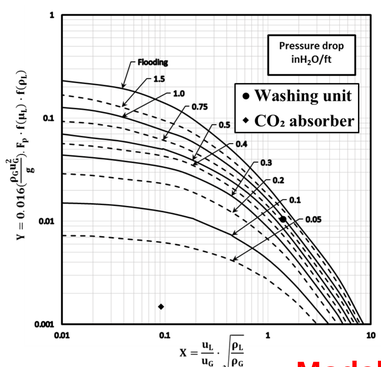


NH_2CH_2COOH = glycine



NH_2CH_2COONa = sodium glycinate

Hydraulics [7]



$$X = \frac{u_L}{u_G}\cdot\sqrt{\frac{\rho_L}{\rho_G}}$$

$$Y = 0.016\frac{\rho_G u_G^2}{g}F_p\cdot f(\mu_L)\cdot f(\rho_L)$$

$$f(\rho_L) = 1.5052\cdot\ln\left(\frac{\rho_w}{\rho_L}\right) + 1.1883$$

$$\log[f(\mu_L)] = 0.0591\cdot\log^3(\mu_L) + 0.0226\cdot\log^2(\mu_L) + 0.1701\cdot\log(\mu_L) - 0.0135$$

u_L is superficial liquid velocity, ft/s
u_G is superficial gas velocity, ft/s
ρ_L is liquid density, lb/ft^3
ρ_G is gas density, lb/ft^3
ρ_w is water density, lb/ft^3
F_P is packing factor, ft^{-1}
μ_L is liquid viscosity, mPa·s

Model Results

Table 2. Packed-bed absorber for the GWU

Flue gas flow rate, m^3/s	0.2	0.4	0.6
Absorber inside diameter, m	0.500	0.710	0.866
Packing height, m	3.00	4.26	5.20
Washing water flow rate, m^3/min	0.60	1.20	1.80
Impurities removal efficiency, %	100	100	100
Packing type	Mellapak 250Y		
Voidage, %	98.7		
Packing specific surface area, m^{-1}	256		

	Mol%	
	Flue gas	Washed Gas
O_2	4.000	4.194
H_2O	7.000	2.357
CO_2	16.000	16.220
N_2	72.859	77.228
HCL	0.010	1.81E-07
SO_2	0.080	1.07E-05
SO_3	0.001	5.14E-11
NO_2	0.025	2.13E-06
NO	0.025	2.55E-04

Table 3. Specification of BW30-400 R O membrane [8]

Active Area of membrane, m^2	37
Length of membrane, mm	1016
Diameter of the membrane, mm	201
Feed space, mm	0.08636
Feed flow rate range, m^3/h	0.8~19
Permeate flow, m^3/day	40
Stabilized contaminant rejection, mol%	99.5
Operating pressure, bar	15.5
Pure water permeability constant, kg/m^2/s/bar	7.50E-04
Salt permeability constant, kg/m^2/s	6.20E-05
Membrane cost, $ (2007)	900

Table 4. Reverse osmosis unit (ROU) setup [9]

Flue gas flow rate, m^3/s	0.2	0.4	0.6
	Number vessel x Number of membranes in series in a vessel		
Stage 1	2 x 6	5 x 6	7 x 6
Stage 2	1 x 6	2 x 6	3 x 6
Stage 3	1 x 6	1 x 6	2 x 6
Total number of membranes	24	48	72

Table 5. Performance the CO_2 capture absorber

Flue gas flow rate, m^3/s	0.2	0.4	0.6
Diameter, m	1.50	2.12	2.60
Height, m	15.0	21.2	26.0
Packing type	Ceramic Berl Saddle 13 mm		
2M Sodium glycinate flow rate, m^3/min	0.042	0.084	0.126
CO_2 Absorption efficiency	98.6%	99.6%	99.8%

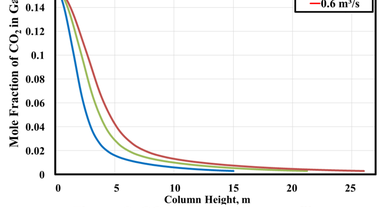


Figure 3. CO_2 mole fraction profile

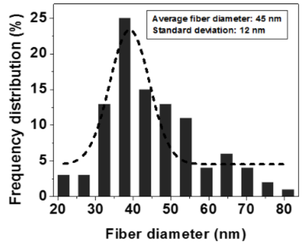


Figure 4. Diameter distribution of $NaHCO_3$ nanofibers

Table 6. Specifications of the UFU membrane (SFP-2660) [10]

Active area of membrane, m^2	33
Flow range, m^3/h	1.3 – 4.0
Length of membrane, mm	1860
Diameter of the membrane, mm	165
Nominal pore diameter, micron	0.03
Maximum transmembrane pressure, bar	2.1
Operating PH	2 - 11

Table 7. Production of $NaHCO_3$ nanoparticles

Flue gas flow rate, m^3/s	0.2	0.4	0.6
$NaHCO_3$ production, kg/s	0.1107	0.2234	0.3359
NaOH makeup, kg/s	0.0527	0.1064	0.1599

Table 8. CO_2 material balance

CO_2 in flue gas, kg/s	6.156E-02	1.231E-01	1.847E-01
CO_2 in clean gas, kg/s	8.439E-04	5.162E-04	3.446E-04
CO_2 in ROU retentate, kg/s	2.727E-03	5.553E-03	8.363E-03
CO_2 in $NaHCO_3$ kg/s	5.799E-02	1.170E-01	1.759E-01
Relative Error, %	3.824E-03	2.299E-02	1.117E-02

Conclusions

1. **A novel continuous process using aqueous sodium glycinate solutions (Gly-NaOH-H_2O) for CO_2 capture from a typical flue gas of post-combustion applications to obtain a pure high-value product (sodium bicarbonate nanoparticles) was developed.**
2. **The process can remove 100% of the gaseous contaminants from a typical post-combustion flue gas stream and can capture more than 98% of CO_2 from flue gas stream at different flow rates using aqueous glycine and sodium hydroxide solutions.**

Acknowledgement:
The material presented in this poster is based upon work supported by the US-DOE under Award Number (DE-FE0031707).

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