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Mitigation of inhibition effect of acid gases in flue gas using trona buffer for autotrophic growth of Nannochloris sp

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A B S T R A C T

In this study, trona buffer was used to mitigate the previously reported inhibition effect of CO2, SO2, NO, and HCl gases in combustion flue gases for the growth of Nannochloris sp. Culture medium with trona buffer after absorbing CO2(g) contains high dissolved inorganic carbon (DIC) concentration that can help maximize the growth and alleviate the inhibition effect as long as the pH of the medium is controlled at an optimum pH (pH ~7–8) window for the growth of Nannochloris sp. A supply of high purity CO2(g) did not inhibit the growth. The acid gaseous constituents including SO2, NO, and HCl gases did not significantly reduce the growth as compared to the results previously reported. This study suggests that trona buffer can be effectively used for microalgae cultivation as biological CO2 remediation when it is considered being integrated into a coal-fired power plant after wet flue gas desulfurization system.

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1. Introduction

Carbon dioxide (CO2) is one of the main contributors (more than 75%) to climate change [1]. As an increase in human activities, the CO2 concentration in atmosphere has reached 404.02 ppm in February 2016 that is reported to exceed a safe upper limit (350 ppm) [2,3]. According to the U.S. Environmental Protection Agency, ~37% of entire CO2 emissions in the U.S. were produced from the combustion of fossil fuels to generate electricity in 2013 [4]. Plants can convert CO2 gas (CO2(g)) into organic matter and store in the forms of carbohydrate, protein, and lipids by photosynthesis for diverse applications and products [5–7]. In this context, an interest in microalgae has recently increased due to fast growth (approximately 3 times faster than terrestrial plants) using CO2, a fair amount of lipids, and high heating values for potential use of carbon cycle and energy recovery [8–12].

In microalgae cultivation processes, bubbling air is conventionally used to supply dissolved inorganic carbon (DIC=HCO3− + CO2(aq)) for the autotrophic growth. However, atmospheric CO2(g) concentration is not high enough to generate the DIC concentration in culture medium for fast growth in engineered cultivation systems, however, it was reported that microalgal growth was significantly inhibited when CO2(g) concentration was higher than 5% and thus CO2(g) diluted with air was used in many previous studies [13–17].

Biological CO2 conversion via autotrophic microalgae cultivation could be a good option for reducing risk and offsetting the cost of carbon capture and sequestration. Coal combustion flue gas typically comprises of ~10–16% of CO2 [13]. Therefore, direct use of the flue gas for the growth of microalgae can greatly reduce the cost for the separation and purification of CO2. However, the growth of microalgae was reported to be inhibited by other gaseous components in flue gas, such as NOx (100–300 ppmv) and SOx (230–320 ppmv) [13]. When a coal-fired power plant is equipped with SO2 and NOx control devices, these two concentration ranges are high enough to cover their maximum concentrations in the flue gas. According to previous studies, SO2 and NO significantly inhibited the growth rate of microalgae by lowering the pH of the culture medium [13,17]. Therefore, sodium hydroxide (NaOH) was previously used to control the pH when high CO2 and acid flue gas components were present in flue gas [17,18]. However, it was reported that this method was effective only for some strains, such as Chlorococcum littorale and Chlorella KR-1 [17,18].

In this study, trona (Na2(CO3)·H2O) was used as a buffer chemical to minimize the inhibition effect of CO2, SO2, NO, and HCl gases. Trona is a naturally-occurring mineral and comprises of sodium bicarbonate (NaHCO3) and sodium carbonate (Na2CO3) at a 1:1 molar ratio. Trona is also inexpensive compared to other sodium-based buffer chemicals such as NaHCO3 and Na2CO3 (trona: $0.10/lb; industrial grade NaHCO3: $0.46/lb; industrial grade Na2CO3 $0.55/lb). Trona has high solubility in water (120 g/L at 0 °C,

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2. Materials and methods

2.1. Culture medium and conditions

*Nannochloris* sp. used (LB1999) in this study was purchased from UTEX Culture Collection of Algae at the University of Texas at Austin (UTEX). A trona sample used in this study (Na$_2$CO$_3$/HCO$_3$) 2H$_2$O, T200, purity: 90–98%) was provided by Solvay Chemicals, Inc. A 3.5-L culture medium was prepared by following the modified Shuusheng-4 medium (SH4M) in a 4-L cylindrical reactor (24 cm (height) × 14 cm (diameter)) and 0.02 M (4.5206 g/L H$_2$O) of trona was added to the medium. Here, 350 mL of the modified SH4M was placed in a 400-mL cylindrical bottle was separated before adding trona for a culture without trona (S0).

Then *Nannochloris* sp. was inoculated in the medium. After inoculating the initial cell density of *Nannochloris* sp. in the SH4M medium was found to be 168.0 ± 0.1 mg/L. 350 mL of the prepared SH4M medium was added to each 800-mL cylindrical bottle. After preparing the cultures, the pH of the cultures was daily controlled at 7.4 by bubbling 10% CO$_2$, 5% NO, and 88% H$_2$O gas mixture with different concentrations, including S0-S4, N1-N4 and H1-H4: S0 (CO$_2$ = 100%, N2 = 0%, SO$_2$ = 0 ppmv, NO = 0 ppmv, HCI = 0 ppmv), S1 (=N1 + H1) (CO$_2$ = 100%, N2 = 0%, SO$_2$ = 0 ppmv, NO = 0 ppmv, HCI = 0 ppmv), S2 (=N2 + H2) (CO$_2$ = 12%, N2 = 88%, SO$_2$ = 0 ppmv, NO = 0 ppmv, HCI = 0 ppmv), S3 (CO$_2$ = 12%, N2 = 88%, SO$_2$ = 50 ppmv, NO = 0 ppmv, HCI = 0 ppmv), S4 (CO$_2$ = 12%, N2 = 88%, SO$_2$ = 50 ppmv, NO = 0 ppmv, HCI = 0 ppmv), S5 (CO$_2$ = 12%, N2 = 88%, SO$_2$ = 50 ppmv, NO = 100 ppmv, HCI = 0 ppmv), S6 (CO$_2$ = 12%, N2 = 88%, SO$_2$ = 50 ppmv, NO = 300 ppmv, HCI = 0 ppmv), H3 (CO$_2$ = 12%, N2 = 88%, SO$_2$ = 50 ppmv, NO = 300 ppmv, HCI = 0 ppmv), and H4 (CO$_2$ = 12%, N2 = 88%, SO$_2$ = 50 ppmv, NO = 300 ppmv, HCI = 10 ppmv). The compositions of individual gaseous components in a simulated flue gas were controlled by individual mass flow controllers. During the culture, all of the cultures were mixed by using magnetic stirrers at a speed of 550 rpm to suspend *Nannochloris* sp. cells. The mixing speed was found to be enough to homogenize microalgal cells inside the reactor based on our previous study [11].

During the culture, fluorescent lamps with 6500 K color temperature were used as a light source. The incident light intensity at the reactor surface was set to 257.0 ± 11.7 μmol/(m$^2$ s), and a 16-h light and 8-h dark cycle was applied to all the cultures.

2.2. Determination of cell mass density of *Nannochloris* sp

The cell mass density of *Nannochloris* sp. in the culture medium was determined by measuring the optical density at 750 nm every 157 g/L at 20 °C), and the solution can generate high DIC concentrations after CO$_2$(g) absorption. In our previous study, *Chlorella vulgaris* could successfully grow using high purity CO$_2$(g) (>99%) in conjunction with NaHCO$_3$ buffer [11]. Therefore, it is expected that the inhibition effect of the gases may be reduced when trona is used for the growth of microalgae.

*Nannochloris* sp. has been selected for this study because *Nannochloris* is reported to contain a large amount of lipids (25–56% dry wt.) [19–21]. In addition, the mitigation effect of trona buffer on SO$_2$ and NO gases can be compared with the previous results reported with the inhibition effect of 400 ppmv SO$_2$ and 300 ppmv NO gases on the growth of *Nannochloris* sp. [20]. An optimum trona concentration (0.02 M) that did not inhibit the growth rate of *Nannochloris* sp. was determined for this study. Therefore, a main objective of this study is to investigate the mitigation effect of trona buffer without a need for its continuous addition on the inhibition effect of CO$_2$, SO$_2$, NO, and HCl gases in coal combustion.

### Table 1

<table>
<thead>
<tr>
<th>Name</th>
<th>CO$_2$(%)</th>
<th>N$_2$(%)</th>
<th>SO$_2$(ppmv)</th>
<th>NO(ppmv)</th>
<th>HCl(ppmv)</th>
<th>Incident Light Intensity (μmol/(m$^2$ s))</th>
<th>Total dry Biomass (g/kJ)</th>
<th>A/V (m$^2$/m$^3$)</th>
<th>Growth Yield, Y (g CO$_2$/kJ)</th>
<th>Photosynthetic Efficiency (%)</th>
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<td>0</td>
<td>0</td>
<td>0</td>
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<td>0</td>
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<td>0</td>
<td>0</td>
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<td>100</td>
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<td>246.95</td>
<td>57.31</td>
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</table>

The pH of all cultures was controlled at 7.4 once daily.

A/V – ratio of surface area (A) to volume of culture medium (V).
The cell mass density was determined using the following calibration equation.

\[
\text{Cell mass density (mg/L)} = 80.67 \times \exp(\text{optical density}/0.6061) + 77.87
\]  

The wavelength is not reported to interfere with pigments for the determination of cell mass density [22].

The absorbance of UV–vis spectrophotometer at 750 nm was calibrated by measuring the weight of dried Nannochloris sp. The dried Nannochloris sp. was prepared by the following procedure. A 50-ml sample in the culture medium was placed in 50 ml of Falcon tube for centrifugation at 3500 rpm for 30 min. After the centrifugation, supernatant was discarded and the wet biomass in the Falcon tube was moved in a 15-ml cryogenic tube. The cryogenic tube was covered with a coarse filter paper to facilitate the drying of the wet biomass. Then, the wet biomass in the cryogenic tubes was dried in a freeze dryer below -40°C and 0.133 mbar for 3 days (model: Labconco Freezone 12 Freeze Dryer) and used for the calibration.

2.3. Determination of DIC, NO₃⁻, and PO₄³⁻ concentrations

An acid-based titration method was used to determine the concentrations of DIC species present in the aqueous phase. This titration method determines a total inorganic carbon (TIC) concentration \([\text{DIC}] = [\text{HCO₃}^-] + [\text{CO₃}^{2-}] + [\text{H₂CO₃}] + [\text{CO₂(aq)}] \) in a 15-ml sample using 1 N, 0.1 N, and 0.01 N HCl solutions for the titration of high and low carbon concentrations, respectively. Then, the DIC concentrations were calculated by using the equilibrium relations among HCO₃⁻, CO₃⁻, H₂CO₃, and CO₂(aq) [11].

The concentration of nitrate (NO₃⁻) was determined by using ion chromatography (IC, Model: Dionex DX 500 Ion Chromatography System). IC eluent was prepared by adding 371 mg of Na₂CO₃ and 84 mg of NaHCO₃ in 1 L deionized water. Helium gas (99.999% Ultra High Purity (UHP)) was used to suppress the eluent and RPIC™ IonPac® AS14 4 × 250 mm column was used. During the IC analysis, Self-Regenerating Suppressor (SRS) was set to 100 mA and the flow rate of effluent was set to 1.2 ml/min.

Orthophosphate (PO₄³⁻) was measured using the Phosver 3 phosphate reagent (HACH Company). A 5-ml sample was collected from the culture medium and filtered out using a syringe filter with a 0.45-µm pore size and a 32-mm diameter to remove the algal cells from the culture medium. Then, the resultant sample was diluted by 30 times because the Phosver 3 phosphate reagent can be used in a range of 0.02 to 2.50 mg/L of PO₄³⁻ concentration. After diluting the sample, a 5-ml sample was collected and added to a 50-ml beaker, and a pack of the reagent was added to the beaker. If PO₄³⁻ is present in the solution, the color of the solution changes to blue. After 2 mins of mixing, the color intensity was measured using a UV–vis spectrophotometer (UV–1800, Shimadzu Scientific Instruments) at 880 nm. The absorbance of UV–vis at 880 nm was calibrated by measuring the intensity of a known amount of PO₄³⁻ concentration in deionized water.

2.4. Determination of caloric value of Nannochloris sp. for photosynthetic efficiency

IKA C2000 Calorimeter System was used to determine the caloric value of Nannochloris sp. After Nannochloris sp. was freeze
dried, approximately 1 g of a sample was loaded in a crucible placed on the crucible holder. The prepared crucible holder was placed in the decomposition vessel and the vessel was closed using a cap screw. Then, the vessel was placed in the IKA C2000 Calorimeter system for the determination of the calorific value of Nannochloris sp. with oxygen gas. The measurements were made three times and the calorific value of Nannochloris sp. was determined to be 22.0 ± 0.2 kJ/g, comparable to an approximate lower heating value of sub-bituminous coal (16.7 to 24.3 kJ/g) [23]. The calorific value was used to determine the photosynthetic efficiency as shown in Table 1.

2.5. Determination of chlorophyll a and b concentrations

A 2-mL sample was collected from the culture medium and added to a 2-mL micro-centrifuge tube. The sample was centrifuged using Eppendorf Centrifuge 5410D at 10,000 rpm for 3 min and the supernatant was carefully discarded. After discarding the supernatant, 60 °C of dimethyl sulfoxide (DMSO) was added to the tube, and Nannochloris sp. cells were re-suspended in the DMSO solution using Vortex Mixer. Then, the sample was immersed in water bath at 60 °C. After 30 min, the sample was centrifuged at 10,000 rpm for 3 min and the supernatant in the solution was moved to a vial. The supernatant includes pigments such as Chlorophyll a and b. Then, the supernatant was diluted by a factor of 3, and the optical density of the sample was measured at 649 nm and 665 nm using UV–vis spectrophotometer. The concentration of Chlorophyll a and b were determined using the following equations [22].

\[
\text{Chlorophyll a(mg/L)} = 12.47(OD_{665}) - 3.62(OD_{649}) \\
\text{Chlorophyll b(mg/L)} = 25.06(OD_{649}) - 6.5(OD_{665})
\]

3. Results and discussion

3.1. CO$_2$(g) absorption in trona solution for Nannochloris sp. culture

When 0.02 M (4.5206 g/L H$_2$O) of trona dissolves in water, it is readily dissociated into Na$^+$, CO$_3^{2-}$, and HCO$_3^-$ ions due to its high solubility (120 g/L at 0 °C, 157 g/L at 20 °C) and the dissociated CO$_3^{2-}$ and HCO$_3^-$ are distributed to H$_2$CO$_3$, CO$_2$(aq), HCO$_3^-$ and CO$_3^{2-}$ at equilibrium pH = 10.3 determined by the equilibrium relations. After absorbing CO$_2$(g), a trona solution can be converted into a NaHCO$_3$ solution at pH = 8.3. After trona solution is switched to NaHCO$_3$ buffer system, the NaHCO$_3$ solution contains high DIC concentration and pH is also kept at pH = 8.3 that is suitable for the growth of many green algae [11].

A buffer capacity is defined as the concentration of acid or base required to produce a unit pH change [24]. It means a degree of resistance of a solution to pH change when acid or base is added to the solution, and can be calculated using a software package called Buffer Maker program provided by ChemBuddy. The buffer capacity of a 0.02 M trona solution was calculated to be 1.238 × 10$^{-3}$ at pH = 8.3 at 25 °C.

3.2. Effects of CO$_2$ and SO$_2$ concentrations in simulated flue gas on growth of Nannochloris sp

Nannochloris sp. was cultured in different concentrations of trona (0 M (S0) and 0.02 M (S1-S4), CO$_2$ (100% (S0 & S1) and 12% (S2)) and SO$_2$ (0 ppmv (S2), 100 ppmv (S3), and 300 ppmv (S4)), as shown in Fig. 1(a). When bubbling the simulated flue gases, a NO concentration for S3 and S4 cultures was set to the 50 ppmv because (1) NO and SO$_2$ gases always co-exist in flue gas and (2) the level did not affect the growth of Nannochloris sp. according to a previous study [20]. During the culture, the pH of culture media increased up to pH = 10.8 because Nannochloris sp. absorbed HCO$_3^-$ and released OH$^-$ ions during the growth. Thus, the increased pH of all culture media was adjusted to the pH = 7.4 once daily using simulated flue gas because Nannochloris sp. was found to grow well up to pH = 7–8. When the growth rates for the cultures without trona (S0) and with 0.02 M trona (S1) under the same 100% CO$_2$(g) addition are compared, the growth rate for S1 was much faster. Trona can enhance the growth of Nannochloris sp. in two ways. First, trona has a buffer capacity which can absorb a change in pH derived from acid gases such as CO$_2$, SO$_2$, NO, and HCl (in this case, CO$_2$). Many green algae grow best near neutral pH, including Nannochloris sp. Second, trona buffer with CO$_2$ gas can keep the DIC concentration high during the culture, which promotes the growth of Nannochloris sp. If 0.02 M trona had been the only inorganic carbon source during the culture with CO$_2$ gas, all DIC supplied from trona would have been consumed within 144 h and it could not continue to grow over 288 h. Overall, trona works like sodium bicarbonate that we studied in the past [11]. However, trona is more cost-effective than sodium bicarbonate for large-scale cultivation. The growth rates of Nannochloris sp. were almost the same in all cultures regardless of the CO$_2$ concentrations (i.e. 100% CO$_2$ in S1 vs. 12% (v) CO$_2$ in S2) and the inhibition effect of high CO$_2$ concentrations could be eliminated using trona buffer system. Different from CO$_2$, the growth rates of Nannochloris sp. slightly decreased with an increase in SO$_2$ concentrations (S2, S3, and S4). However, the decrease was insignificant compared with the results reported in a previous study [20].

A degree of pH fluctuations can be used as a good indicator to evaluate the growth rates of Nannochloris sp. when the same trona concentration is used for the cultures because the buffer capacity in
the cultures that can absorb the pH change is the same. As a result, a degree of pH fluctuations was almost the same in all cultures (S1, S2, S3, and S4) regardless of the CO2 and SO2 concentrations except for S0 culture. This pH result was in a good agreement with the growth result.

During the culture, NO3\(^{-}\) and PO4\(^{3-}\) were measured, as shown in Fig. 1(b) and (c). The NO3\(^{-}\) and PO4\(^{3-}\) concentrations in S1-S4 cultures remarkably decreased over time and the S1-S4 cultures showed almost the same consumption rates regardless of the CO2 and SO2 concentrations. These two nutrients started to be depleted after ~192 h in all the cultures and thus the changes in the growth and pH fluctuations also decreased.

Chl a and Chl b are essential pigments for the photosynthesis process. In this respect, the temporal changes in Chl a and Chl b concentrations were monitored with respect to CO2 and SO2 concentrations as shown in Fig. 2. The two Chlorophyll concentrations were normalized by a unit mass (mg) of biomass. The changes in Chl a and Chl b were almost the same regardless of CO2 and SO2 concentrations. Therefore, it is confirmed that the level of photosynthesis was not inhibited by high CO2 and SO2 concentrations in the trona buffer system.
Fig. 5. (a) Growth of *Nannochloris* sp., (b) consumption of NO$_3^-$ concentration, and (c) consumption of PO$_4^{3-}$ as a function of HCl concentrations (0 and 10 ppmv) in simulated flue gas. Note: Error bars in (a) and (c) indicate standard deviation.

Fig. 6. (a) Chlorophyll a and (b) Chlorophyll b concentrations normalized by a unit mass (mg) of biomass as a function of HCl concentrations (0 and 10 ppmv) in simulated flue gas. Note: Error bars in (a) and (b) indicate standard deviation.

### 3.3. Effects of NO concentrations in simulated flue gas on growth of *Nannochloris* sp.

*Nannochloris* sp. was cultured in different concentrations of NO (0, 100, and 300 ppmv); N2, N3, and N4, as shown in Fig. 3(a). During the culture, the SO$_2$ concentration for N3 and N4 cultures was kept constant at 50 ppmv because the level was reported not to affect the growth of *Nannochloris* sp. in a previous study [20]. The increased pH of all culture media was adjusted to pH = 7.4 once daily using the simulated flue gas. The result indicates that the growth rates of *Nannochloris* sp. under 100 and 300 ppmv NO concentrations (N3 and N4, respectively), slightly decreased but the decrease was insignificant compared with the result previously reported [20]. Similar to the growth result, a degree of pH fluctuations was almost the same in all the cultures. Also, the NO$_3^-$ and PO$_4^{3-}$ concentrations in N1–N4 cultures remarkably decreased over time and all the cultures showed almost the same trend as shown in Fig. 3(b) and (c).

The temporal changes in Chl a and Chl b concentrations were also monitored with respect to NO concentrations as shown in Fig. 4. The changes in Chl a and Chl b showed almost the same pattern in all the cultures, indicating that the level of photosynthesis was not significantly inhibited by NO in the trona buffer system.
3.4. Effects of HCl concentrations in simulated flue gas on growth of Nannochloris sp.

Finally, Nannochloris sp. was cultured in different concentration of HCl (0 ppmv (H3) and 10 ppmv (H4)) in order to evaluate the inhibition effect of HCl in the trona buffer system as shown in Fig. 5(a). During the cultures, both SO2 and NO concentrations were set to 300 ppmv because the concentration insignificantly inhibited the growth of Nannochloris sp. as shown in Sections 3.2 and 3.3. The increased pH in all the culture media was adjusted to pH = 7.4 once daily using simulated flue gas. As a result, the growth of Nannochloris sp. slightly decreased in the presence of HCl, but the decrease was insignificant, similar to the results for the SO2 and NO gases. A degree of pH fluctuations showed almost the same pattern in all culture media, and the consumption rates of NO3− and PO43− in all the cultures were almost the same (Fig. 5(b) and (c)). The changes in Chl a and Chl b also showed almost the same pattern in all the cultures regardless of the HCl concentrations as shown in Fig. 6. Therefore, trona buffer could minimize the inhibition effect of CO2, SO2, NO, and HCl on the growth of Nannochloris sp.

3.5. Effects of CO2, SO2, NO, and HCl in simulated flue gas on photosynthetic efficiency

Based on the above results, the photosynthetic efficiency [%] was determined in terms of CO2, SO2, NO, and HCl concentrations using the following Eq. (4).

\[
\text{Photosynthetic efficiency} = 100 \times k \times Y
\]

where \(k\) (kJ/g) is an average calorific value of Nannochloris sp. and \(Y\) (g/kj) is the growth yield [25]. The growth yield (g/kj) is defined as a total dry biomass increase obtained from a total amount of light intensity supplied to the reactor for 12 d. The raw data used to calculate the photosynthetic efficiency are summarized in Table 1, and the photosynthetic efficiencies are shown in Fig. 7. The PE did not decrease with an increase in CO2 concentrations. In contrast, the PE slightly decreased with an increase in SO2, NO, and HCl concentrations, and the decrease did not exceed more than 7.5% except for SO2 (19.1%). These results indicate that CO2, NO, and HCl slightly reduced the PE and SO2 moderately decreased the PE. Previous studies reported that SO2 and NO can inhibit the growth rate of microalgae due to a decrease in pH of culture medium [2–4, 7]. In this respect, a previous study attempted to reduce the toxic effect of the acid gases by controlling the pH of culture medium with a continuous addition of alkaline NaOH solution [8]. Although the concentrations of Na+ ions for the tests were not reported in the study, Na+ ions were very likely to be accumulated in the culture medium during the growth due to the continuous addition of NaOH. Then, the accumulated Na+ ions can inhibit the growth rate of microalgae by increasing the salinity of culture medium [9]. In this regard, the growth rate of microalgae in the study began to decrease at ~50 h, and the growth study was conducted only for ~65 h. On the other hand, the trona buffer system presented in this study has several advantages compared to the aforementioned previous NaOH system. First, unlike NaOH, trona does not need to be continuously added to culture medium in order to control the pH of culture medium. Second, trona is an inexpensive buffer chemical that can keep the DIC concentrations high in culture.
medium [9]. When trona is used with CO₂ gas, high DIC concentration can promote the growth rate of *Nannochloris* sp. Third, a trona buffer system can be used to capture CO₂ gas in culture medium for microalgal growth and ultimately for sustainable carbon recycle. Last, the inhibition effect of CO₂, SO₂, NO, and HCl on photosynthetic efficiency reported in previous studies can significantly be minimized using trona buffer [2–7].

4. Conclusions

This study demonstrates a mitigation capability of trona buffer against a possible inhibition effect of acid gaseous constituents in combustion flue gas on the growth of *Nannochloris* sp. Trona buffer could keep the DIC concentration high after CO₂(g) absorption at benign pH, and could alleviate the inhibition effect of the acid gases including SO₂, NO and HCl in simulated flue gas. Pure CO₂(g) did not adversely impact on the growth of *Nannochloris* sp. using trona buffer as long as the pH of the media was controlled within its benign window. The sustained photosynthetic efficiency also supports that the use of trona buffer could successfully help grow *Nannochloris* sp. using flue gas consisting of the acid gaseous constituents.

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