EXPERIMENTAL DESIGN FOR CO\textsubscript{2} CONVERSION INTO DIMETHYLCARBONATE (DMC) USING Bu\textsubscript{2}SnO AT SUBCRITICAL CONDITIONS

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ABSTRACT

CO\textsubscript{2} conversion into dimethylcarbonate (DMC) was studied by the reaction with methanol at subcritical conditions, using dibutyltin(IV) oxide (Bu\textsubscript{2}SnO) or dibutyltin(IV) dimethoxide (Bu\textsubscript{2}Sn(OMe)\textsubscript{2}) as catalysts. Fractional factorial and complete factorial designs were used to evaluate the most important factors capable of affecting this conversion reaction. This study found that the optimal conditions for CO\textsubscript{2} conversion into DMC using Bu\textsubscript{2}SnO were a reaction pressure of 45 bar, a volume of methanol of 5mL, a temperature of 110\textdegree}C, and a reaction time of 6 hours. The present study also employed these optimal conditions with Bu\textsubscript{2}Sn(OMe)\textsubscript{2}. Even under subcritical conditions, results showed a DMC yield (based on Sn) of 40\% using Bu\textsubscript{2}Sn(OMe)\textsubscript{2}, with TON= 1.

KEYWORDS

CO\textsubscript{2} fixation; DMC; factorial design; tin oxide; experimental design

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1. INTRODUCTION

Carbon dioxide (CO$_2$) is regarded as the principal greenhouse gas (Viola, 2002; Aresta, 2003; Jessop et al., 1995) and has been related to the augment of the global warming (Viola, 2002; Aresta, 2003). CO$_2$ from fossil fuels represents the major percentage of Green House Gases (GHG) emissions, according to IPCC reports (IPCC, 2007). For this reason, different scenarios foresee a maximum of 550 ppm of CO$_2$-equivalvent for a 2-3°C exceeding temperature. Thus, several efforts should be made to reduce GHG emissions and the goals of these reductions were proposed in Kyoto’s Protocol which established for the countries of Annex I a reduction of 5% in GHG emissions below the levels of 1990 in the commitment period of 2008-2012 (United Nations, 1998).

Several researches support a more sustainable economy with the development of projects that seek for GHG reduction (Chicco et al., 2012). The concept of Carbon Capture and Storage (CCS) has been proposed as a tool for reducing CO$_2$ emissions from fossil fuels worldwide in several projects with the participation of the most important energy companies with a great diversity of projects (CO$_2$ Capture Project, 2000; Leite et al., 2012). Examples of different sectors that aim GHG reductions include EOR (Enhanced Oil recovery), building design (Georgiadou et al., 2012), road transport and transportation sector (Rubin et al., 2012; Andress et al., 2011), farm biogas production (Massé et al., 2012) and conversion catalytic researches (Jessop et al., 1995; Omae, 2006).

Developing countries such as Brazil are sponsoring Clean Development Mechanism (CDM) projects, such as the first CDM project approved by UNFCCC (United Nations Framework Convention on Climate Change), which was the Brazilian’s “NOVAGERAR” project that captures biogas to produce energy (Segreti and Bito, 2006).

CO$_2$ can also be used as a raw material for several synthetıc processes in order to obtain products of great economic value, such as carbamates, urethanes, lactones, pyrones, formic acid or methanol (Jessop et al., 1995). The main challenge to overcome CO$_2$ conversion is its stability, which requires more severe conditions for it and also motivates the research on different types of catalysts to obtain reasonable results.

Although some CO$_2$ reactions previously studied were able to produce interesting products such as methanol, formaldehyde and formic acid (Jessop et al., 1995; Chiavassa et al., 2008; Mahajan et al., 2003), they also presented low efficiency and selectiveness. In addition, another challenge in CO$_2$ conversion is the development of processes able to be scale up for industrial use (Omae, 2006).

The conversion of CO$_2$ specifically into dimethylcarbonate (DMC) has been of great interest and extensively studied, since this compound is a key reagent to produce several other chemicals, including polycarbonates (PC). One of the routes for DMC production from CO$_2$ is already in use at Asahi Chemical Industry, employing a reaction with ethylene oxide and replacing phosgene, which is extremely poisonous (Jessop et al., 1995).

The study of DMC synthesis using CO$_2$ through the reaction with methanol began in the 1990’s (Sakakura et al., 1998) (Equation 1). The reaction can be catalyzed by different metals, although the most used is tin, employed as an oxide compound or as an organometallic complex (Hoffman, 1982; Dibenedetto et al., 2006; Choi et al., 1999; Choi et al., 2002).

$$2 \text{MeOH} + \text{CO}_2 \leftrightarrow \text{MeO}^+\text{OMe}^- + \text{H}_2\text{O}$$ (1)

The proposed mechanism for DMC formation in Eq 1, using tin catalyst is based on CO$_2$ insertion in Sn-O bond of catalyst, forming a carbonate complex intermediary (Sakakura et al., 2000).

Ballivet-Tkatchenko et al. (2003, 2011) studied CO$_2$ conversion with methanol at 50°C and 200 bar using SnO$_2$ as catalyst. These researchers found a yield of 0.3% and 4% with unsupported and supported SiO$_2$, respectively. Kizlink et al. (1993, 1994) used dibutyltin(IV) oxide, Bu$_2$SnO, as the catalyst for the same reaction.

Other class of compounds used for CO$_2$ conversion with methanol is the alkoxides. Aresta et al. (2008) and Bian et al. (2009) proposed a catalytic mechanism with alkoxides, involving CO$_2$ insertion into the tin methoxide bond. Kizlink and Pastucha (1994) proposed CO$_2$ conversion with
methanol into DMC using Sn(OEt)$_4$ and different dehydrating agents. They observed interesting yields in relation to the catalyst, with TON values of 1 to 1.8, using hydrating and initiator agents. Dibenedetto et al (2006) used polystyrene-C$_6$H$_5$-CH$_2$CH$_2$-SnBu(OCH$_3$)$_2$ as catalyst and obtained a yield of 0.12% at 40 bar. In other study, Sakukara et al. (1998) used different tin alkoxide as catalysts, such as Bu$_2$Sn(OMe)$_2$, Bu$_3$Sn(OMe), Me$_2$Sn(OMe)$_2$, obtaining yields up to 20% in relation to the catalyst (TON= 0.2).

Although there are several works regarding CO$_2$ conversion, none of them has taken into account the interaction among the variables that can be relevant for its optimization. This work focuses in the optimization of CO$_2$ conversion into methanol at subcritical conditions using dibutyltin(IV) oxide (Bu$_2$SnO) or dibutyltin(IV) dimethoxide (Bu$_2$Sn(OMe)$_2$). Fractional factorial and complete factorial designs were done for CO$_2$ conversion with methanol and dibutyltin(IV) oxide in order to evaluate the most important factors in this process, as well as their influence in the reaction and the possible interactions among them.

2. EXPERIMENTAL

2.1 General

Methanol (Acros, HPLC grade, 99.8%) was distilled and dried over 3A molecular sieve. Carbon dioxide was purchased from LINDE Gases, 99.999% purity. Dibutyltin(IV) dimethoxide (99%) and dibutyltin(IV) oxide (98%) were purchased from Sigma Aldrich. All of the products were used without further purification.

2.2 Infrared and Raman analyses

Infrared analyses were done using Magna-IR 760 Nicolet spectrometer, in the range of 4000 to 200 cm$^{-1}$ with a resolution of 4 cm$^{-1}$ and 16 scans. The platelets were prepared using cesium iodide. During the study of design of experiments, the resultant solids obtained after experiments were analyzed by infrared spectroscopy. Bu$_3$SnO was analyzed by infrared spectroscopy before and after the conversion reaction.

The Raman spectra were obtained at room temperature using Jobin-Yvon HR800UV spectrometer, coupled to a BX41 Olympus microscope. Excitation was provided by a He/Ne operating at 632.8 nm. A CCD detector at -170°C was used and the resolution of the spectrometer was 1 cm$^{-1}$. The Raman spectra of the solids were done with D1 filter in order to prevent local heating.

2.3 Catalytic tests

The initial chosen conditions for the catalytic tests were based on the already reported experiments for CO$_2$ conversion to DMC using tin catalysts (Ballivet-Tkatchenko, 2003; Sakai, 1975; Yamazaki, 1978; Kizlink, 1994; Keller et al., 2010; Sakakura and Kohno, 2009; Ma et al., 2009; Sakakura et al., 1999; Ballivet-Tkatchenko et al., 2000; Choi et al., 2002; Sakakura et al., 2000; Aresta et al., 2006).

The catalytic tests were carried out in a 100mL Parr 4560 reactor, with 0.5g of Bu$_3$Sn(OMe)$_2$ or Bu$_3$SnO dissolved in methanol (5-10mL) and CO$_2$ at an initial pressure of 300-500 psi (21 to 35 bar). The temperature range was 80 to 120°C and the reaction time was from 60 to 180 minutes. The pressure measured during the reaction at 80 to 120°C temperature range was 28 to 70 bar.

The final reaction mixture was centrifuged and the solid phase was dried at 60°C in vacuum line (10$^{-1}$ mbar) and further analyzed by infrared spectroscopy. The liquid phase was analyzed in triplicate by gas chromatography coupled with mass detector – (Agilent 7890A CG couple with Agilent 5975C) using an HP-5 column (30m x 0.32mm x 0.25μm film). The conditions used in chromatography analysis were a gradient temperature of 40-200°C, with an initial isotherm at 40°C, using nitrogen as the carrier gas and a detector temperature of 280°C.

DMC quantification analysis was done in the liquid phase using chromatography calibration curves with an auto sample injector in the concentration range of 1.29x10$^{-3}$ mol.L$^{-1}$ to 5.00x10$^{-2}$ mol.L$^{-1}$ in methanol as a solvent, obtaining R$^2$ = 0.9949. All standard samples and pos-reaction liquid phase were analyzed in triplicates.

2.4 Experimental designs

For the optimization of the CO$_2$ conversion to
DMC, a fixed amount of Bu₂SnO (500 mg) was used in all experiments. The choice of Bu₂SnO as the catalyst, instead of the more often used Bu₂Sn(OMe)₂, was based on the cost, an aspect that should be considered for further applications of this study.

Fractional factorial design (FFD) (Neto et al., 2002) was employed as a first screening design for CO₂ conversion into DMC using dibutyltin (IV) oxide, Bu₂SnO. In this study, FFD 2⁴⁻¹ was done with ten experiments, carried out randomly, in order to evaluate and reduce the number of variables that influence this reaction, as well as the interactions among them. Each experiment was done in duplicate and analyzed twice. The variables used for this design were the reaction temperature, CO₂ pressure, reaction time and volume of methanol. These variables have been selected based on a screening of several already reported experiments (Keller et al., 2010; Sakakura and Kohno, 2009; Ma et al., 2009; Sakakura et al., 1999; Ballivet-Tkatchenko et al., 2000; Choi et al., 2002; Sakakura et al., 2000; Aresta et al., 2006) using the same reagents. The experimental response analyzed for this design was the peak area related to DMC obtained from the chromatograms (retention time = 2.28 min), since it is proportional to the analyte concentration (Harris, 2001). The percentage of conversion in relation to DMC could not be calculated from its concentration because in some analyses it was below the quantification limit.

Table 1. Plan of experiments for FFD 2⁴⁻¹ design for four variables with twofold repetition of the central point.

<table>
<thead>
<tr>
<th>Exp</th>
<th>Temperature (°C)</th>
<th>Time (min)</th>
<th>CO₂ Pressure (Psi)</th>
<th>Volume of MeOH (mL)</th>
<th>Area (DMC)</th>
<th>Standard Deviation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>80</td>
<td>60</td>
<td>300</td>
<td>5</td>
<td>112436</td>
<td>0.2</td>
</tr>
<tr>
<td>2</td>
<td>120</td>
<td>60</td>
<td>300</td>
<td>10</td>
<td>481670</td>
<td>4.9</td>
</tr>
<tr>
<td>3</td>
<td>80</td>
<td>180</td>
<td>300</td>
<td>10</td>
<td>253924</td>
<td>4.8</td>
</tr>
<tr>
<td>4</td>
<td>120</td>
<td>180</td>
<td>300</td>
<td>5</td>
<td>1566593</td>
<td>3.4</td>
</tr>
<tr>
<td>5</td>
<td>80</td>
<td>60</td>
<td>500</td>
<td>10</td>
<td>160807</td>
<td>3.4</td>
</tr>
<tr>
<td>6</td>
<td>120</td>
<td>60</td>
<td>500</td>
<td>5</td>
<td>948646</td>
<td>4.7</td>
</tr>
<tr>
<td>7</td>
<td>80</td>
<td>180</td>
<td>500</td>
<td>5</td>
<td>110998</td>
<td>4.9</td>
</tr>
<tr>
<td>8</td>
<td>120</td>
<td>180</td>
<td>500</td>
<td>10</td>
<td>1793243</td>
<td>3.6</td>
</tr>
<tr>
<td>9</td>
<td>100</td>
<td>120</td>
<td>400</td>
<td>7.5</td>
<td>942443</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>120</td>
<td>120</td>
<td>400</td>
<td>7.5</td>
<td>987874</td>
<td></td>
</tr>
</tbody>
</table>

The data obtained from FFD have been used for the second step of this design, a Complete Factorial Design (CFD) (Neto et al., 2002), in which only the variables with greater significance were employed. The analyses done for CFD, however, have been done in a different day of those used for FDD.

3. RESULTS AND DISCUSSION

3.1 Experimental Design

3.1.1 The fractional factorial design (FFD)

All variables, levels and their responses used for FFD 2⁴⁻¹ are shown in Table 1. Ten experiments were carried out in a random way and the responses of the experiments were their peak areas of DMC, which are shown in fifth column of Table 1. In addition, the standard deviations percentages were all below 5% which indicated the reproducibility of all tests.

Pareto’s chart (Fig. 1), which bar length is proportional to the absolute value of the standardized effects, was constructed using the data from Table 1. This chart was used to evaluate the significance of each variable in a 95% level of confidence. It can be observed in Fig.1 that the most significant variable was the reaction temperature, followed by reaction time, both with positive effects. Other variables such as volume of methanol, CO₂ pressure and curvature, however,
presented a level of confidence lower than 95% and were deemed not significant.

From the variance analysis, one can observe that the lack of fit (0.057) and the curvature (0.052) of the model were not significant at a level of 95% of confidence in the tested conditions. Furthermore, one can conclude that the used model was able to explain 85% of the variance and presented a small pure mistake (smaller than 5), showing data consistency.

### 3.1.2 Complete factorial design

After evaluating the principal factors that influenced CO$_2$ conversion into DMC with Bu$_2$SnO using FFD $2^{4-1}$, and checking the validation of the method, a complete design was done. Thus, a $2^2$ complete factorial design was done regarding the central point with the following two variables: reaction temperature and reaction time. The values of the two variables used, as well as the DMC areas, are shown in Table 2. The non-significant variables were fixed as follow: volume of methanol at 5mL and CO$_2$ pressure at 400 psi (28 bar). For the evaluation of the proposed model for the optimization of reaction temperature and reaction time, a variance of 99.9 (R-sqr = .99941 in Fig. 2) was observed, with a small pure error (1.612269E+08, Fig. 2), indicating a good accuracy with the experimental results (Neto et al., 2002). In addition, according to Figure 2, the curvature was not significant at a level of confidence of 95% under the tested conditions since its p-value (0.085) was higher than the set value for the model (0.05).

![Pareto’s Chart from 2$^{4-1}$ design for Bu$_2$SnO.](image)

**Figure 1.** Pareto’s Chart from $2^{4-1}$ design for Bu$_2$SnO.

**Table 2.** Values used for each variable in a $2^2$ factorial design.

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Time (min)</th>
<th>Area (DMC)</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>120</td>
<td>180</td>
<td>724450</td>
<td>2.0</td>
</tr>
<tr>
<td>170</td>
<td>180</td>
<td>631428</td>
<td>1.9</td>
</tr>
<tr>
<td>120</td>
<td>360</td>
<td>1303439</td>
<td>1.5</td>
</tr>
<tr>
<td>170</td>
<td>360</td>
<td>846400</td>
<td>1.2</td>
</tr>
<tr>
<td>145</td>
<td>270</td>
<td>966687</td>
<td>2.2</td>
</tr>
<tr>
<td>145</td>
<td>270</td>
<td>948730</td>
<td>1.6</td>
</tr>
</tbody>
</table>
The adjustment of the model can be observed by the comparison between experimental and predicted values obtained from 2^2 design using Bu₂SnO (Fig. 3), which shows a good dispersion of the points, indicating a well adjusted model.

A surface plot of a 2^2 factorial design was done (Fig. 4) in order to evaluate the optimal reaction conditions for CO₂ conversion into DMC. From the surface plot (Fig. 4), it can be observed that the optimal conditions for this reaction were around 110°C and 6 hours of reaction time. Besides temperature and reaction time, Table 3 also presents other important variables for the optimal conditions, such as methanol volume and pressure reaction.

3.2 Infrared and Raman analyses of Bu₂SnO

The infrared spectra of the resultant solids from all analyzed experiments in FFD 2^4-1 are shown in Fig. 5. The principal bands characteristics of the Bu₂SnO could be observed, such as ν C=O in 1030 to 1070 cm^-1, as well as those relative to the Sn-ligand bonds, the symmetric and asymmetric ν Sn-C bands in 500-600 cm^-1 region and ν Sn-O around 500 cm^-1, respectively (Bradley, 2001). The infrared data from experiments 1 to 8 in Fig. 5 presented small changes when compared to the catalyst before the reaction, showing that Bu₂SnO should remain stable after the conversion reaction.

Figure 2. Table of ANOVA for the factorial design 2^2 for the conversion of CO₂ to DMC using Bu₂SnO as catalyst.

Figure 3. Comparison between experimental and predicted values obtained from 2^2 design using Bu₂SnO.
Raman spectra of the Bu₂SnO (Figure 6) before and after reaction confirmed the infrared data and also indicated small changes, probably due to the conversion of Bu₂SnO into dialkyltin oxide, which is the key intermediate for this reaction, as reported by Sakakura et al. (2000). Thus, the new observed bands after the catalytic test were typical of alkoxides, at 1070 cm⁻¹ and 580-600 cm⁻¹, relative to ν C-O and ν Sn-O, respectively (Bradley et al., 2001).

The analyses of the Raman spectra of the other catalyst used, Bu₂Sn(OMe)₂, is shown in Fig. 7.
profiles of the Raman spectra of Bu$_2$Sn(OMe)$_2$ before (Fig. 7b) and after catalytic reaction (Fig. 7a) were similar, with an exception of the bands around 500 cm$^{-1}$ and considering the lower intensity of the bands after the reaction. The bands in the region around 500 cm$^{-1}$ could be assigned to $\nu$ Sn-C and $\nu$ Sn-O stretching modes (Bradley et al., 2001). In Fig 7, one of these bands has its intensity diminished and the other one has the bands disappeared after the reaction, which was probably due to a condensation reaction.

3.3 CO$_2$ Conversion and Comparison of the Catalysts Performance

Using these optimal conditions described in
Table 3, the experiment tested Bu₂Sn(OMe)₂ as catalyst for CO₂ conversion with methanol, using the same reactor and CG used for Bu₂SnO. CO₂ conversion using Bu₂SnO as catalyst had a TON of 0.2 (in relation to DMC) whereas using Bu₂Sn(OMe)₂ had a TON=1 (Table 4). These are reasonable good results in comparison with the already reported data and considering the conditions used in this study.

In order to make a better comparison among the catalysts and experimental conditions, the study selected from Table 4 experiments on CO₂ conversion, using the catalyst Bu₂Sn(OMe)₂ and proximal reaction conditions. The experiments collected in Table 4 presented pressure varying from 25 to 200 bar and temperature ranging from 110 to 180°C, whereas the reaction time varied from 6 to 27h. Nevertheless, it is important to evaluate the amount of energy necessary in each of this CO₂ conversion tests in order to know how energetically and economically is its viability. Higher temperature reaction, time and pressure also imply in higher energy demand and costs for the application in a large scale.

Experiments 1 and 2 are related to our work. It is interesting to observe that even employing subcritical conditions, 45 bar and 110°C, and few hours of reaction (6 h), TON values using Bu₂SnO and Bu₂Sn(OMe)₂ were 0.2 and 1, respectively (TON= mol of DMC/mol of catalyst). Experiment 4 presented a higher TON (3) than the one found in this study, however it employed higher pressure reaction, temperature and reaction time, implying more energetic conversion. The difference in pressure used in Experiment 4, 200 bar, is more than four times larger than the pressure used in the present work. Experiment 7 presented almost the same TON as this work, however with much higher time reaction and the employment of a dehydrating agent, DCC- N,N'-

Table 3. Optimal conditions for CO₂ conversion with methanol into DMC, using Bu₂SnO as catalyst.

<table>
<thead>
<tr>
<th><strong>Optimal conditions for CO₂ conversion into DMC using Bu₂SnO</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reaction Pressure</strong></td>
</tr>
<tr>
<td><strong>Volume of methanol</strong></td>
</tr>
<tr>
<td><strong>Temperature</strong></td>
</tr>
<tr>
<td><strong>Time</strong></td>
</tr>
</tbody>
</table>

Table 4. Comparison of CO₂ Conversion into DMC using Bu₂Sn(OMe)₂ and Bu₂SnO in different Conditions.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Catalyst</th>
<th>Dehydrating agent</th>
<th>Conditions</th>
<th>DMC yield (TON)</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bu₂Sn(OMe)₂</td>
<td>-</td>
<td>110°C, 45 bar, 6 h</td>
<td>1</td>
<td>This work</td>
</tr>
<tr>
<td>2</td>
<td>Bu₂SnO</td>
<td>-</td>
<td>110°C, 45 bar, 6 h</td>
<td>0.2</td>
<td>This work</td>
</tr>
<tr>
<td>3</td>
<td>Bu₂Sn(OMe)₂</td>
<td>-</td>
<td>150°C, 66 bar, 6 h</td>
<td>0.32</td>
<td>Kizlink, 1993</td>
</tr>
<tr>
<td>4</td>
<td>Bu₂Sn(OMe)₂</td>
<td>-</td>
<td>150°C, 200 bar, 12 h</td>
<td>3</td>
<td>Ballivet-Tkatchenko, 2003</td>
</tr>
<tr>
<td>5</td>
<td>Bu₂Sn(OMe)₂</td>
<td>-</td>
<td>100°C, 30 bar, 27 h</td>
<td>0.1</td>
<td>Sakai, 1975</td>
</tr>
<tr>
<td>6</td>
<td>Bu₂Sn(OMe)₂</td>
<td>-</td>
<td>100°C, 50 bar</td>
<td>0.98</td>
<td>Yamazaki, 1978</td>
</tr>
<tr>
<td>7</td>
<td>Bu₂Sn(OMe)₂</td>
<td>DCC*</td>
<td>150°C, 25 bar, 20 h</td>
<td>1.2</td>
<td>Kizlink, 1994</td>
</tr>
<tr>
<td>8</td>
<td>Bu₂Sn(OMe)₂</td>
<td></td>
<td>180°C, 28 bar, 20 h</td>
<td>1</td>
<td>Kizlink, 1994</td>
</tr>
</tbody>
</table>

*N,N’-Dicyclohexylcarbodiimide (DCC); TON = Turnover Number, mol DMC/mol of catalyst.
Dicyclohexylcarbodiimide. The problem with this use is its cost and recyclability (Sakakura and Kohno, 2009). Experiment 8 had a greater time reaction, 20h, and a greater temperature, presenting the same TON value than this work. Experiment 6 had a very close TON to this work, 0.98, using a slightly greater pressure. The other experiments had values of TON smaller than 1.0.

All experiments done in this work were selective to DMC formation. Thus, one can conclude that it is possible to employ less energetic, subcritical conditions, and achieve reasonable results for CO₂ conversion by employing experimental design and thus, reducing the number of analyses and the cost of the study.

4. CONCLUSIONS

CO₂ conversion into DMC was optimized using factorial designs. Initially, the experiments carried out a preliminary analysis of all possible variables using fractional factorial designs. After identifying the most significant variables, which were temperature and time, a 2² factorial design was applied. The relevance of applying these models is the possibility of evaluating the interactions between the variables, which are neglected in univariate optimizations.

The use of optimization and experimental designs for CO₂ conversion evaluation, which remains unreported, may be an interesting tool to develop more sustainable experiments in this area. In this study, values of TON equal to 0.2 for Bu₂SnO and 1 for Bu₂Sn(OMe)₂ were achieved, which are in good agreement with the data already reported, but with less reaction time. The use of this approach implies in the consumption of a smaller amount of energy and reagents and, consequently, in less carbon input during research and development stages, which certainly contributes to a more environmental friendly chemistry.

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5. REFERENCES


