Plasma-induced CO_2 conversion: Experimental and Computational study

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Abstract: A proposed technique to convert sporadic sustainable electricity into storable chemical energy is the conversion of CO_2 into CO via plasma processing. The two most significant obstacles to developing this technology are proving its viability on an industrial scale and obtaining an effective CO_2 conversion with high energy efficiency. In this work, we developed the plasma reactor for effective CO_2 conversion. The transformation of CO is monitored by using Fourier Transform Infrared Spectroscopy.

Keywords: CO_2 conversion, Plasma, Simulation.

1. General

Plasma, known as the "fourth state of matter," is an ionized plasma made up of neutral ground-state molecules in addition to electrons, different types of ions, radicals, excited atoms, and molecules. As a result, it has a high degree of reactivity, which makes it attractive for various applications. When electricity is supplied, the resulting electric field heats the electrons, which then excite, ionize, and dissociate the gas molecules to produce plasma and permit mild chemical reactions at ambient temperature and pressure. Because the electrons may activate the CO_2 molecules and create new products without heating the entire gas, plasma is exciting for the conversion of CO_2 [1].

Global energy consumption will increase 28% between 2015 and 2040, according to a report by the U.S. Department of Energy's Energy Information Administration (EIA). The increased energy use will be matched by a 16% increase in energy-related carbon dioxide (CO2) emissions over that same period, with annual emissions rising from 33.9 billion metric tons in 2015 to 39.3 billion metric tons in 2040, according to EIA's report. The CO2 conversion to produce sustainable carbonaceous fuels is the most promising option to tackle greenhouse gases in the short to medium term. CO_2 is a promising renewable, cheap, and abundant C1 feedstock for producing valuable chemicals, such as CO.

Thus, CO_2 conversion using plasma technology can be energy-efficient. Hydrogen produced by water electrolysis and turning CO_2 into CO through plasma can be converted into liquid hydrocarbons like methanol, methane, or methane [1]. This strategy may transform renewable energy into chemical energy that can be conveniently stored, transported, and disseminated using the existing infrastructure [2]. It also provides a means of lowering carbon emissions.

The efficient conversion of CO_2 to CO utilizing affordable methods that are practical on an industrial scale is one of the main hurdles in doing this. This problem has spurred research toward conversion using various techniques [3]. Although each approach has particular benefits and has made progress, we focus only on CO_2 conversion employing plasma technologies [4]. Along with the direct conversion of pure CO_2, syngas, hydrocarbons, and other chemicals can also be produced from mixed gasses, such as $CO_2 + CH_4$ or $CO_2 + H_2$.

2. Experimental method

We used the arc plasma working at a total power of 11 W, with the continuous flow of CO_2 at 60 sccm. The total power was measured using a watt monitor (TAP-TST8N, Sanwa Supply), as discussed in our earlier paper [5]. The outgas outlets are connected with the Nicolet ™ iS ™ 5 FT-IR spectrometer from Thermo Scientific ™ company.

3. Results and Discussion

Our system has a continuous flow of CO_2 to the plasma reactor. The plasma discharges for several minutes, and we measure the spectra each minute. The FT-IR measurements took 1 minute to measure the radical changes in the gas phase. As we see in Figure 1, for the control CO_2, there was no peak observed between 2000 and 2200 cm^{-1}. But as the plasma treatment increases, the two peaks observed between 2000-2200 cm^{-1} after 1 min resemble the CO formation, which is supported by the previous articles [6].

Whereas the peaks between 1400 to 1800 cm-1 are attributed to the presence of NO_2, HNO_2, HNO_3, and NO, as supported by a previously published article [7]. As the discharge is performed in the open air, water and Air (nitrogen and oxygen source) can contaminate the air, which can result in the formation of NO_2, HNO_2, HNO_3, and NO. Additionally, a peak between 1000-1100 cm^{-1} can be attributed to the presence of O_3, as supported by previously published work [8].

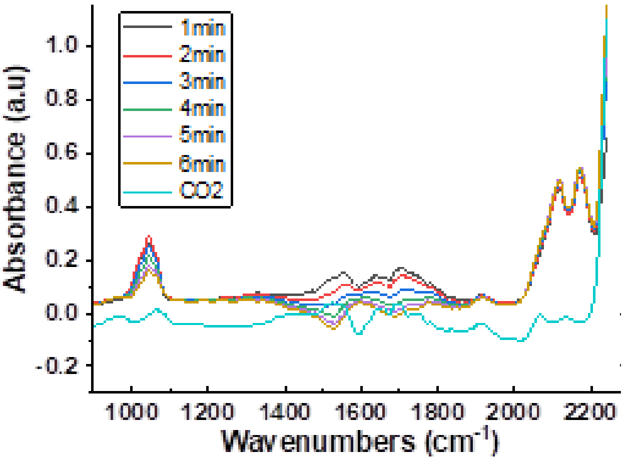

Fig. 1. FTIR spectra of CO_2 treatment with plasma.

Although we also performed the 2D simulation using COMSOL Multiphysics® software to determine how the potential reaction generated gas phase was diffused to the liquid phase, as shown in Fig. 2.

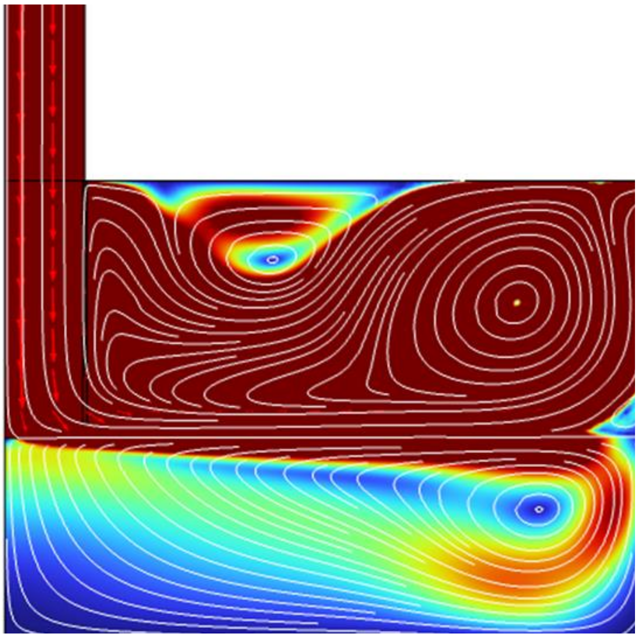

Fig. 2. 2D simulation using COMSOL Multiphysics® software for CO_2 flow from gas to the liquid phase.

4.Conclusion

Our results show that our plasma streamer reactor can convert CO_2 to CO effectively. The increase in CO_2 conversion depends upon the treatment time.

5.References

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