PACS: 52.65.-y, 52.80.Pi

Decomposition of CO_2 in a glow discharge (analytical review)

Yu. A. Lebedev and V. A. Shakhatov

A.V. Topchiev Institute of Petrochemical Synthesis, Russian Academy of Science
29 Leninskii Ave., Moscow, 119991, Russia
E-mail: lebedev@ips.ac.ru

Received August 02, 2022

An analytical review of the results of experimental and theoretical studies of carbon dioxide decomposition in glow discharges is given. From a comparative analysis of the literature data, an attempt is made to determine the discharge parameters at which the maximum values of decomposition degree of carbon dioxide and energy efficiency for a particular device are provided. The maximum values of the decomposition degree of dry carbon dioxide of 40 % and energy efficiency of 32 % are achieved in discharge devices at a current of 10 to 100 mA, a specific power of 0.2 to 3.6 W/cm per unit length of the positive column, at average (50–60 Torr) and atmospheric pressures in the subsonic gas flow with a volumetric flow rate of 300 cm^3/s. Discharge devices in which a pulse–periodic (in the range from a few tenths to several tens of kHz) glow discharge of atmospheric pressure is used for the utilization of carbon dioxide can be promising.

Keywords: glow discharge, carbon dioxide, dissociation.

DOI: 10.51368/2307-4469-2022-10-4-323-342

REFERENCES

1. *Смирнов Б. М.* // УФН. 1978. Т. 126. Вып. 3. С. 527.[B. M. Smirnov, Sov. Phys. Usp. **126**, 527 (1978)].
2. S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, and H. L. Miller, Contribution of work-ing group I to the fourth assessment report of the intergovernmen-tal panel on climate change, Cambridge University Press, Cam-bridge, United Kingdom and New York, NY, USA, 2007.
3. The State of Greenhouse Gases in the Atmosphere Based on Global Observations Through 2013, WMO Greenhouse Gas Bulletin: World Meteorological Organization, 2014, pp. 1–10.
4. B. Pardia, S. Iniyan, and R. Goic, Renew. Sustain. Energy Rev. **15**, 1625 (2011).
5. M. Thirugnanasambandam, S. Iniyan, and R. Goic, Renew. Sustain. Energy Rev. **14**, 312 (2010).
6. A. Lebouvier, et al., Energy Fuels **27**, 2712 (2013).
7. C. S. Song, Catal. Today **115**, 2 (2006).
8. G. Centi and S. Perathoner, Catal. Today **148**, 191 (2009).
9. I. Omae, Coord. Chem. Rev. **256**, 1384 (2012).
10. I. Dimitriou, P. Garcia-Gutierrez, R. H. Elder, R. M. Cuellar-Franca, A. Azapagic, and R. W. K. Allen, Energy Environ. Sci. **8**, 1775 (2015).
11. E. V. Kondratenko, G. Mul, J. Baltrusaitis, G. O. Larrazabal, and J. Perez-Ramirez, Energy Environ. Sci. **6**. 3112 (2013).
12. M. Mikkelsen, M. Jorgensen, and F. C. Krebs, Energy Environ. Sci. **3**, 43 (2010).
13. P. Lahijani, Z. A. Zainal, M. Mohammadi, and A. R. Mohamed, Renew. Sustain. Energy Rev. **41**, 615 (2015).
14. R. Snoeckx and A. Bogaerts, Chem. Soc. Rev. **46**, 5805 (2017).
15. A. George, B. Shen, M. Craven, Y. Wang, D. Kang, C. Wu, and X. Tu, Renew. Sustain. Energy Rev. **135**, 109702 (2021).
16. Yu. A. Lebedev and V. A. Shakhatov, Plasma Physics Reports **48**, 693 (2022).
17. *Лебедев Ю. А., Шахатов В. А.* // Журнал прикладной химии. 2022. Т. 95. № 1. С. 39. [Yu. A. Lebedev and V. A. Shakhatov, Russian Journal of Applied Chemistry **95**, 1 (2022)].
18. L. V. Gurvich, G. V. Karachevtsev, V. N. Kondratiev, Yu. A. Lebedev, V. A. Medvedev, V. K. Potapov, and Yu. S. Khodeev, *Chemical bond breaking energies. Ionization potentials and electron affinity.* (Nauka, Moscow, 1974) [in Russian].
19. K. S. Krasnov, N. K. Vorobyev, I. N. Godnee, et al., *Physical chemistry.* (Higher School, Moscow, 2001) [in Russian].
20. N. M. Kuznetsov, *Kinetics of monomolecular reactions*. (Nauka, Moscow, 1982) [in Russian].
21. *Ибрагимова Л. Б.* // Математическое моделирование. 2000. Т. 12. № 4. С. 3. [L. B. Ibragimova, Mathematical Modeling **12** (4), 3 (2000)] [in Russian].
22. *Ибрагимова Л. Б.* // Хим. физика. 1990. Т. 9. С. 785. [L. B. Ibragimova, Chemical physics **9**, 785 (1990)] [in Russian].
23. A. V. Eremin and V. V. Shumova, Vibration-dissociation kinetics of triatomic molecules at high temperatures. 21-st Symp. on Rarefied Gas Dynamics. Marseille (France). July 1998. Book of Abstracts, v. l, pp. 306–307.
24. *Еремин А. В., Зиборов В. С.* // Хим. физика. 1989. Т. 8. С. 475. [A. V. Eremin and B. C. Ziborov, Chemical physics **8**, 475 (1989)] [in Russian].
25. A. V. Eremin and V. S. Ziborov, Shock Waves **3** (1), 11 (1993).
26. *Еремин А. В., Зиборов В. С., Шумова В. В.* // Кинетика и катализ. 1997. Т. 38. № 1. С. 5. [A. V. Yeremin, V. S Ziborov, and V. V. Shumova, Kinetics and catalysis **38** (1), 5 (1997)] [in Russian].
27. *Герцберг Г.* Электронные спектры и строение многоатомных молекул. – М.: Мир, 1969. [G. Hertzberg, *Electronic spectra and the structure of polyatomic molecules*. (Mir, Moscow, 1969) [in Russain].
28. J. Albo, M. Alvarez-Guerra, P. Castano, and A. Irabien, Green Chem. **17**, 2324 (2015).
29. G. A. Olah, A. Goeppert, and G. K. S. Prakash J. Org. Chem. **74** (2), 487 (2009).
30. E. V. Kondratenko, G. Mul, J. Baltrusaitis, G. O. Larrazabal, J. Perez-Ramirez, G. O. Larrazabal, and J. Perez-Ramirez, Energy Environ. Sci. **6** (11), 3112 (2013).
31. J. Qiao, Y. Liu, F. Hong, and J. Zhang, Chem. Soc. Rev. **43**, 631 (2014).
32. B. Kumar, M. Lorente, J. Froehlich, T. Dang, A. Sathrum, and C. P. Kubiak, Annu. Rev. Phys. Chem. **63**, 541 (2012).
33. I. Ganesh, Renew. Sustain. Energy Rev. **31**, 221 (2014).
34. S. Verma, B. Kim, H.-R. Jhong, S. Ma, and P. J. A. Kenis, ChemSusChem. **9**, 1972 (2016).
35. G. P. Smestad and A. Steinfeld, Ind. Eng. Chem. Res. **51**, 11828 (2012).
36. J. R. Scheffe and A. Steinfeld, Mater. Today **17**, 341 (2014).
37. Y. Izumi, Coord. Chem. Rev. **257**, 171 (2013).
38. W. C. Chueh, C. Falter, M. Abbott, D. Scipio, P. Furler, S. M. Haile, and A. Steinfeld, Science **330**, 1797 (2010).
39. A. H. McDaniel, E. C. Miller, D. Arifin, A. Ambrosini, N. Cok , R. O’Hayre, W. C. Chueh, and J. Tong, Energy Environ. Sci. **6**, 2424 (2013).
40. S. Das and W. M. A. Wan Daud, RSC Adv. **4**, 20856 (2014).
41. S. C. Roy, O. K. Varghese, M. Paulose, and C. A. Grimes, ACS Nano **4**, 1259 (2010).
42. P. M. Schenk, S. R. Thomas-Hall, E. Stephens, U. C. Marx, J. H. Mussgnug, C. Posten, O. Kruse, and B. Hankamer, Bioenergy Res. **1**, 20 (2008).
43. L. Brennan and P. Owende, Renew. Sustain. Energy Rev. **14** (2), 557 (2010).
44. R. Halim, M. K. Danquah, and P. A. Webley, Biotechnol. Adv. **30**, 709 (2012).
45. Y. Shen, RSC Adv. **4**, 49672 (2014).
46. M. Mikkelsen, M. Jorgensen, and F. C. Krebs, Energy Environ. Sci. **3** (1), 43 (2010).
47. J. A. Martens, A. Bogaerts, N. De Kimpe, P. A. Jacobs, G. B. Marin, K. Rabaey, M. Saeys, and S. Verhelst, ChemSusChem. **10**, 1039 (2017).
48. M. Aresta, A. Dibenedetto, and A. Angelini, Chem. Rev. **114**, 1709 (2014).
49. W. Wang, S. Wang, X. Ma, and J. Gong, Chem. Soc. Rev. **40**, 3703 (2011).
50. A. Navarrete, G. Centi, A. Bogaerts, A. Martin, A. York, and D. Stefanidis, Energy Technol. **5** (6), 796 (2017).
51. X. Zhang, C. S. Lee, D. M. P. Mingos, and D. O. Hayward, Catal. Lett. **88**, 129 (2003).
52. B. Fidalgo, A. Dominguez, J. Pis, and J. Menendez, Int. J. ydrogen Energy **33**, 4337 (2008).
53. *Легасов В. А., Животов В. К., Крашенинников Е. Г., Кротов М. Ф., Патрушев Б. И., Русанов В. Д., Рыкунов Г. В., Спектор А. М., Фридман А. А., Шолин Г. В.* // ДАН СССР. 1978. Т. 238. С. 66. [V. A. Legasov, V. K. Zhivotov, E. G. Krasheninnikov, M. F. Krotov, B. I. Patrushev, V. D. Rusanov, G. V. Rykunov, A. M. Spektor, A. A. Fridman, and G. V. Sholin, Dokl. Akad. Nauk SSSR 238 (1), 66 (1978)].

54. *Русанов В. Д., Фридман А. А.* Физика химически активной плазмы. – М.: Наука, 1984. [V. D. Rusanov and A. A. Friedman, *Physics of chemically active plasma*. (Nauka, Moscow, 1984) [in Russian].

55. A. Fridman, *Plasma chemistry*. (Cambridge, Cambridge University Press, 2008).

56. Y. Qin, G. Niu, X. Wang, D. Luo, and Y. Duan, J. CO_2 Util. **28**, 283 (2018).

57. Yu. A. Lebedev and V. A. Shakhatov, Plasma Physics Reports **48** (4), 415 (2022).

58. *Шехтер А. Б.* Химические реакции в электрическом разряде. – Ленинград, Москва: ОНТИ – Главная редакция общетехнической литературы, 1935. [A. B. Shekhter, *Chemical Reactions in the Electric Discharge.* (Chief Editorial Board of General Technical Literature, Leningrad, Moscow, 1935)] [in Russian].

59. *Словецкий Д. И.* Механизмы химических реакций в неравновесной плазме. – М.: Наука, 1980. [D. I. Slovetskii, *Mechanism of Chemical Reactions in Plasma.* (Nauka, Moscow, 1980)] [in Russian].

60. Райзер Ю. П. Физика газового разряда. – М.: Наука, Главная ред. физико-матем. литературы, 1992. [Yu. P. Raizer, *Gas Discharge Physics*. (Springer–Verlag, Berlin, 1991].

61. Очкин В. Н. Спектроскопия низкотемпературной плазмы. – М.: Физматлит, 2006. [V. N. Ochkin, *Spectroscopy of Low Temperature Plasma*. (Wiley-VCH, Weinheim, Berlin, 2009].

62. W. H. Crew and E. O. Hulburt, Phys. Rev. **30**, 124 (1927).

63. F. Fischer, H. Kuster, and K. Peters, Brennstoff-chemie **11**, 300 (1930).

64. K. K. Corvin and S. J. Corrigan, J. Chem. Phys. **50**, 2570 (1969).

65. C. Dang, J. Reid, and B. K. Garside, Appl. Phys. **B 27**, 145 (1982).

66. *Демьяненко А. В., Засавицкий И. Я., Очкин В. Н. и др.* // Квант. электрон. 1987. Т. 14. № 4. С. 41. [A. V. Demyanenko, I. Ya. Zasavitsky, V. N. Ochkin, et al., Quantum. electron. **14** (4), 41 (1987)] [in Russian].

67. M. Spiridonov, C. Leys, D. Toebaert, S. Sazhin, E. Desoppere, P. Wild, and S. M. P. McKenna, J. Phys. D: Appl. Phys. **27**, 962 (1994).

68. G. Trenchev, A. Nikiforov, W. Wang, St. Kolev, and A. Bogaerts, Chemical Engineering Journal **362**, 341 (2019).

69. Bharathi Raja, Ramanujam Sarathi, Ravikrishnan Vinu, Energy Technol. **8**, 2000535 (2020).

70. *Максимов А. И., Сергиенко А. Ф., Словецкий Д. И.* // Физика плазмы. 1978. Т. 4. С. 347. [A. I. Maksimov, A. F. Sergienko, and D. I. Slovetsky, Fiz. Plasmy **4**, 347 (1978)] [in Russian].

71. T. Silva, M. Grofulovic, L. Terraz, C. D. Pintassilgo, and V. Guerra, Plasma Chemistry and Plasma Processing **40**, 713 (2020).

72. *Знаменская И. А., Гвоздева Л. Г., Знаменский Н. В.* // Методы визуализации в механике газа. – М.: Московский Авиационный институт, 2001. [I. A. Znamenskaya, L. G. Gvozdeva, and N. V. Znamenskii, *Metody vizualizatsii v mekhanike gaza* (*Imaging Methods in Gas Mechanics*). (Mosk. Aviats. Inst., Moscow, 2001)] [in Russian].

73. *Лелевкин В. М., Оторбаев Д. К.* Экспериментальные методы и теоретические модели в физике неравновесной плазмы. – Фрунзе: Илим, 1988. [V. M. Lelevkin, D. K. Otorbaev, and D. C. Schram, *Physics of Non-equilibrium Plasmas*. (North-Holland Publishing Co., Amsterdam, 1992)].

74. *Демтредер В.* Лазерная спектроскопия: Основные принципы и техника эксперимента / Пер. с англ. / под ред.