CHEMICAL ENGINEERING TRANSACTIONS

VOL. 105, 2023

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: David Bogle, Flavio Manenti, Piero Salatino

ISBN 979-12-81206-04-5; **ISSN** 2283-9216

DOI: 10.3303/CET23105089

Bioelectricity Generated by Microbial Fuel Cells from Spearmint (Mentha Spicata) and Ribbon Plant (Chlorophytum Comosum)

Eusterio H. Acosta Suasnabar*, Milagros Y. Gómez De La Cruz, Paola Y. Medina Simeón, Wilber S. Quijano Pacheco, Carlos A. Castañeda Olivera, Elmer Benites-Alfaro

Universidad César Vallejo, Campus Los Olivos, Lima, Perú
eacostas@ucv.edu.pe

Clean energy such as bioelectricity, a sustainable energy, obtains electricity associated with biological processes that do not generate greenhouse gases. The research aimed to produce bioelectricity using microbial fuel cells (MFCs) that transform chemical energy stored in organic matter into electricity. Peppermint (Mentha spicata) and ribbon plant (Chlorophytum comosum) MFC were designed in the district of Yanacancha, Chupaca-Junín. For the experimental process, microbial fuel cells were built, 3 batteries for mint and 3 batteries for ribbon plant, using graphite rods as electrodes. The initial characterization of the soil used in the pile was carried out, and then the global solar radiation was measured during the operation of the pile. In the investigation, a greater bioelectricity was achieved when the pH and temperature of the soil of the microbial fuel cell were 7.04 and 10.80 °C in peppermint MFC and 6.43 and 12.83 °C in tape MFC where bioelectricity of 245.37 mV was generated, 601.15x10-6 W in peppermint MFC and 505.45 mV, 2552.52x10-6 W in ribbon MFC respectively, so the ribbon microbial fuel cell (MFC) was the most efficient for bioelectricity generation.

1. Introduction

Within alternative energies, new technologies have emerged to generate electricity sustainably. Microbial fuel cells (MFCs) operate efficiently at room temperature and even at very low temperatures produce less CO_2, they are bioreactors used to generate energy from biomass found in organic waste and represent a promising method for waste disposal and electricity production (Aboela et al., 2020). In addition, solar energy is converted into bioelectricity without generating polluting emissions, using two principles: photosynthesis and electrochemical active bacteria, this process results in the generation of electrical energy without the need to harvest the plant (Azri et al., 2018).
Microbial fuel cells (MFCs) are a promising technology for the treatment of wastewater and substrate plants, have the potential to counteract the energy crisis and environmental pollution (Hoang et al., 2022). These cells are electrochemical devices that convert chemical energy contained in organic and inorganic matter into electric current using microorganisms as catalysts (Singh and Kalia, 2017). These consist of two chambers (anodic and cathodic) separated by a proton exchange membrane, with electrodes inside connected by an external circuit. Organic substrates are placed inside the chambers which can be organic matter or any plant waste (Deng et al., 2022 and Jatoi et al., 2021). The electricity generated inside these types of devices is through oxidation and reduction processes, converting chemical energy into electrical energy (Rojas-Flores et al., 2021 and Ghazali et al., 2019). Microorganisms oxidize organic matter producing electrons, which migrate through an external circuit, are oxidized in the cathodic chamber. According to this process, a flow of electrons is produced which produces electricity (Slate et al., 2019 and Ma et al., 2019). In microbial fuel cells there is a wide variety of substrates that are used, with biological factors being a fundamental property because they are used as a medium for microbial growth and other metabolic activities, at the same time, the composition and

Paper Received: 17 May 2023; Revised: 11 July 2023; Accepted: 22 September 2023
Please cite this article as: Acosta Suasnabar E.H., Gomez De La Cruz M.Y., Medina Simeon P.Y., Quijano Pacheco W.S., Castaneda-Olivera C.A., Benites Alfaro E., 2023, Bioelectricity Generated by Microbial Fuel Cells from Spearmint (Mentha Spicata) and Ribbon Plant (Chlorophytum Comosum), Chemical Engineering Transactions, 105, 529-534 DOI:10.3303/CET23105089

biodegradability of the substrate increases the activity rate for electron generation, which results in better performance of microbial fuel cells (Al Lawati et al., 2019 and Uddin et al., 2021).
The research used plants that have at their base a rhizome from which several dark violet subway stems grow in all directions, according to Ortiz (2010), which makes possible a more considerable number of root connections at the anode and, therefore, the number of electrons to generate electricity. This technology is an alternative for generating energy because it is possible to use living plants and substrate in microbial fuel cells that generate electricity such as peppermint (mentha spicata) and ribbon (chlorophytum comosum), an environmentally sustainable energy.

2. Methodology

The research was carried out in the district of Yanacancha in the province of Chupaca - Junín whose coordinates are; 12°12′07″S 75°23′14″W. The research was of applied type, with quantitative approach and experimental design, because the microbial fuel cells of peppermint and tape were constructed. The study was conducted in 7 steps as described below.

2.1 Materials and components

Peppermint (mentha spicata) and ribbon (chlorophytum comosum) plants were used; soil with compost and nutrient-rich black soil. The plants have various health benefits. Peppermint treats problems of indigestion, dizziness and aches and pains, and ribbon as an air purifier.

2.2 Obtaining mint plants from a seedbed

The mint plant was obtained moistened and the first irrigation was given, after a few weeks its germination began, we proceeded to obtain the 12 cuttings of mint, the following procedures were followed according to Saray, C. and Ugás, (2001). The ideal measure between the beginning of the stem is 7 cm and 12 cm, it was deposited in water in a bottle, then the 12 stems were submerged in the bottles. It was waited until roots come out to a measure of 5 cm (ideal measure), then it was planted to the microbial fuel cells to generate electricity.

2.3 Transplanting ribbon plant

The tape plant with adequate stem that presented the flowers ready to be transplanted was 15 cm, the 12 of these shoots were introduced into the piles with the soil pressing lightly, the transplants were kept in places where sunlight reaches and watered with a sprinkler to promote their growth, which became noticeable after 15 days.The plants, mint and tape were placed in the cells and measurements of the operating and performance variables were taken. Measurement of the temperature of the soil used in the cell (Figure 1).

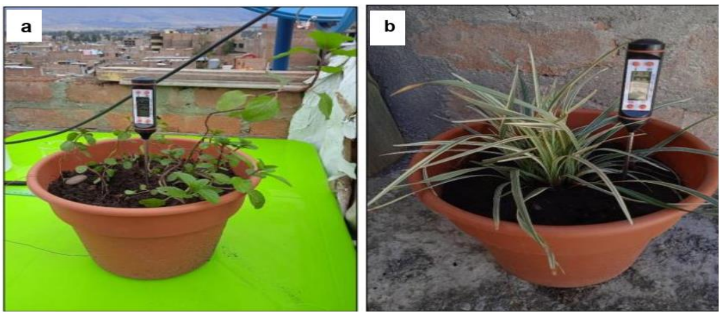

Figure 1: The cells and soil temperature measurement used: a) peppermint plant, b) ribbon plant.

2.3 Assembly of the microbial fuel cell

The research was carried out at the pilot plant level in the district of Yanacancha. According to Pamintuan et al., (2018), the following procedure was carried out for the operation of peppermint and ribbon microbial fuel cells for electricity generation: 07 cylindrical pots with dimensions of 10 cm in height and 5 cm in diameter were acquired (Sophia and Sreeja, 2017), with a fine mesh cotton separator, placed 2 inches from the bottom of the pile, connected with two graphite rods (A = 4.85 × $10^{-4} m2$) as electrodes, the cathode was connected to the bottom of the container while the anode was connected near the roots of the plants, the graphite electrode and copper wires were connected sealed to prevent copper exposure. The plants were immediately placed in their corresponding cell, 3 cells for spearmint and 3 cells for ribbon, directly in the anode chamber with their root system, as shown in Figure 2. The microbial fuel cells were then filled with black or growing soil.

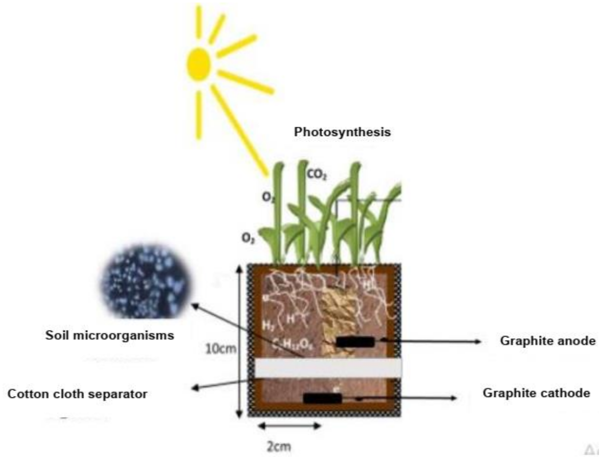

Figure 2. Experimental set-up scheme

2.4 Physicochemical analysis of the soil used in the MFCs

Before the generation of electricity, the soil of the peppermint and tape were made their physicochemical and nutrient analysis at the National Institute of Agrarian Innovation (INIA) for the growth of both plants.

2.5 Measurement of solar radiation

The solar radiation of the days of the week in which the generation of electrical energy was monitored was reported from the solar radiation records of the Geophysical Institute of Peru, Huayao-Chupaca, because it is located near the jurisdiction of the investigation.

2.6 Measurement of the pH and temperature of the soil used in MFCs

The measurement of the pH and temperature of the soil used in the mint and ribbon plant piles were carried out before and during electricity generation, every day at 9 a.m., 3 p.m. and 9 p.m. for a week.

3. Results

3.1 Characterization of the soil used in microbial fuel cells

The soil used in the cell with a pH close to neutral and rich in organic matter, as shown in Table 1, the K concentration was 189.20 ppm, a value that is within the normal classification, so it is a soil favorable that stimulates the growth and flowering of plants (Andrades, 2016).

Table 1: Physicochemical characteristics of the soil prepared with nutrients for peppermint and ribbon

Parameters	Unit	Results
pH		7.01
Organic material	%	5.14
P	ppm	10.54
K	ppm	189.20
Al	me/100g	0.00
N	%	0.21
soil type		sandy loam
Sand	%	73.80
Clay	%	7.70
silt	%	18.20

3.2 Bioelectricity obtained in microbial fuel cells

Table 2 shows the results of voltage, intensity and electrical power measured in both microbial cells during the one-week experiment.

Table 2: Voltage, intensity and electrical power results measured in the spearmint and ribbon plant microbial fuel cells.

		Peppermint (mentha spicata)			Ribbon plant (chlorophytum comosum)		
Experiment day	Hour of monitoring	Voltage (mV)	Intensity (mA)	Potency ($x10^{-6}$ W)	Voltage (mV)	Intensity (mA)	Potency ($x10^{-6}$ W)
	9 a.m.	19.60	0.20	3.92	24.66	0.25	6.16
1	3 p.m.	22.23	0.22	4.89	28.65	0.29	8.30
	9 p.m.	21.61	0.22	4.75	29.28	0.29	8.49
	9 a.m.	22.79	0.23	5.24	38.58	0.39	15.04
2	3 p.m.	19.25	0.19	3.65	41.68	0.42	17.50
	9 p.m.	20.56	0.21	4.32	49.83	0.50	24.92
	9 a.m.	16.05	0.16	2.57	52.08	0.52	27.08
3	3 p.m.	13.30	0.13	1.73	49.97	0.50	24.99
	9 p.m.	23.09	0.23	5.31	49.16	0.49	24.09
	9 a.m.	21.74	0.22	4.78	120.06	1.20	144.07
4	3 p.m.	14.51	0.15	2.17	120.51	1.21	145.82
	9 p.m.	14.81	0.15	2.22	119.57	1.20	143.48
	9 a.m.	106.73	1.07	114.20	504.24	5.05	2546.41
5	3 p.m.	110.53	1.11	122.68	505.45	5.05	2552.52
	9 p.m.	101.34	1.01	102.35	504.24	5.04	2541.37
	9 a.m.	238.17	2.38	566.84	444.99	4.45	1980.20
6	3 p.m.	245.37	2.45	601.15	474.27	4.74	2248.04
	9 p.m.	209.44	2.09	437.73	478.00	4.78	2284.84
	9 a.m.	150.22	1.50	225.33	420.90	4.21	1771.99
7	3 p.m.	139.24	1.39	193.54	480.43	4.80	2306.06
	9 p.m.	130.78	1.31	171.32	481.77	4.82	2322.13

Table 2 presents the results obtained in the cells, maximum values of bioelectricity in the peppermint cell were given at 3.00 pm on the sixth day, which were 245.37 mV, 2.45 mA and $601.15x10^{-6}$ W and in the ribbon cell the maximum values were given at 3.00 pm on the fifth day with results of 505.45 mV, 5.05 mA and $2552.52x10^{-6}$ W respectively. The power did not present significant variations in relation to the electrical intensity, in addition to the electrical voltage it is observed that on the sixth day the electrical intensity generated was maximum, while in the first four days of the test the intensities were very close. In the ribbon cell, it is observed that on the fourth day the voltage, intensity and electrical potential had a small increase compared to the first days of the test; however, on the fifth day a considerable increase in the generation of bioelectricity is observed, values that fluctuated during the sixth to the seventh day.

3.3 Solar radiation, pH and temperature of soil used in microbial fuel cells

Table 3 shows that the solar radiation was intense at 9 in the morning, while at 9 at night the global solar radiation decreased, it is also observed that the highest global solar radiation monitored was 721.2 W/ m² monitored at 3 p.m. on the third day of the study, while the lowest radiation monitored was -2.98 W/m² at 9 pm on the fourth day of the study. As of the fifth day, the increase in solar radiation caused an increase in the bioelectricity generated in the mint and ribbon microbial fuel cells, this same relationship is observed at 3 p.m. and 9 p.m. of the sixth day in which the decrease in solar radiation was accompanied by the reduction of the electrical voltage generated, which solar radiation had some effects during the experiment.

It is observed that the pH of the peppermint microbial fuel cell soil fluctuated between 4.87 and 7.33, this value being the highest value recorded on the sixth day at 9 a.m., the temperature of the fuel cell soil microbial range varied from the lowest of 7.86 °C to 19.20 °C recorded at 3 p.m. on the first day of study. The highest voltage generated was 245.37 mV recorded at 3 p.m. on the sixth day, this voltage was reached when the soil pH was 7.04 and the soil temperature was 10.80 °C

In the ribbon microbial fuel cell, the pH values presented mostly neutral values, considering that on the last day of the test at 9 p.m. the pH presented an acid value of 5.31; Regarding the temperature, it is observed that the average temperatures fluctuated between 8.03 °C to 19.43 °C, recorded at 9 a.m. on the fourth day and at 3 p.m. of the first day of trial respectively. The highest voltage generated in the was 505.45 mV recorded at 3 p.m. on the fifth day, this voltage was reached when the soil pH was 6.43 and the soil temperature was 12.83 °C.

Table 3: Solar radiation, pH and temperature results measured in the peppermint and ribbon plant cells.

			Peppermint			Ribbon plant		
Experiment day	Hour of monitoring	Solar radiation (W/m^2)	Voltage (mV)	pH	Temperature (°C)	Voltage (mV)	pH	Temperature (°C)
	9 a.m.	657.50	19.60	6.36	13.63	24.66	6.96	13.67
1	3 p.m.	311.30	22.23	6.76	19.20	28.65	6.55	19.43
	9 p.m.	-2.76	21.61	6.11	9.67	29.28	6.08	9.10
	9 a.m.	652.10	22.79	6.89	10.77	38.58	6.36	13.37
2	3 p.m.	697.50	19.25	6.64	14.73	41.68	6.30	15.60
	9 p.m.	-2.95	20.56	6.45	8.37	49.83	6.82	8.33
	9 a.m.	643.90	16.05	6.17	8.86	52.08	5.96	9.37
3	3 p.m.	721.20	13.30	5.97	12.47	49.97	6.06	14.80
	9 p.m.	-2.44	23.09	6.05	9.20	49.16	6.02	8.30
	9 a.m.	417.20	21.74	6.03	8.37	120.06	6.08	8.03
4	3 p.m.	272.20	14.51	6.09	17.41	120.51	5.98	16.97
	9 p.m.	-2.98	14.81	5.59	9.00	119.57	5.39	8.70
	9 a.m.	642.90	106.73	6.17	8.67	504.24	6.10	9.27
5	3 p.m.	606.00	110.53	6.13	11.80	505.45	6.43	12.83
	9 p.m.	-2.44	101.34	6.00	10.40	504.24	6.41	10.57
	9 a.m.	686.70	238.17	7.33	7.86	444.99	7.33	8.97
6	3 p.m.	332.90	245.37	7.04	10.80	474.27	7.02	10.80
	9 p.m.	-1.05	209.44	6.32	10.00	478.00	5.93	9.43
	9 a.m.	659.70	150.22	5.79	9.80	420.90	6.27	10.35
7	3 p.m.	199.80	139.24	5.66	12.44	480.43	6.28	12.10
	9 p.m.	-1.74	130.78	4.87	9.73	481.77	5.31	11.84

4. Discussion

In the peppermint pile, the highest voltage was 245.37 mV, when the soil pH was 7.04 and the temperature was 10.80 °C, the soil pH increased its value from an initial 5.80 to 6.32, as in the research of Khudzari et al. (2018) who observed that the pH values of the sandy loam microbial fuel cell increased from 6.3 to 7 reaching a voltage of 594 mV. In the ribbon pile the highest voltage was 505.45 mV when the soil pH was 6.43 and the temperature was 12.83 °C, due to solar radiation the voltage increased. According to Rojas-Flores et al. (2021) in cells with cranberry residues generated a current and a peak voltage of 1.13 mA, 1.127 V, comparing with the tape pile the intensity is lower and the voltage slightly higher due to the pH levels that were acidic. According to the research of Rojas-Flores et al. (2022) in double chamber microbial fuel cells used avocado waste, the current and voltage values of 3.7326 mA and 0.74 V on the seventh day, resulting current below the ribbon cell and voltage slightly higher due with an optimum operating pH of 5. 98 and, according to Luke et al. (2020) in double chamber microbial piles, used canteen-based food waste leachate as substrate, obtained a maximum voltage of 0.49 V and current of 1.67 A voltage and current values lower than that of ribbon cell and slightly higher in voltage than the peppermint cell. Moqsud, Hannan and Omine (2015) used a rice plant with 1 % soil mixed with compost and additional organic matter their highest voltage result was around 700 mV slightly higher than that of ribbon pile due to solar radiation, temperature and humidity. Van der Velden et al. (2022) in their research opines that, the efficiency of microbial fuel cells (MFCs) is of priority nowadays the search for renewable and sustainable energy solutions that can cope with the energy demand. Therefore, mint and ribbon microbial fuel cells are a good efficiency and alternative in the current global energy crisis.

5. Conclusions

The bioelectricity generated in the microbial fuel cells of the plant species, mint and ribbon reached voltages of 245.37 mV and 505.45 mV with substrate soils presenting pH 7.04 and 10.8 °C and pH 6.43 to 12.83 °C, respectively; the power obtained was 601.15x10-6 and 2552.52x10-6 W per cell. Solar radiation was not a determining factor in the generation of bioelectricity in the cells; however, from the fifth day on, an energetic improvement was observed, as an influence of the better stability and growth of the vegetable plants in the MFCs, the degradation of organic matter and the conversion of the chemical energy contained in the substrate into electrical energy; therefore, the cells fulfill two functions: elimination and bioremediation of organic matter and generation of electricity.

Acknowledgments

The authors thank the Vice-Rector for Research of the César Vallejo University for financing this publication.

References

Aboela D., Solimán M. A., Ashur I., 2020, A Reduced Model for Microbial Fuel Cell, Chemical Engineering Transactions, 79, 43-48.

Al Lawati M. J., Jafary T., Baawain, M. S., Al-Mamun A. A., 2019, mini review on biofouling on air cathode of single chamber microbial fuel cell; prevention and mitigation strategies. Biocatal. Agric. Biotechnol, 22, 101370.

Andrades M., 2016. Soil fertility and parameters that define it. Journal of Agricultural Sciences, 4, 1, 55-63. (Spain)

Azri Y.M., Tou I., Sadi M. and Benhabyles L., 2018. Bioelectricity generation from three ornamental plants: Chlorophytum comosum, Chasmanthe floribunda and Papyrus diffusus. International Journal of Green Energy, 15 (4), 254-263.

Deng L., Ngo H.H., Guo W., Chang S.W., Nguyen D.D., Pandey A., Varjani S., Hoang N.B., 2022, Recent advances in circular bioeconomy based clean technologies for a sustainable environment, Journal of Water Process Engineering, 46.

Ghazali N.F., Mahmood N.A.N., Abu Bakar N.F., Ibrahim K.A., 2019, Temperature dependence of power generation of empty fruit bunch (EFB) based microbial fuel cell, Malays. J. Fundam. Appl. Sci. 2019, 15, 489–491.

Hoang A.T., Nižetić S., Ng K.H., Papadopoulos A.M., Le A.T., Kumar S., Hadiyanto H., Pham V., 2022, Microbial fuel cells for bioelectricity production from waste as a sustainable prospect for future energy sector, Chemosphere, 287, 3.

Jatoi A.S., Akhter F., Mazari S.A., Sabzoi N., Aziz S., Soomro S.A., Mubarak N.M., Baloch H., Memon A.Q., Ahmed S., 2021, Advanced microbial fuel cell for wastewater treatment—A review, Environ Sci Pollut Res, 28, 5, 5005-5019

Khudzari, J., Kurian, J., Gariépy, Y., Tartakovsky, B., Raghavan, G.S. V, 2018, Effects of salinity, growing media, and photoperiod on bioelectricity production in plant microbial fuel cells with weeping alkaligrass, Biomass and Bioenergy, 109, 1-9.

Luke A. J. S., Sunny S., Thomas G., Chithra V.S., Santhosh R. P., Ravindran S., 2020, Electricity Production From Food Waste Leachate Using Microbial Fuel Cell, Indian Journal of Environmental Protection, 40, 6, 628 – 6321.

Ma F., Yin Y., Pang S., Liu J., Chen W., 2019, A Data-Driven Based Framework of Model Optimization and Neural Network Modeling for Microbial Fuel Cells. IEEE Access, 7, 162036 – 162049.

Moqsud M., Hannan M., Omine K., 2015, Assessment of factors influencing bioelectricity generation in paddy plant microbial fuel cells, Global Advanced Research Journal of Agricultural Science, 4, 12, 2315-5094.

Ortiz R., 2010, Evaluation of the effect of three organic fertilizers at three different doses on the growth rate and yield of beans (phaseolus vulgaris) l. var. cerinza, in urban agriculture conditions, Thesis, Pontificia Universidad Javeriana, Bogotá, Colombia. (Spain)

Pamintuan K.R.S., Clomera J.A.A., Garcia K. V., Ravara G.R. and Salamat E.J.G., 2018, Stacking of aquatic plant-microbial fuel cells growing water spinach (Ipomoea aquatica) and water lettuce (Pistia stratiotes). IOP Conference Series: Earth and Environmental Science, 191, 1.

Rojas-Flores S., Benites S., De La Cruz-Noriega M., Cabanillas-Chirinos L., Valdiviezo-Domínguez F., Álvarez M. Q., Vega-Ybañez V., Angelats-Silva L., 2021, Bioelectricity Production from Blueberry Waste, Processes, 9, 1301.

Rojas-Flores S., De La Cruz-Noriega M., Nazario-Naveda R., Benites S. M., Delfín-Narciso D., Rojas-Villacorta W., Romero C., 2022, Bioelectricity through microbial fuel cells using avocado waste, Energy Reports, 8, 9.

Salinas-Juárez M.G., Roquero P., Durán-Domínguez-de-Bazúa M. del C., 2016, Plant and microorganisms support media for electricity generation in biological fuel cells with living hydrophytes. Bioelectrochemistry, 112, 145 -152.

Saray C., Ugas R., 2001, Cultivation of aromatic and medicinal herbs. National Institute of Agrarian Research, pp. 0-36. (Spain)

Singh L., Kalia V.C. (Eds.), 2017, Waste biomass management - A holistic approach, Springer Int. Publishing.

Slate A. J., Whitehead K. A., Brownson D. A., Banks C. E., 2019, Microbial fuel cells: An overview of current technology. Renew. Sustain. Energy Rev. 101, 60 – 81.

Uddin M.J., Jeong Y. K., Lee W., 2021, Microbial fuel cells for bioelectricity generation through reduction of hexavalent chromium in wastewater: A review. Int. J. Hydrogen Energy, 46, 11458 – 11481.

Van der Velden, M., Matsena M.T., Chirwa E. M. N.,2022, The Impact of Marine Bacteria (from Saldanha Bay) on the Performance of an Air-Cathode Microbial Fuel Cell, Chemical Engineering Transactions 96, 331-336.