Journal of
Chemical Engineering & Process Technology

Severo et al., J Chem Eng Process Technol 2016, 7:4
DOI: 10.4172/2157-7048.1000310

Short Communication Open Access

Photobioreactors and Oxycombustion: A Mini-Review on the Process Integration

Severo IA, Deprá MC, Zepka LQ and Jacob-Lopes E*

Department of Food Science and Technology, Federal University of Santa Maria, Santa Maria, RS, Brazil

Abstract

Some strategies for reducing greenhouse gas emissions to the atmosphere, especially carbon dioxide, have been gaining growing attention by researchers with the aim of develop new technologies that are energy-efficient and economically viable in industrial processes. In this sense, the aim of this paper is to provide a mini review of industrial systems of oxycombustion integrated in microalgal photobioreactors. Divided into four distinct topics, the paper discusses issues related to biological carbon capture and utilization, the elements of oxycombustion technology, the reuse of exhaust gases from photobioreactor and the process integration, summarizing a range of useful strategies directed to the industrial sustainable development.

Keywords: Biological carbon capture and utilization; Bio-oxycombustion; Oxyfuel; Microalgae

Introduction

Concerns over global climate change lead efforts on developing technologies to reduce carbon dioxide emissions from anthropogenic activities. Technological solutions to this problem includes research and development systems and alternative techniques that are economical and energy-efficient in industrial processes, enabling mitigation of polluting compounds [1]. The oxycombustion has proven to be one of the best forms of carbon capture from stationary sources, due to its ability to mitigate emissions and improve combustion performance. This technological route is based on the replacement of the air used in combustion processes by oxygen-rich atmospheres. As a consequence, there is a gain in thermal capacity, resulting in greater overall efficiency of equipment and reducing fossil fuel consumption [2]. Despite the oxycombustion be an attractive technology, this approach has faced significant difficulties in implementation related to the high cost and the purity of the oxygen produced, unfeasible their application in industrial scale [3].

These issues can be circumvented through the photobioreactors, using photosynthetic microorganisms, as the microalgae, which have as a metabolic co-product the O_2 supported by the water photolysis reactions. Additionally, the bioprocess mediated by microalgae produce in parallel numerous volatile organic compounds that have considerable energy content, besides releasing substantial concentrations of CO_2 in exhaust gases, serving as N_2 diluent [4,5].

Several technologies have been proposed for reducing CO_2 emission focusing on the capture, storage and/or utilization of carbon [6]. The biological carbon capture and utilization (BCCU) is a highly potential technology for industrial application, because it converts biologically carbon dioxide with their integration into a oxycombustion process [7]. Therefore, the bio-oxycombustion technique is discussed in this mini review, including fuels derived from biological conversion processes of greenhouse gases through photosynthesis.

Biological Carbon Capture and Utilization

Global emissions of carbon dioxide reach more than 20 billion tons per year. In contrast, it is estimated that such emissions should be reduced by at least 50% to mitigate the increase in global temperature. In this scenario, the oxycombustion technology have been proposed as a viable option to capture approximately 90% CO_2 in large point sources of emissions, consisting of compression stages, capture, transport and storage or utilization [8]. Complementing the carbon capture and storage (CCS) and carbon capture and utilization (CCU) technologies, more recently the BCCU technology represents a potential strategy for CO_2 capture from polluting sources. This technological route consists of the biological conversion of CO_2 into biomass through photosynthesis, for the extraction of high value-added products. In this context, the microalgae-based processes, for example, present high conversion rates, which provide an attractive form of BCCU, recycling the CO_2 from different industrial processes [7,9].

Elements of Oxycombustion Technology

The use of pure oxygen as oxidant in combustion processes is a relatively new approach to the greenhouse gases mitigation. In oxycombustion, the fuel is burnt in an atmophere enriched with high purity oxygen and free nitrogen, differing from conventional processes that use air as oxidant. The flue gas are recycled, producing a stream containing mainly CO_2 and H_2O. After this step, CO_2 is ready for capture after purification and compression [10]. Due to the high flame temperature resulting from burns with practically pure O_2, part of the gas from combustion, rich in CO_2, returns to the system to refund the volume of gas lost when N_2 is removed from the air and to prevent the excessive increasing temperature in the system [11]. The main differences in the replacement of N_2 for O_2 are in relation to the temperature, the stability, the propagation velocity and delay in the flame ignition, the heat transfer and reduction of pollutants emissions, impacting positively in the overall heat capacity of the equipment. Many of these effects can be explained by differences in gas properties CO_2 and N_2, which influence both heat transfer and combustion reaction kinetics (density, heat capacity, diffusivity and radiative properties of

***Corresponding author:** Jacob-Lopes E, Department of Food Science and Technology, Federal University of Santa Maria, Roraima Avenue, 1000, 97105-900, Santa Maria, RS, Brazil, Tel: 555532208822; E-mail: jacoblopes@pq.cnpq.br

Received October 04, 2016; **Accepted** October 07, 2016; **Published** October 07, 2016

Citation: Severo IA, Deprá MC, Zepka LQ, Jacob-Lopes E (2016) Photobioreactors and Oxycombustion: A Mini-Review on the Process Integration. J Chem Eng Process Technol 7: 310. doi: 10.4172/2157-7048.1000310

the gases). The oxycombustion can be used with any fuel to thermal energy production [12]. Despite the inherent advantages of this technology, one of the main drawbacks associated with oxycombustion refers to O_2 production of high purity. In this case, a unit for separation and purification is necessary, which causes an additional cost for the plant and increased energy consumption. These problems are the main challenges to be overcome [13].

Reuse of Exhaust Gases from Photobioreactors

Photobioreactors may be defined as systems utilized for the development of photosynthetic reactions. These equipments present different configurations, although the most common designs for the cultivation of microalgae are open or closed systems. Besides, some process parameters should be taken into account to achieve good yields, such as nutrient availability, efficient supply of CO_2, temperature control, agitation, mass transfer, ease of control of the reaction conditions and ease of scale-up [14]. Regardless of these questions, growth of microalgae in photobioreactors occurs through the photosynthetic mechanism. This in turn, consists in a chemical process that converts carbon dioxide into biomass using light energy and producing oxygen molecules [15]. Photosynthesis is characterized by two interdependent phases. Firstly, carbon dioxide is incorporated into ribulose 1,5-biphosphate (rubisco) energy being required during the catalytic reaction of the enzyme rubisco carboxylase. The reaction product is broken into three-carbon molecules, 3-phosphoglyceraldehyde (PGA). In the presence of ATP (adenosine triphosphate) and NADPH (nicotinamide adenine dinucleotide phosphate), the PGA is reduced to glyceraldehyde 3-phosphate (G3P), leads to the production of sugars and subsequently glucose. This sequence of metabolic transformations is known as the Calvin-Benson cycle. Therefore, the light energy is retained in two photoreactions prepared by two pigment-protein complexes, called photosystem I and II, exciting the chlorophyll *a* molecule and their electrons are transferred to a molecule electron acceptor. Part of the energy liberated is incorporated into ATP in the phosphorylation process [16]. The ultimate source of electrons for photosynthesis is H_2O, which yields in the process of photolysis, or Hill's reaction, hydrogen atoms, electrons and free oxygen. Thus, this reaction is an important product obtained from photosynthesis microalgae, because the O_2 in the process is generated exclusively from the water photolysis [17].

Despite the existence of many studies considering the fraction of non-volatile metabolites, it is also observed that the yield in biomass does not completely fulfill the total carbon balance of the system. One should consider that other products are involved in the photosynthetic conversion of the CO_2, including the secretion of biopolymers into the culture media, and of particular interest, the release of volatile organic compounds (VOCs) [4]. The VOCs are unexplored biomolecules, which are influenced by the culture parameters. This way, microalgae are capable of synthesizing and release specific compounds which indicate a great commercial interest in biomolecules from renewable sources, such as alcohol, esters, hydrocarbons, terpenes, ketones, carboxylic acids and sulfurized compounds [18]. Some cyanobacteria are known to synthesize alkanes or alkenes that have desirable properties for combustion. These VOCs can be used for the biofuels production, representing sustainable solutions for the energy sector [19]. The occurrence of VOCs in photosynthetic microorganisms is a consequence of their metabolism, and their biosynthesis, will depend exclusively on the availability of carbon, nitrogen and energy from the primary metabolism. The possible metabolic pathways CO_2 conversion for the synthesis of VOCs, were previously described in other studies [4,20,21]. These compounds could, therefore, be considered a source of useful chemical products with potentiality for commercial applications.

Process Integration: Photobioreactors Integrated to Oxycombustion Systems

The process integration is a relatively current concept and has been implemented in most industrial production processes. This technological route is defined as a series techniques and methods in integrated production systems that combine several unit operations inside an industrial plant [22]. Thus, the main objectives this strategy is to reduce the operational costs of the plant and the minimization of large equipment. As result, there is a lower energy consumption and increased overall efficiency in the system [23].

Alternatively, industrial processes which using fossil inputs have been gradually replaced by biobased processes. Microalgae-based processes, for example, are a potential way to a sustainable and economically viable production of consumables. The integration of microalgae into industrial processes is a suitable and innovative strategy to comply with the requirements of green engineering. For this technological route, is possible lowered its overall energy consumption of the process, which implies the reduction of fossil raw materials, potable water consumption and minimizing emissions [24,25]. Several integrated processes have been developed and some possibilities are considered through the reuse, the recovery and the possibly recycling of surpluses mass, effluents, water and energy for industrial application [26]. These strategies are highlighted for being economically viable and for improving the thermal performance of industrial combustion systems, effectively contributing to sustainable development.

The different strategies of integration of the bio-based processes are considered important approaches towards sustainable development. For this reason, the use of oxygen biologically generated in photobioreactors and their integration in processes that require the enrichment of this compound as oxidizer, such as bio-oxycombustion process, are considered potential examples for industrial application. These technological routes can significantly contribute to the bioeconomy of the future.

References

1. IPCC - International Panel on Climate Change (2014) Climate change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
2. Escudero AI, Espatolero S, Romeo LM (2016) Oxy-combustion power plant integration in an oil refinery to reduce CO_2 emissions. International Journal of Greenhouse Gas Control 45: 118-129.
3. IEA - International Energy Agency (2011) Cost and performance of carbon dioxide capture from power generation. OECD/IEA, Paris.
4. Jacob-Lopes E, Scoparo CHG, Queiroz MI, Franco TT (2010) Biotransformations of carbon dioxide in photobioreactors. Energy Conversion and Management 51: 894-900.
5. Borowitzka MA (2013) High-value products from microalgae their development and commercialization. Journal Applied Phycology 25: 743-756.
6. Gladysz P, Ziebik A (2016) Environmental analysis of bio-CCS in an integrated oxy-fuel combustion power plant with CO_2 transport and storage. Biomass and Bioenergy 85: 109-118.
7. Jajesniak P, Ali H, Wong TS (2014) Carbon Dioxide Capture and Utilization using Biological Systems: Opportunities and Challenges. Bioprocessing and Biotechniques 4: 155.
8. Cuéllar-Franca RM, Azapagic A (2015) Carbon capture, storage and utilization technologies: A critical analysis and comparison of their life cycle environmental impacts. Journal of CO_2 utilization 9: 82-102.

9. Oh ST, Martin A (2016) Thermodynamic efficiency of carbon capture and utilisation in anaerobic batch digestion process. Journal of CO_2 utilization 16: 182-193.

10. Stanger R, Wall T (2011) Sulphur impacts during pulverized coal combustion in oxy-fuel technology for carbon capture and storage. Progress in Energy and Combustion Science 37: 69-88.

11. Irfan MF, Arami-Niya A, Chakrabarti MH, Daud WMAW, Usman MR (2012) Kinetics of gasification of coal, biomass and their blends in air (N2/O2) and different oxy-fuel (O2/CO2) atmospheres. Energy 37: 665-672.

12. Yin C, Yan J (2016) Oxy-fuel combustion of pulverized fuels: Combustion fundamentals and modeling. Applied Energy 162: 742-762.

13. Toftegaard MB, Brix J, Jensen PA, Glarborg P, Jensen AD (2010) Oxy-fuel combustion of solid fuels. Progress in Energy and Combustion Science 36: 581-625.

14. Singh RN, Sharma S (2012) Development of suitable photobioreactor for algae production – A review. Renewable and Sustainable Energy Reviews 16: 2347-2353.

15. Zhao B, Su Y (2014) Process effect of microalgal-carbon dioxide fixation and biomass production: A review. Renewable and Sustainable Energy Reviews 31: 121-132.

16. Calvin M, Benson AA (1948) The Path of Carbon in Photosynthesis. Science 107: 476-480.

17. Heldt HW, Piechulla B (2011) Plant Biochemistry. 4th edn. German edition: Academic Press in an imprint of Elsevier, p: 618.

18. Keppler F, Eiden R, Niedan V, Pracht J, Schöler HF (2000) Halocarbons produced by natural oxidation processes during degradation of organic matter. Nature 403: 298-301.

19. Lau NS, Matsui M, Abdullah AA (2015) Cyanobacteria: Photoautotrophic Microbial Factories for the Sustainable Synthesis of Industrial Products. BioMed Research International 2015: 1-9.

20. Jacob-Lopes E, Franco TT (2013) From oil refinery to microalgal biorefinery. Journal of CO_2 utilization 2: 1-7.

21. Santos AB, Fernandes AS, Wagner R, Jacob-Lopes E, Zepka LQ (2016) Biogeneration of volatile organic compounds produced by Phormidium autumnale in heterotrophic bioreactor. Journal of Applied Phycology 28: 1561-1570.

22. International Energy Agency (2000) Tutorial on Process Integration. A Process Integration Primer. SINTEF Energy Research.

23. Baldea M (2015) From process integration to process intensification. Computers and Chemical Engineering 81: 104-114.

24. Francisco EC, Franco TT, Zepka LQ, Jacob-Lopes E (2015) From waste-to-energy: the process integration and intensification for bulk oil and biodiesel production by microalgae. Journal of Environmental Chemical Engineering 3: 482-487.

25. Wohlgemuth R (2009) The locks and keys to industrial biotechnology. N Biotechnol 25: 204-213.

26. Fresewinkel M, Rosello R, Wilhelm C, Kruse O, Hankamer B, et al. (2014) Integration in microalgal bioprocess development: Design of efficient, sustainable, and economic processes. Engineering in Life Sciences 14: 560-573.