Application of Nanoparticles in Bioreactors to Enhance Mass Transfer during Syngas Fermentation

Subjects: Energy & Fuels

Contributor: Evelyn Sajeev, Sheshank Shekher, Chukwuma C. Ogbaga, Kwaghtaver S. Desongu, Burcu Gunes, Jude A. Okolie

Gas–liquid mass transfer is a major issue during various bioprocesses, particularly in processes such as syngas fermentation (SNF). Since SNF involves the movement of gases into the fermentation broth, there is always a rate-limiting step that reduces process efficiency. Improving this process could lead to increased efficiency, higher production of ethanol, and reduced energy consumption. One way to improve fluid transfer between gas and liquid is by incorporating nanoparticles (NPs) into the liquid phase. This entry describes recent advances in using NPs to improve gas–liquid mass transfer during SNF. The entry also describes the basics of SNF and the impact of NPs on the process and suggests areas for future research. For example, carbon nanotubes have been found to elevate the available surface area needed for gas–liquid transfer, thus improving the process efficiency. Another area is the use of NPs as carriers for enzymes involved in syngas fermentation.

Keywords: nanoparticles ; syngas fermentation ; mass transfer ; biofuel ; bioethanol

---

Climate change, rising global population, and the ongoing need for energy have driven research into alternative energy sources in recent years. Technologies that convert biogenic waste into green fuels and chemicals, such as thermochemical processes including pyrolysis and gasification, and biological processes such as anaerobic digestion and syngas fermentation, show promise as viable alternatives [1]. Among biological processes, syngas fermentation (SNF) is a particularly promising technology for the production of ethanol from lignocellulosic biomass. SNF has the advantage of not requiring biomass pretreatment, and it is a viable alternative to Fischer-Tropsch Synthesis (FT) for the production of liquid hydrocarbon fuels. It has been studied extensively and has the potential for industrial-scale applications. Unlike FT, SNF does not require a fixed CO/H_2 ratio [2]. SNF can also be combined with thermochemical processes in a hybrid process that involves gasifying the feedstock for syngas production and subsequent microbial action of the produced syngas for bioethanol production [3].

One of the major challenges in implementing SNF on a large scale is the low mass transfer rate at the gas–liquid interface [4]. To overcome this limitation, an efficient bioreactor configuration and other key factors are required to ensure a successful mass transfer. However, even with an optimized bioreactor, the process may still be limited by a low rate of mass transfer that cannot meet the demands of cell growth.

The key bottleneck in SNF is how to move the gas molecules to the fermentation broth which is mostly in liquid form. The mass transfer restrictions between gas and liquid often induce low yield and process heterogeneity [2]. Therefore, a bioreactor configuration that can produce efficient mass transfer and a high cell density in a cost-effective manner is crucial for SNF. Common reactors such as the continuous stirred tank reactor (CSTR), bubble column, and airlift reactors are usually adopted in SNF to overcome mass transfer limitations [5].

The volumetric gas–liquid mass transfer coefficient (k_{La}) is commonly utilized in evaluating the mass transfer efficiency among different reactor configurations. While various reactor designs have been explored to improve the performance of SNF, the options for altering reactor design are limited. Alternative methods such as using nanoparticles (NPs) have shown promising potential for enhancing mass transfer in syngas fermentation [4].

Kim et al. [6] conducted a study where they tested six nanoparticles to improve gas–liquid mass transfer during SNF. The nanoparticles tested are made up of carbon-based materials, palladium and alumina-based materials. Their results indicated that silica nanoparticles with 0.3 wt.% showed the best enhancement of SNF. Mass transfer coefficient improvement resulting from the adhesion of NPs to the gas–liquid interface was further clarified based on three distinct mechanisms: shuttling or grazing effect, hydrodynamic effects at the gas–liquid boundary layer, and changes in the specific gas–liquid interfacial area. Additionally, an easy and affordable recovery method is essential for making the process economically viable. Magnetic nanoparticles (MNPs) are a promising option for easy recovery of the nanoparticles [6].

In another study, Kim et al. [7] evaluated the influence of MNPs on CO, H_2 and CO_2 solubility as well as the acid and alcohol production during SNF [7]. Based on their observations, the magnetic silica nanoparticles with Co and Fe oxides improved the gaseous solubility and production of alcohols and acids compared to the experiments without MNPs.

Given the impact of MNPs on SNF, it is crucial to comprehend the underlying mechanism. However, research in this field is limited. Sun et al. [8] provided a comprehensive review of SNF with a focus on process development but the authors did not discuss the role of MNPs in detail [8]. Recently, Gunes [2] outlined the current status and prospects of biofilm reactors for enhancing higher syngas fermentation yields. Although MNPs were discussed briefly, more information is still lacking in the literature. To fill the knowledge gaps, the present review outlines the advances and progress in MNPs applications for the improvement of gas-liquid mass transfer limitations during SNF. A brief overview of SNF is outlined as well as the effects of MNPs on the syngas fermentation process. It should be mentioned that information about the type of nanoparticles, shapes and detailed information about the process of producing various magnetic NPs as well as their respective composites are not within the scope of this review. Such information has been meticulously described elsewhere [9].

References

1. Nanda, S.; Rana, R.; Zheng, Y.; Kozinski, J.A.; Dalai, A.K. Insights on Pathways for Hydrogen Generation from Ethanol. Sustain. Energy Fuels 2017, 1, 1232–1245.
2. Gunes, B. A Critical Review on Biofilm-Based Reactor Systems for Enhanced Syngas Fermentation Processes. Renew. Sustain. Energy Rev. 2021, 143, 110950.
3. Okolie, J.A.; Tabat, M.E.; Gunes, B.; Epelle, E.I.; Mukherjee, A.; Nanda, S.; Dalai, A.K. A Techno-Economic Assessment of Biomethane and Bioethanol Production from Crude Glycerol through Integrated Hydrothermal Gasification, Syngas Fermentation and Biomethanation. Energy Convers. Manag. X 2021, 12, 100131.
4. Stoll, I.K.; Sauer, J.; Stoll, I.K.; Boukis, N. Syngas Fermentation At Elevated Pressure-Experimental Results Dehydrogenation of Methanol in Gas-Phase with Help of Organic and Inorganic Initiators View Project syngas fermentation at elevated pressure-experimental results. In Proceedings of the 27th European Biomass Conference and Exhibition, Lisbon, Portugal, 27–31 May 2019.
5. Shen, Y. Attached-Growth Bioreactors for Syngas Fermentation to Biofuel. Ph.D. Thesis, Iowa State University, Ames, IA, USA, 1 January 2013.
6. Kim, Y.K.; Park, S.E.; Lee, H.; Yun, J.Y. Enhancement of Bioethanol Production in Syngas Fermentation with Clostridium ljungdahlii Using Nanoparticles. Bioresour. Technol. 2014, 159, 446–450.
7. Kim, Y.K.; Lee, H. Use of Magnetic Nanoparticles to Enhance Bioethanol Production in Syngas Fermentation. Bioresour. Technol. 2016, 204, 139–144.
8. Sun, X.; Atiyeh, H.K.; Huhnke, R.L.; Tanner, R.S. Syngas Fermentation Process Development for Production of Biofuels and Chemicals: A Review. Bioresour. Technol. Rep. 2019, 7, 100279.
9. Chidhambaram, N.; Kay, S.J.J.; Priyadharshini, S.; Meenakshi, R.; Sakthivel, P.; Dhanbalan, S.; Shanavas, S.; Kamaraj, S.K.; Thirumurugan, A. Magnetic Nanomaterials as Catalysts for Syngas Production and Conversion. Catalysts 2023, 13, 440.

Retrieved from https://encyclopedia.pub/entry/history/show/96052