# Syngas production via optimized oxidative reforming of model biogas

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Biogas, produced through the anaerobic digestion of organic matter, is gaining attention as a clean and renewable energy source. It primarily comprises methane ($CH_4$) and carbon dioxide ($CO_2$), with composition varying based on the feedstock [1]. Oxidative reforming (OR) of biogas has been widely studied as a method for hydrogen and syngas production. These processes are valuable not only for energy generation but also for reducing greenhouse gases, as both methane and carbon dioxide are consumed. A key advantage of oxidative reforming of biogas lies in the exothermic catalytic partial oxidation (CPO) of methane, which lowers energy requirements. When CPO is combined with the endothermic dry reforming (DR) process, a thermoneutral condition can be achieved by adjusting the $CH_4/CO_2/O_2$ ratios. Moreover, the presence of oxygen at high temperatures mitigates carbon deposition on catalyst surfaces, thereby enhancing long-term efficiency [2,3].

Catalysts are crucial in reforming reactions. While noble metals exhibit high activity, their high cost limits large-scale application. Nickel-based catalysts, when supported on metal oxides, provide a cost-effective alternative but suffer from deactivation [4]. To improve their stability, redox-active supports such as cerium oxide and hydrotalcite-derived mixed oxides are employed, offering enhanced performance across various reforming systems [5,6].

In this study, Mg-Al mixed oxide supports were synthesized from hydrotalcite via co-precipitation, followed by sequential impregnation with Ni and Ce. The resulting catalyst (10 wt% Ni and 5 wt% Ce on a Mg-Al (3:1) support) was evaluated for syngas production through oxidative reforming of model biogas. The effect of feed ratios ($O_2/CH_4$ and $CO_2/CH_4$) and reaction conditions (temperature and space velocity) on reactivity and product distribution were analyzed in relation to catalyst structure and texture.

Process parameters for the oxidative reforming of biogas were optimized using response surface methodology (RSM) with Design-Expert software. A total of 30 experimental runs were designed using a three-level approach and conducted in random order to evaluate the effects of independent variables on response outputs.

The effects of the independent variables (Table 1) was investigated within their respective operating ranges to identify optimal feed ratios and reaction conditions in the OR of biogas.

Table 1. Independent variables and responses studied in oxidative reforming of biogas.

| Factors | Range | Responses |
|---|---|---|
| $CO_2/CH_4$ | 0.3-1 | $CH_4$ conversion |
| $O_2/CH_4$ | 0-0.5 | $CO_2$ conversion |
| Temperature (°C) | 600-800 | $H_2$/CO ratio |
| Space velocity ($mL/g_{cat}.h$) | 45,000-90,000 | $H_2$ yield |

The results indicate that increasing $CO_2/CH_4$ and $O_2/CH_4$ ratios enhances $CH_4$ conversion and $H_2$ yield. However, higher $O_2$ levels reduce $CO_2$ conversion due to $CH_4$ combustion and CO oxidation. Temperature positively influences $CH_4$ and $CO_2$ conversions by promoting endothermic reactions such as dry reforming, but it lowers the $H_2$/CO ratio owing to the reverse water-gas shift reaction. Variations in space velocity exhibited minimal impact on reaction performance, suggesting that temperature and feed composition are the primary factors influencing reactivity.

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