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Syngas fermentation to ethanol: the effects of gas recycling on economics

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Abstract

Syngas fermentation is a biochemical pathway to produce ethanol and has been commercialized successfully. The economic viability of this process could be further improved to become more competitive in the existing ethanol market. Improving gas utilization is the key, and can be done by recycling the unreacted syngas. This work is an early-stage techno-economic assessment of recycling in producing ethanol from Basic Oxygen Furnace (BOF) gas. Economic viability is measured in terms of Relative Competitive Percentage (RCP) and is a measure of closeness to the current market. Two scenarios, firstly a once-through process, and secondly a process with recycling (0.9 split ratio: recycle/purge) of gas is considered. None of them showed a positive RCP as compared to the current ethanol market. Comparing these scenarios, beyond the single pass conversion of 60%, the additional production costs due to recycling become dominating and lead to a lower RCP compared to once-through systems.

Keywords: Syngas fermentation, Ethanol, Basic oxygen furnace Gas, Recycling, Profitability

1. Introduction

Syngas fermentation is a ground-breaking industrial biotechnology platform to produce Ethanol from various feedstocks. Lanzatech, a carbon recycling company has Commercialized this technology at various locations around the world. At the same time, the produced ethanol is not competitive enough to the existing ethanol market based on thermo-catalytic processes (Benalcázar 2017). One of the promising ways to improve the profitability of ethanol is by increasing gas utilization. This is possible via improving the mass transfer, genetic engineering to enhance the microbial rate or recycling the unreacted reactants. The latter is a possible scenario at the commercial scale, but the same has not been studied in detail in the large-scale syngas fermentation processes. Therefore, this work is an attempt to give an early-stage techno-economic evaluation of the recycling of unreacted reactants in the gas fermentation process.

2. Methodology

The process concept for ethanol from BOF is shown in figure1. A bubble column fermenter and a distillation-based downstream process were considered as they are the most used types for ethanol production in large-scale syngas fermentation industries. Aspen Plus V8.8 was used to model this process concept in a steady state. The BOF gas with a composition (mole %) of 0.65% CO, 0.03% H_2, 0.16% CO_2, and 0.16% N_2 was the feedstock and a process reaction to ethanol was developed by the black box thermodynamic approach (Heijnen 1992). Gas-liquid mass transfer rates of the reactants were also integrated into the model using the empirical relations of the bubble column reactor for the mass transfer coefficient, and Henry's law for the compositions. The sizing of the units for economic evaluations was carried out either manually or by using Aspen Process Economic Analyzer. The economic viability of ethanol via syngas fermentation was checked in terms of relative competitive percentage (RCP), which is the measure of its marketability compared to the current ethanol market. The effect of recycling unreacted gas was studied via sensitivity analysis, and RCPs were measured in each case.

2.1. Process Description

As shown in figure 1, a mixture of fresh BOF gas and recycle gas is adjusted to the inlet pressure and temperature of the fermenter. In the bubble column fermenter, the gas (syngas + NH_3) and the medium (water+NH_4OH) are fed counter currently. The ethanol is fully stripped off by the gas leaving the fermenter, and it mainly contains product, water, and other unreacted components of syngas. Therefore, the gas is condensed first and sent to a phase separator. The liquefied stream mainly contains ethanol and water with other dissolved gases. Ethanol is further purified in a distillation-based downstream separation section. A part of the unreacted gas is purged (10%) to avoid the accumulation of H_2 in the reactor. The rest of the gas (90%) is sent back to the fermenter after separating N_2, and CO_2. The fermenter broth mainly contains water, biomass, & ammonium acetate, and the solids are separated before reusing the water in the fermenter. The fermenter operating conditions (Temperature at 37°C, pH at 6) are selected based on the optimal growth conditions for acetogens. The top pressure in the fermenter is 1 atm and the bottom pressure was calculated based on the hydrostatic pressure as follows;

$$p_b = p_t + \rho_{broth} * g * h_g \tag{1}$$

Where,

p_b	Bottom Pressure (atm)
p_t	Top Pressure (atm)
ρ_{broth}	The density of broth (kg/m^3)
g	acceleration due to gravity (m/s^2)
h_g	Height of the broth (m)

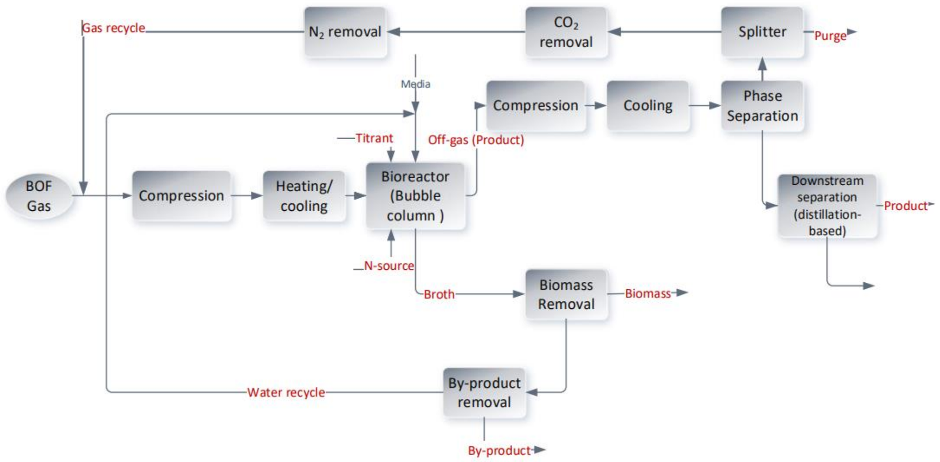

Figure 1 schematic block diagram of ethanol from BOFG via syngas fermentation

2.2. Economic evaluation

To calculate the economic viability of the process, the capital expenditure (CAPEX), and the annual operating cost (OPEX) are estimated using the factorial method proposed by Peters and Timmerhaus (1959). As given in Table 1, The CAPEX is estimated based on the bare equipment cost (BEC) of the units. These values are adjusted to the scale, and the base year of 2019 using six tenth rule and cost indices respectively. OPEX is evaluated based on the direct calculations from the process models and is called process-related cost (PRC). PRC consists of the cost of raw materials, utilities, and waste management. Raw material includes syngas, NH_3, NH_4OH, and deionized water. The cost of utilities is evaluated from the energy balances and average utility price in the Netherlands (2019). The cost of waste management is estimated using the avg. carbon releasing tax in Europe (5 Euro/ ton CO_2 release, 2019). For the depreciation cost, a straight-line depreciation method is used with 10% of the purchase cost as salvage value after a plant life of 15 years. The annual tax paid is calculated from the annual sales and the tax rate which is taken as 25%.

To measure the economic viability, the relative competitive percentage (RCP) is measured as follows;

$$RCP = 100 * \frac{(MP - MSP)}{MP} \qquad (2)$$

Where MP is the market price of ethanol in 2019 and is 780 €/kg. And Minimum Selling Price (MSP) is evaluated for a payback time of 3 years.

Table 1 Calculation of CAPEX (Peters, 1959)

Items		Factors on FCI (%)
Direct cost (DC)	Bare Equipment cost	21.8
	Installation	7.6
	Process piping	11.1
	instrumentation	4
	insulation	1.4
	electrical	4.7
	buildings	8.4
	yard improvements	3.1
	service facilities	7.2
	land	1.7
Indirect cost (IDC)	Engineering	7.5
	construction	9.7
	contractor's fee	4
	contingency	7.8
Fixed Capital Investment (FCI)	Sum up above	100
Start-up related cost	working capital	OPEX/12
	start-up cost	9
CAPEX	FCI + working capital + start-up cost	

Table 2 Calculation of OPEX (Peters,1959)

Items		Calculation
Facility-dependent costs	Depreciation	(DC-PC*0.1)/10
	maintenance	0.15 purchase cost
	insurance	0.01 TFC
	local taxes	0.01 TFC
	plant overhead	0.05 Revenue

Process related cost	Utility	
	Raw material cost	
	Waste management	
	(CO_2 tax)	
Labour-related cost	labour	0.07 (PRC+FDC)
	Laboratory charges	
		0.1 labour
OPEX	Sum up above	

2.3. Parametric studies

A sensitivity study was carried out for various conversions and the corresponding recycling ratios. The purge was fixed at 10%, and the rest 90% are recycled in all cases. In each case, the RCPs have been calculated.

3. Results

Figure 2 shows the relation between the single pass conversion of CO, and the recycle ratio (recycle flowrate/(fresh syngas+ recycle flowrate)). In all cases, the split ratio of recycle flow rate is fixed at 0.9. As we see, a lower conversion would lead to high recycle flow rates.

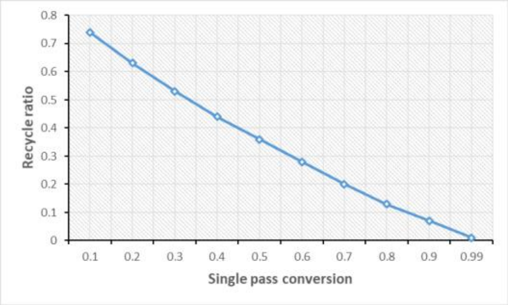

Figure 2 Single pass conversion vs Recycle ratio

The effect of recycling on the economic feasibility of the process is shown in figure 3. The economic feasibility is represented in RCP as indicated in the previous section. It shows the positive or negative economic viability of ethanol as compared to the present market. Two scenarios are compared in this figure. Firstly, the RCP of the once-through process (no recycling) and secondly RCP of the process with recycling of unreacted CO. None of the cases showed positive viability compared to the existing market, and therefore further optimization of the process, and support (subsidies) may be required to bring ethanol from syngas fermentation to the market.

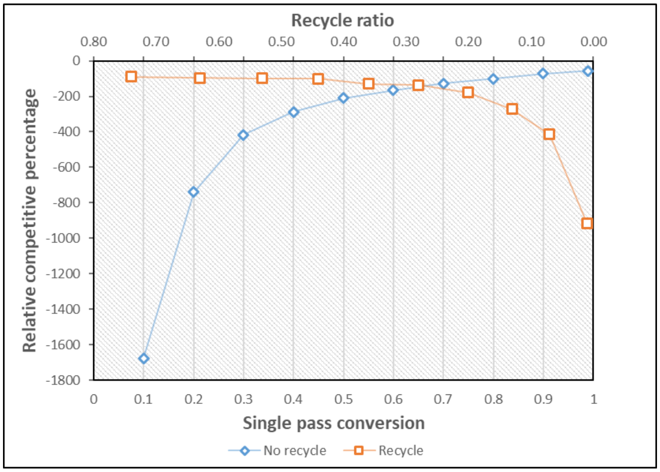

Figure 3 RCP (relative competitive percentage) for once through process and process with recycling in the production of ethanol from BOF gas via syngas fermentation.

Comparing the scenarios, recycling has improved the economic viability in multiple folds at lower conversions. It is due to the improved gas utilization, and production rates of ethanol. This is the trend up to around 60% of single pass conversion, and then the additional production cost of recycling is dominating. Therefore, at higher conversion rates, scenarios without recycling have better economic viability.

These results show a clear tradeoff between additional recycling costs and productivity improvement due to recycling. Therefore, to recycle the unreacted CO in improving the economic viability, the economic hot spots due to recycling must be identified, These units or variables must be optimized to minimize the recycling cost. Similarly, the limiting mechanism of improved production performance must be identified and must be tuned further to fully benefit from recycling CO back to the fermenter.

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