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Technical and Economic Analysis for Production of Bio-ammonia from African Palm Rachis

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The 95% of ammonia destined for fertilizer production via Haber-Bosch process comes from natural gas. This process is preceded by a series of stages, in which methane available in natural gas is reformed to syngas (a gas mixture consisting of H_2, CO_2, CO, CH_4 and H_2S). The stage of syngas production represents a bottleneck from the economic point of view. The natural gas availability and its commercial cost imply a high commercial price on fertilizer which in turn increases the cost per hectare of crop. Currently, gasification technology has caught attention as a waste treatment technology due to its capacity to transform large volumes of biomass into syngas with low retention time. Therefore, this study aimed to evaluate techno-economically the bio-ammonia production from syngas obtained by gasification of African palm Rachis. The study was conducted by process simulation using Aspen Tech software. The process was simulated from the collection of the raw material to conversion of synthesis gas into ammonia. The simulation comprises a pretreatment stage to obtain an optimum particle size for biomass, a stage of gasification to convert Palm rachis into Syngas, a stage of heat recovery for steam production, a gas shift (WGS) reactor to increase the concentration of hydrogen into syngas, an acid gas remover unit (AGR) to avoid poisoning of catalysts; and the final stage of Bio ammonia synthesis; this simulation was validated based on data reported in the literature. The technical analysis measured the complexity of the new process in terms of equipment and the efficiency of the proposed operations. On the other hand, economic analysis evaluated the profitability to adapt the process to the biomass. According to results, 1,630,000 metric tonnes (Mt) of palm Rachis per year produced a syngas with a concentration hydrogen of 99% which yielded 35,755 Mt yearly of Bio ammonia. It could be inferred that highest reactor conversion was 20% at a temperature of 360°C and 250 bar pressure. It was observed that the return of investment (ROI) of 13.2% was higher than the discount rate of 12% which it demonstrates the economic viability of the project. However, The ROI value was high sensitive to the cost and availability of raw materials.

1. Introduction

The increase of the world population in recent years is demanding a continuous challenge in agriculture: providing more food maintaining the same crop area (Andersson & Lundgren., 2014). The improvement of crop yield has been achieved using nitrogenous fertilizers that provide nourishment essential for growth of crops and the maintenance of the soil (Alkusayer & Ollerhead., 2016). Fertilizers are often based on Ammonia (NH_3), one of the most demanded inorganic chemical in the world. The world NH_3 production was estimated to be 150 megatonnes, meanwhile for 2020 is expected an increment until 239 megatonnes (Roper, 2016). The 95% of ammonia produced in the world is obtained from natural gas via Haber-Bosch process. This process is preceded by a series of stages in which methane available in natural gas is reformed to syngas (a gas mixture consisting of H_2, CO_2, CO, CH_4 and H_2S). The syngas is enriched and purified to obtain hydrogen with a purity of 99%. However, the production stage of the syngas represents a bottleneck from the economic point of view due to its dependence on the costs and availability of natural gas in the market. This fact implies a high cost in the commercial price of the fertilizer that increases the costs per hectare of crop (Andersson & Lundgren., 2014). Consequently, several authors proposed others methods to produce syngas in order to reduce

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dependences on natural gas. The gasification has been proposed by different researches as an efficient technique to produce syngas and hydrogen as fuels or raw materials for obtaining other chemicals (e.g. methanol, Hydrazine, Hydrogen additives, etc.) (Bula et al., 2012). The gasification is a thermodynamic conversion technique where the solid biomass is converted into gaseous fuels trough partial oxidation in the presence of a gasifying agent (e.g. air, oxygen and/or steam) (Shahbaz, 2017)

Andersson & Lundgren. (2014) carried out a techno-economic evaluation of NH_3 production via an integrated pressurized entrained flow biomass gasifier (PEBG) in an existing pulp and paper mill in order to determinate if the process proposed is feasible taking into account the variable market conditions. They concluded that a high Ammonia price, estimated in the range of 509-774 USD/t, and a plant with a larger production capacity is needed to reach economic feasibility. Gilbert et al. (2014) assessed through techno-economic and life cycle analysis the economic viability of the ammonia production using forestry by-products as a carbon source to produce syngas in a Fast Internal Circulating Fluidized Bed Gasifier. A greenhouse gas saving of 65% was achieved using this method to produce syngas; in a process which is, from the economic point of view, very affected by the volatility of ammonia and feedstock prices.

On the other hand, Colombia is the world's fourth largest palm oil producer, the palm cultivations in Colombia are destined to obtain red oil extracted from the palm fruit. The extraction process involve a stage of peeling in which African palm rachis (APR) is obtained as the main residue of the operation. According to literature, the processing of African palm fruits generates 0.23 megatonnes yearly of APR, equivalent to 20% of the crop (Harrison, 2015). The current treatment of APR involves burning to obtain thermal energy for boilers (Bouza, 2016) In order to reduce this practice, the APR has been proposed as feedstock to obtain syngas through gasification for power generation and chemicals. As the process of ammonia synthesis is completely independent of the route followed for syngas production; it is possible to replace reforming natural gas by APR gasification in other to obtain syngas and to reduce the dependencies on the fossil feedstock for ammonia production. Then, this study aimed to evaluate techno-economically the bio-ammonia production from syngas obtained by gasification of African palm Rachis. The study was conducted using process simulation as a tool to determine the profitability of an industrial scale-up.

2. Materials and methods

The process was designed according with that described by Perez et al. (2016). The biomass used to produce the syngas was the APR obtained from oil palm plantations located in the North and East Zone of Colombia. In figure 1, the ammonia production through biomass gasification is presented. Before the gasification, a pretreatment to the APR was carried out in order to increase the conversion of fixed carbon into syngas during the gasification. In this stage, the APR particle size was reduced in 1-0.3 mm and then dried in a rotatory dryer until a wet percentage of 5%. An entrained flow gasifier was selected due to its high thermal efficiency and the low complexity of its design. The gasifier was modeled as a black box, in which the operation parameters applied were the proposed by of Ogi et al. (2013). In their work, downstream stages were simulated using the parameters proposed by the EFMA for the Ammonia synthesis through the partial oxidation of heavy fuel oil. For the technical analysis, mass and energy balances were carried out in process simulation software Aspen Plus® and Aspen HYSYS®. A sensitivity analysis was necessary in order to increase the yield and reduce the demand of utilities in the purification and synthesis stages.

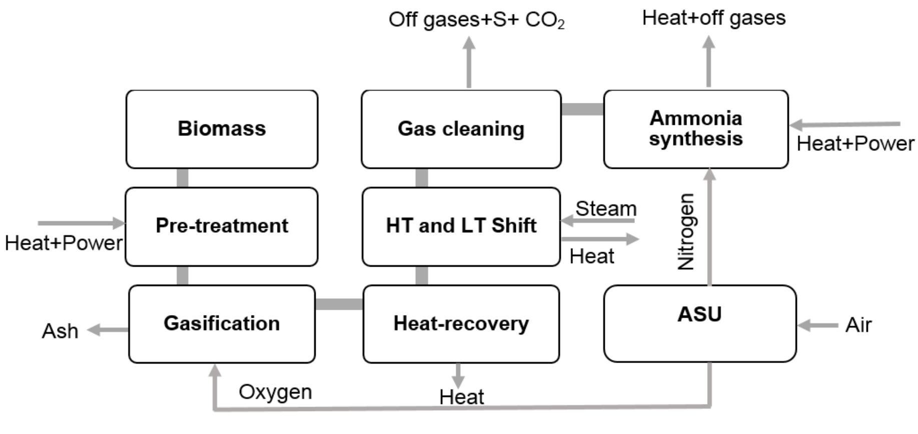

Figure 1: Block diagram of the ammonia production through biomass gasification. EFMA

For the economic analysis, the African Palm Rachis (APR) cost was estimated assuming that the production facility is located in an oil palm bunch collection center, being the cost of handling the APR from mills to the pretreatment stage in the ammonia plant to cover. In table 1, economic parameters used to carry out the analysis are presented.

$$COM_d = 0.180FCI + 2.73C_{OL} + 1.23(C_{UT} + C_{RM}) \quad (1)$$

$$VPN = \sum_n \frac{ACF_n}{(1+i)^n} - I_0 \quad (2)$$

$$BEP = \frac{AFC+AOC}{AnnualProduction} \quad (3)$$

The equations applied were taken from the economic analysis model proposed by Turton (Turton et al., 2009) and El-Halwagi (El-Halwagi, 2012).To carry out the economic analysis, capital cost (FCI) was determined taking into account the cost associated with equipment that are part of the bio-ammonia production facility. Cost of Operating Labor (C_{OL}) was estimate considering the number of operators per shift to work in the plant. Otherwise, for the Cost of Utilities (C_{UT}), the cost of the stream service used were considered, which in the simulation of the process were tower water and electricity. The cost of manufacturing (COM) was evaluated taking into account costs mentioned above. Indicators calculated were the Net Present Value (NPV), Internal Rate of Return (IRR) and the Break-Even Point (BEP) Equations (1) - (3) describe these economic indicators; where FCI is the capital cost, C_{OL} is the cost of operating labor, C_{UT} is the utility cost, C_{RM} is the cost of raw materials, ACF_n is the net profit for the period n, $i$is the interest rate, $I_0$is the initial investment, AFC is the annual fixed charges and AOC is the annual operating cost.

Table 1: Parameters for the technical and economic analysis of the bio-ammonia plant

Processing capacity (t/y)	1,630,000
Main product flow (t/y)	35,755
Raw material cost ($/t)	5
Final product cost ($/t)	570
Capital cost (FCI) ($/y)	15,632,418
Fixed capital investment ($/y)	36,574,062
Working capital ($/y)	6,583,331
Sales revenue ($/y)	22,780,350
Manufacturing costs ($/y)	14,358,312
Plant life (years)	30
Construction time of the plant (years)	2
Location	Colombia
Tax rate	39%
Discount rate	12%
Number of workers per shift	20
Salary per operator ($/h)	1.38
Utilities	gas, steam, water, electricity
Process fluids	solid-liquid-gas
Depreciation method	MACRS-5 Years

3. Results

The techno-economic analysis of the Bio-ammonia production, using the APR gasification as syngas source, was carried out. The plant was designed to produce a rate of 100 t/day of Bio-Ammonia at 250 bar and 360°C, with a hydrogen flow rate from the gasification stage**.** Although the yield of fixed carbon conversion was high (~99.5%), the low fixed carbon content in the APR increases the biomass needed in the gasification stage, increasing the cost of raw materials as well. This condition makes the process less competitive in comparison with others where biomass with a higher fixed carbon content (forestry by-products, wood, etc.) is used like feedstock. On the other hand, in terms of power consumption, the APR pre-treatment was one of the largest energy consumers; given the high percentage of wet present in the APR as result of the bunch threshing. The Air distillation and the loop were the other stages with the highest power consumption due to the compressor trains. In the HTS and LTS stages, the operational parameters that generate the highest conversion rate were selected through a sensitivity analysis. For HTS, $[H_2O]/[CO]$ molar ratios of 2, 4, 6 and 8 were assessed, obtaining the highest yields in the $[H_2O]/[CO]$ = 8; however, an $[H_2O]/[CO]$ molar ratio of 6 was selected considering the cost implied in the use of more steam to rise the yield. In the LTS stage, even though an higher yield at low temperatures were observed; a value of 240°C was selected. It was mainly due to the limitation of the dew point of the steam that goes into the reactor with the syngas (233.88°C @ 30 bar). Table 2 shows the mass balance of the biomass gasification system; It can be seen that about 23.11 kg of the biomass is needed annually to produce 1 kg of NH3.

Table 2. Mass balance of the biomass gasification system, expressed as kg/kg NH_3.

Gasification	
Inputs	
Biomass (5% wet)	23.11
Steam (H_2O/C)	7.77
Oxygen (O_2/C)	1.93
Outputs	
Syngas	6.81
Solids	0.67

On the other hand, Table 3, shows the manufacturing costs associated with the plant, where is evident that the raw material represents the highest percentage of the total direct manufacturing cost; The raw material is an important element to take into account for the management of the final cost of a product, these depend greatly on the quality of the same but also within the cost of the product is incorporated to a large extent the value of the raw materials used within the process.
Research and development are important for innovation, which allows competing globally with products and services with high added value; by heuristics, it was assumed that the value of research and development corresponds to 5% of the cost of manufacturing. For the proposed plant, the value was high considering that in Colombia approximately 7,000 million dollars are invested annually, therefore, this value must be verified at the moment of determining the viability in the economic analysis of a chemical plant.

Table 3: Manufacturing costs of the bio-ammonia plant

Direct Manufacturing Costs	**Total US($)**
Raw materials(C_{RM})	8,150,000
Utilities(C_{UT})	703,071
Operating labor(C_{OL})	240,000
Direct supervisory and clerical labor	43,200
Maintenance and repairs	937,945
Operating supplies	140,692
Laboratory changes	36,000
Patents and royalties	430,749
Total direct Manufacturing Costs	10,681,657
Fixed Manufacturing Costs	
Depreciation	1,563,242
Local taxes and insurance	500,237
Plant overhead costs	732,687
Total Fixed Manufacturing Costs	2,796,166
General Manufacturing Expenses	
Administration costs	183,172
Distribution and selling costs	1,579,414
Research and development	717,916
Total General Manufacturing Costs	2,480,502

In order to determine the NPV, the initial investment, the investments during the operation, the cash flow, the discount rate, the tax rate and the number of periods estimated to last the project were taken into account. The NPV obtained was $180,651 for the year twenty, and as the project is developed the income gradually increases, also can be observed that in the year 19.7, the cash flow is zero, this means, there are not gains or debts and from this date the plant will start to obtain economic benefits. Taking into account the NPV, the investment made will produce profits above the required profitability, which indicates that the project is viable. In this case, profits will be reflected year 20.The costs to obtain bio-ammonia from the African palm rachis are higher than other products obtained from this raw material. The costs of obtaining bio-hydrogen from the rachis are lower considering that less equipment, raw materials, industrial services are required, among other expenses, and also, the plant starts to gain in a shorter period of time according to the NPV (Perez Zúñiga et al., 2016). However, as can be observed in the economic analysis, it is feasible to produce bio-ammonia using the African palm rachis. The internal rate of return (IRR) calculated was 13.2%. This means that the project is viable because the internal rate of return is greater than the discount rate, which was 12%; which estimates a performance higher than the minimum required.

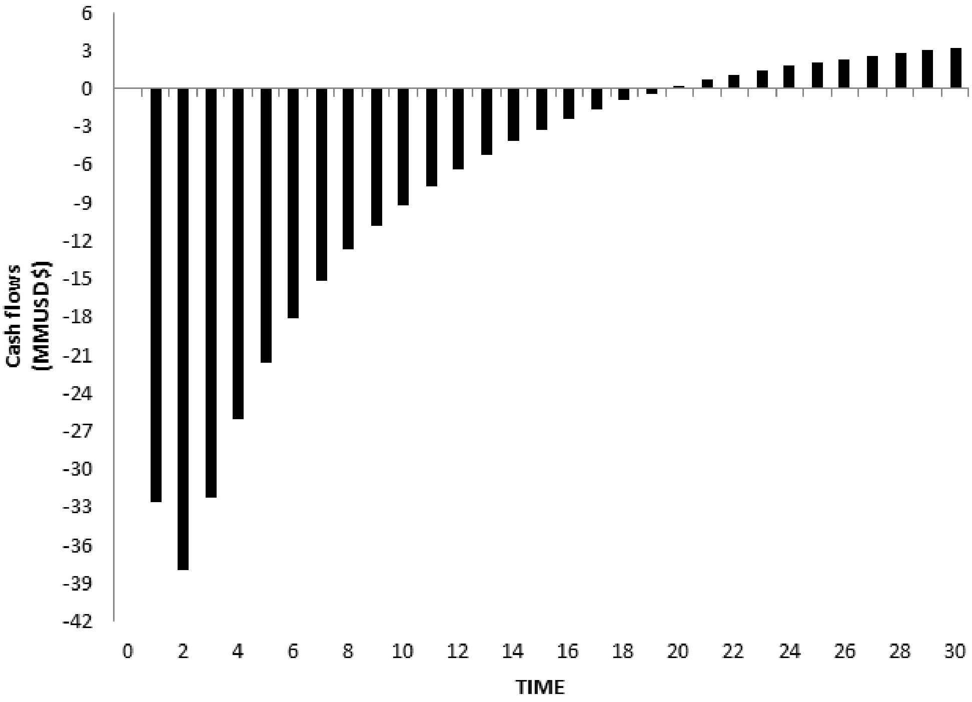

Figure 2: Net Present Value of the project.

In table 4, costs associated with the break-even analysis are presented. These costs were used to determine the break-even point where total revenues are equivalent to the total costs associated with the sale of bio-ammonia. The break-even point was $508/t, which means that the bio-ammonia can be sold at a price higher than the one estimated for the plant to receive benefits, on the other hand, if the bio-ammonia is sold to a lower price, the plant will only produce losses and the project will not be profitable.

Table 4: Costs associated with the break-even analysis

Fixed and variable charges	Total US($)
Annual fixed charges (AFC)	6,893,479
Annual operating cost (AOC)	11,263,940

4. Conclusion

The bio-ammonia production using APR instead of natural gas as feedstock to produce syngas was evaluated from the technic and economic point of view. A yield of 23.11 kg/kg NH_3 of biomass was obtained, which is a high value compared to other process where biomasses with higher lignin and less wet content were used. According to the economic analysis, a high dependence of the process with the international Ammonia price was observed; being a cost of $508/t of ammonia needed to obtain a cash flow with a positive balance. It is important to emphasize that at the moment when this research project started to be carried out, the Ammonia price was established in $600/t. Several ways to make the process more efficient shall be explored, in order to face the unstable ammonia price, one of these important aspects is the location of raw material close to the place of production, in order not to increase transportation costs. Generally, this process represents a sustainable solution to ammonia production being economically viable.

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