ISSN: 0974-5823 Vol. 6 No. 3 December, 2021

International Journal of Mechanical Engineering

ECONOMIC FEASIBILITY ANALYSIS OF BIOGAS PRODUCTION FROM WHEAT BRAN AND CAMEL DUNG

S. Sivamani[a*], Saikat Banerjee[a], B.S. Naveen Prasad[a]

[a]University of Technology and Applied Sciences, Salalah, Oman

ABSTRACT:

A biogas production plant was designed at capacity of processing 0.1 million tonnes per annum (tpa) of wheat bran. The production plant involves 2 anaerobic digesters (1 in use and another as standby). As an alternative to conventional gaseous fuel, production cost of biogas needs to be competitive with that of natural gas. Hence, economic feasibility analysis of biogas production is important in process engineering. In economic feasibility analysis of biogas production plant, annual product sales, fixed cost, variable cost and annual net profit were calculated to be 7.380, 2.588, 1.755, and 12.949 million $ per annum. The breakeven analysis of the biogas production plant reveals the process to be economically feasible as annual product sales is greater than total cost.

Keywords: Wheat bran, Biogas, Equipment cost, Process economics, Breakeven point.

INTRODUCTION:

Biogas is a mixture of methane and carbon dioxide in the molar ratio of 2:1. Organic materials with carbon to nitrogen ratio between 20 and 30 and volatile suspended solids (VSS) to total suspended solids (TSS) ratio greater than 0.6 are appropriate for biogas production [1]. Industrial residues have carbon to nitrogen ratio less than 20. Fresh animal manure has carbon to nitrogen ratio greater than 30. VSS to TSS ratio is < 0.6 for industrial residues and fresh animal manure. Hence, feedstock is prepared by mixing industrial residues and fresh animal in suitable proportion to obtain carbon to nitrogen ratio between 20 and 30 and VSS/TSS ratio > 0.6 [2]. Biogas is produced through anaerobic digestion [3].

In anaerobic digestion process, the steps involved are hydrolysis, acidogenesis, acetogenesis and methanogenesis. During hydrolysis, polymers present in organic materials are broken down to monomers in the presence of water. Acidogenesis converts monomers to short chain volatile organic acids in the presence of acidogenic microorganisms. During acetogenesis, organic acids are converted to acetates and acetic acid with the help of acetogenic organisms. Finally, methanogenesis converts acetates and acetic acid to methane, carbon dioxide and other gases. The final product of gaseous mixture is called biogas [4].

Biogas is an alternative gaseous biofuel to natural gas for use in power and transportation sectors [5]. The demand for high purity biogas or methane is high in oil and gas market as it is widely used in compressed natural gas engines [6]. The economics of biogas production is mainly influenced by raw materials cost, utilities cost, production cost and annual product sales [7]. The economic feasibility analysis of chemical processing plant starts with the calculation of equipment cost for the present year. The various indices are available to calculate present equipment cost [8]. But, chemical engineering plant cost index (CEPCI) is the widely used method [9]. According to the CEPCI, the cost of equipment can be calculated only for 1985. Using the CEPCI available for 2022, the present cost of index could be calculated. From the equipment cost, delivered equipment cost is calculated by assuming 10% of equipment cost for delivery. Total capital investment, sum of fixed (Total direct + indirect costs) and working capital investment, is calculated from delivered equipment cost. Raw materials, utilities, product sales, annual operating labour, variable, fixed, manufacturing, product costs are calculated as a part of economic feasibility analysis. Then, breakeven point analysis is executed to report the economic feasibility of biogas production plant [10]. Breakeven even point analysis is performed by comparing annual product sales and total cost, which includes fixed and variable costs. A business is said to be economically feasible if annual product sales is greater than total cost and vice versa.

A detailed economic analysis, starting from equipment cost to breakeven point, has not been performed by researchers on biogas production. But, limited economic analysis on biogas production is available in literature [11-17]. Hence, the present study aims to perform economic feasibility analysis of 0.1 million tonnes per annum (tpa) of wheat bran with 10-year life span with 300 working days per annum at 24 h per day through 3 shifts. The objectives of the work are: (i) Calculation of total equipment cost in 2022; (ii) Estimation of total capital investment; and (iii) Perform economic feasibility analysis of biogas production process from 0.1 million tpa of wheat bran.

METHODS:

Table 1. Estimation of capital investment by delivered equipment method for solid processing, solid-fluid processing, and fluid processing plants

Particulars	Fraction of purchased equipment		
	Solid-processing plant	Solid-fluid processing plant	Fluid processing plant
Total equipment cost	E'	E'	E'
Delivery equipment cost	0.10E’	0.10E’	0.10E’
Total direct cost			
Total delivered equipment cost, E	Total equipment cost + Delivery equipment cost (1.10E’)		
Purchased equipment installation	0.45E	0.39E	0.47E
Instrumentation & Controls (installed)	0.18E	0.26E	0.36E
Piping (installed)	0.16E	0.31E	0.68E
Electrical systems (installed)	0.10E	0.10E	0.11E
Buildings (including services)	0.25E	0.29E	0.18E
Yard improvements	0.15E	0.12E	0.10E
Service facilities (installed)	0.40E	0.55E	0.70E
Total direct cost (DC)	1.69E	2.02E	2.60E
Total indirect cost			
Engineering and supervision	0.33E	0.32E	0.33E
Construction expenses	0.39E	0.34E	0.41E
Legal expenses	0.04E	0.04E	0.04E
Contractor's fee	0.17E	0.19E	0.22E
Contingency	0.35E	0.37E	0.44E
Total indirect cost (IDC)	1.28E	1.26E	1.44E
Fixed capital investment (FCI)	Total direct cost + Total indirect cost		
Working capital investment (WCI)	0.70E	0.75E	0.89E
Total capital investment (TCI)	Fixed capital investment + Working capital investment		

In the present study, the economic feasibility analysis was performed to process 0.1 million tpa of wheat bran to produce biogas. The equipment cost was calculated for 2022 by using chemical engineering plant cost index (CEPCI) method. The total direct and indirect costs, fixed, working and total capital investments were calculated by percentage of delivered equipment method [18]. Table 1 shows the estimation of capital investment by delivered equipment method for solid processing, solid-fluid processing, and fluid processing plants.

The cost of products, raw materials and utilities are calculated as the product of quantity required per annum and cost per quantity. Annual operating labour cost is calculated as the product of number of operators per shift, number of shifts per day, number of working days per annum and cost of labour per operator [19].

Annual total product cost without depreciation is calculated as follows [20]:

Annual total product cost without depreciation = (Variables cost – royalties + fixed cost – depreciation + plant overhead cost + general expenses – sales and distribution expenses – research and development expenses)/0.9

Variable cost is calculated as follows [21]:

Variable cost = Raw materials cost + Annual operating labour cost + Operating supervision cost + Utilities cost + Maintenance and repair cost + Operating supplies cost + Laboratory charges + Royalties

Operating supervision cost = 15% of annual operating labour cost

Maintenance and repair cost = 6% of fixed capital investment

Operating supplies cost = 15% of maintenance and repair cost

Laboratory charges = 15% of annual operating labour cost

Royalties = 1% of total product cost

Fixed cost is calculated as follows [22]:

Fixed cost = Property tax + Insurance + Depreciation

Property tax = 2% of fixed capital investment

Insurance = 1% of fixed capital investment

Depreciation = Fixed capital investment/shelf-life period of equipment

Plant overhead cost is calculated as follows [23]:

Plant overhead cost = 60% of (operating labour cost + operating supervision cost + maintenance and repair cost)

Total manufacturing cost is calculated as the sum of variable, fixed and plant overheat costs [24].

Total manufacturing cost = Variable cost + Fixed cost + Plant overhead cost

General expense is calculated as the sum of administrative, sales, distribution, research and development expenses [25].

General expenses = Administrative expenses + Sales and distribution expenses + Research and development expenses

Administrative expenses = 20% of (operating labour cost + operating supervision cost + maintenance and repair cost

Sales and distribution expenses = 5% of total product cost

Research and development expenses = 4% of total product cost

Annual gross and net profit, and percentage breakeven point were calculated as follows [26]:

Annual gross profit = Annual product sales – Annual total product cost

Annual net profit = Annual gross profit(1 – Tax%)

Breakeven point = Fixed cost x 100/(Unit selling price of product – Variable cost per unit)

RESULTS AND DISCUSSION:

In the biogas production process, equipment cost was calculated by CEPCI method in 1985 [20]. The equipment cost in 1985 was found to be $ 2274942. The cost indices in 1985 and 2022 are 396 and 736 respectively. Total equipment cost in 2022 was estimated to be $ 4.228 million. Anaerobic digester is considered for equipment cost. All the other facilities such as wheat bran, camel dung, water and digestate will be stored in a single construction facility.

Table 3 shows the total capital investment estimation for biogas production from 0.1 million tpa of wheat bran. Delivered equipment method calculated direct and indirect costs to be $ 14.046 million and $ 5.860 million, respectively. Fixed, working and total capital investments were estimated to be $ 19.905 million, $ 3.488 million and $ 23.394 million, respectively. Direct cost is 70.56% of fixed capital investment, which in turn is 85.09% of total capital investment.

Table 2. Estimation of capital investment by delivered equipment method for biogas production from 0.1 million tpa wheat bran under the category of solid-fluid processing plant

Particulars	Solid-fluid processing plant	Cost (million $)
Total equipment cost	**E'**	**4.228**
Delivery equipment cost	0.10E’	0.423
Total delivered equipment cost, E	**1.10E’**	**4.651**
Purchased equipment installation	0.39E	1.814
Instrumentation & Controls (installed)	0.26E	1.209
Piping (installed)	0.31E	1.442
Electrical systems (installed)	0.10E	0.465
Buildings (including services)	0.29E	1.349
Yard improvements	0.12E	0.558
Service facilities (installed)	0.55E	2.558
Total direct cost (DC)	**2.02E**	**14.046**
Engineering and supervision	0.32E	1.488
Construction expenses	0.34E	1.581
Legal expenses	0.04E	0.186
Contractor's fee	0.19E	0.884
Contingency	0.37E	1.721
Total indirect cost (IDC)	**1.26E**	**5.860**
Fixed capital investment (FC)	**3.28E**	**19.906**
Working capital investment (WC)	**0.75E**	**3.488**
Total capital investment (TC)	**4.03E**	**23.394**

Table 3 shows the annual total product sales and raw materials cost for biogas production from 0.1 million tpa of wheat bran. In the present study, annual product sales cost was calculated by considering the cost of biogas, CO_2 and digestate to be 0.039 $/1000 kWh, 4.68 $/m^3, and 2.6 $/kg, respectively. Also, the raw materials cost was estimated by deliberating the minimum cost. Annual product sales were estimated to be $ 7.38 million. The fluctuations in biogas and vegetable oil prices were not considered in the present study and they were taken on an average.

Table 3. Estimation of annual product sales for biogas production from 0.1 million tpa of wheat bran

Type	Name of material	Cost	Production quantity	Product cost (million $/y)
Annual product sales				
Main product	Biogas	0.039 $/1000 kWh	0.406 million kWh/y	0.00002
Byproduct-1	CO_2	4.68 $/m^3	0.097 million m^3/y	0.45
Byproduct-2	Digestate	2.6 $/kg	2.664	6.93
			Total product sales	7.38

Table 4 shows annual operating labour cost for biogas production from 0.1 million tpa of wheat bran. As per the Oman labour law, the minimum wage for Omani operator is $ 855 per month with working on alternate days. Each operator controls anaerobic digester and storage places at 3 shifts per day. The annual operating labour cost was estimated to be $ 0.094 million.

Table 4. Estimation of annual operating labour cost for biogas production from 0.1 million tpa of wheat bran

Number of operators per shift	Number of shifts per day	Number of days per annum	Salary per operator ($)	Annual operating labour cost (million $/y)
3	3	365	125	0.094

Table 5 shows utilities cost for biogas production from 0.1 million tpa of wheat bran. Utilities cost was calculated by considering the utilization of water as raw material. The biogas production plant processes 100 ktpa of water. The utilities cost was estimated by considering the water quantity for production plant at $ 1.14 per ton. Also, utilities such as electricity was considered in the calculation of capital investment. The utility cost was calculated to be $ 0.114 million per annum.

Table 5. Estimation of utilities cost for biogas production from 0.1 million tpa of wheat bran

Utility	Required quantity (ktpa)	Cost per ton ($/ton)	Utility cost (million $/y)
Water	100	1.14	0.114

Table 6 shows the economic feasibility analysis of biogas production from 0.1 million tpa of wheat bran. Maintenance & repair and operating supplies costs significantly contributed to variable cost. Maintenance & repair and operating supplies share 68 and 10% of variable cost, respectively. The rest was shared by annual operating labour, operating supervision, annual raw material, utilities, laboratory and royalties cost.

Depreciation was calculated as a ratio between fixed capital investment and life span of plant. Depreciated contributed mostly to fixed cost. Depreciation shared 77% of fixed cost. The rest was shared by property tax and insurance. Plant overhead cost was estimated to be $ 0.781 million per annum.

Total manufacturing cost was shared by 34% of variable cost, 51% fixed cost and 15% of plant overhead cost. Total manufacturing cost, general expenses and total product cost without depreciation were estimated to be $ 5.124 million, $ 1.569 million and $ 14.535 million, respectively. Then, annual gross profit was estimated to be $ 19.922 million per annum. After the tax deduction of 35%, annual net profit was calculated to be $ 12.949 million.

Table 6. Economic feasibility analysis of biogas production from 0.1 million tpa of wheat bran

Particulars	Cost (million $/y)
Variable cost	
Raw materials cost	0.000
Annual operating labour cost	0.094
Utilities cost	0.114
Operating supervision cost	0.014
Maintenance and repair cost	1.194
Operating supplies cost	0.179
Laboratory charges	0.014
Royalties	0.145
Variable cost	**1.755**
Fixed cost	
Property tax	0.398
Insurance	0.199
Depreciation	1.991
Fixed cost	**2.588**
Annual total product cost without depreciation	
Plant overhead cost	**0.781**
Total manufacturing cost	**5.124**
Administrative expenses	0.260
Sales and distribution expenses	0.727
Research and development expenses	0.581
General expenses	**1.569**
Annual total product cost without depreciation	**14.535**
Profitability analysis	
Annual gross profit	19.922
Annual net profit	12.949
%ROI	55.351
Pay-out period (y)	1.332
Breakeven point (ktpa)	**1.457**
Actual production units (ktpa)	**7.28**

Pay-out period was estimated to be 1.5 y. Finally, breakeven point was estimated to be 1.457 ktpa against the production rate of 7.28 tpa. The positive value of breakeven point reveals the profitability of business. If the value of breakeven point is negative, it means that the business will incur loss. Negative breakeven point is possible only if annual product sales is less than variable cost. Thus, from all the results of equipment cost, capital investment and breakeven point, it could be concluded that the biogas production business is feasible in terms of economics.

CONCLUSION:

The present study aims to perform process economic feasibility analysis of 0.1 million tpa of wheat bran with 10-year life span with 300 working days per annum. The following conclusions were drawn from the results:

- Total equipment cost in 2022 was estimated to be $ 4.228 million.
- Fixed, working and total capital investments were estimated to be $ 19.906 million, $ 3.488 million and $ 23.394 million, respectively.
- Annual product sales were estimated to be $ 7.38 million.
- Annual operating labour cost and utilities cost were estimated to be $ 0.094 million and $ 0.114 million, respectively.
- Variable, fixed, plant overhead, manufacturing, product, and annual net profit were estimated to be $ 1.755 million, $ 2.588, $ 0.781 million, $ 5.124 million, $ 14.535 million and $ 12.949 million per annum, respectively, with breakeven point of 1.457 ktpa against the production rate of 7.28 tpa.

ACKNOWLEDGEMENT:

We would like to thank the management of University of Technology and Applied Sciences, Salalah College of Technology, and colleagues for their continuous support and consistent encouragement for carried out this research work.

REFERENCES:

1) Sivamani, S., Prasad, B. S., Al-Sharji, Z. A. K., Al-Rawas, K. A. M., Al-Blowshi, A. S. D., Al-Yafii, A. S. B., ... & Al-Mamari, H. S. H. (2020). Stoichiometric analysis of biogas production from industrial residues. In *Biofuel Production Technologies: Critical Analysis for Sustainability* (pp. 141-153). Springer, Singapore.
2) Sivamani, S., Saikat, B., Prasad, B. N., Baalawy, A. A. S., & Al-Mashali, S. M. A. (2021). A Comprehensive Review on Microbial Technology for Biogas Production. *Bioenergy Research: Revisiting Latest Development*, 53-78.
3) Banerjee, S., Prasad, N., & Selvaraju, S. (2022). Reactor Design for Biogas Production-A Short Review. *Journal of Energy and Power Technology*, *4*(1), 1-1.

4) Sivamani, S., Binnal, P., Cuento, A., Al-Shahri, A., Al-Mahri, M., Rafeet, M., ... & Al-Awaid, A. (2020). A comprehensive review of experimental studies on aerobic digestion of wastewater sludge. *Removal of Toxic Pollutants Through Microbiological and Tertiary Treatment*, 211-231.
5) Sivamani, S., Chandrasekaran, A. P., Balajii, M., Shanmugaprakash, M., Hosseini-Bandegharaei, A., & Baskar, R. (2018). Evaluation of the potential of cassava-based residues for biofuels production. *Reviews in Environmental Science and Bio/Technology*, *17*(3), 553-570.
6) Moshi, A. P., Temu, S. G., Nges, I. A., Malmo, G., Hosea, K. M., Elisante, E., & Mattiasson, B. (2015). Combined production of bioethanol and biogas from peels of wild cassava Manihot glaziovii. *Chemical Engineering Journal*, *279*, 297-306.
7) Walas, S. M. (1988). *Chemical process equipment: selection and design* (Vol. 1). Boston: Butterworths.
8) Smith, R. (2005). *Chemical process: design and integration*. John Wiley & Sons.
9) Towler, G., & Sinnott, R. (2021). *Chemical engineering design: principles, practice and economics of plant and process design*. Butterworth-Heinemann.
10) Couper, J. R., Penney, W. R., Fair, J. R., & Walas, S. M. (2005). *Chemical process equipment: selection and design*. Gulf professional publishing.
11) Mignard, D. (2014). Correlating the chemical engineering plant cost index with macro-economic indicators. *Chemical Engineering Research and Design*, *92*(2), 285-294.
12) Vatavuk, W. M. (2002). Updating the CE plant cost index. *Chemical Engineering*, *109*(1), 62-70.
13) Abbas, T., Ali, G., Adil, S. A., Bashir, M. K., & Kamran, M. A. (2017). Economic analysis of biogas adoption technology by rural farmers: The case of Faisalabad district in Pakistan. *Renewable energy*, *107*, 431-439.
14) Cucchiella, F., D'Adamo, I., & Gastaldi, M. (2019). An economic analysis of biogas-biomethane chain from animal residues in Italy. *Journal of Cleaner Production*, *230*, 888-897.
15) Kozłowski, K., Pietrzykowski, M., Czekała, W., Dach, J., Kowalczyk-Juśko, A., Jóźwiakowski, K., & Brzoski, M. (2019). Energetic and economic analysis of biogas plant with using the dairy industry waste. *Energy*, *183*, 1023-1031.
16) Mel, M., Yong, A. S. H., Ihsan, S. I., & Setyobudi, R. H. (2015). Simulation study for economic analysis of biogas production from agricultural biomass. *Energy Procedia*, *65*, 204-214.
17) Vo, T. T., Wall, D. M., Ring, D., Rajendran, K., & Murphy, J. D. (2018). Techno-economic analysis of biogas upgrading via amine scrubber, carbon capture and ex-situ methanation. *Applied energy*, *212*, 1191-1202.
18) Cong, R. G., Caro, D., & Thomsen, M. (2017). Is it beneficial to use biogas in the Danish transport sector?–an environmental-economic analysis. *Journal of cleaner production*, *165*, 1025-1035.
19) Ruiz, D., San Miguel, G., Corona, B., Gaitero, A., & Domínguez, A. (2018). Environmental and economic analysis of power generation in a thermophilic biogas plant. *Science of the Total Environment*, *633*, 1418-1428.
20) Wresta, A., Andriani, D., Saepudin, A., & Sudibyo, H. (2015). Economic analysis of cow manure biogas as energy source for electricity power generation in small scale ranch. *Energy Procedia*, *68*, 122-131.
21) Swanson, R. M., Platon, A., Satrio, J. A., & Brown, R. C. (2010). Techno-economic analysis of biomass-to-liquids production based on gasification. *Fuel*, *89*, S11-S19.
22) Bellamy, D., & Pravica, L. (2011). Assessing the impact of driverless haul trucks in Australian surface mining. *Resources Policy*, *36*(2), 149-158.
23) Peters, M. S., Timmerhaus, K. D., & West, R. E. (2003). *Plant design and economics for chemical engineers* (Vol. 4). New York: McGraw-Hill.
24) Garrett, D. E. (2012). *Chemical engineering economics*. Springer Science & Business Media.
25) Budzianowski, W. M., & Budzianowska, D. A. (2015). Economic analysis of biomethane and bioelectricity generation from biogas using different support schemes and plant configurations. *Energy*, *88*, 658-666.
26) Zareh, A. D., Saray, R. K., Mirmasoumi, S., & Bahlouli, K. (2018). Extensive thermodynamic and economic analysis of the cogeneration of heat and power system fueled by the blend of natural gas and biogas. *Energy conversion and management*, *164*, 329-343.