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ECONOMIC ANALYSIS OF MICROALGAE BASED BIOGAS COGENERATION SYSTEM

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Abstract

In this study, economic analysis of the cogeneration system using the biogas produced in the anaerobic reactor feed by microalgae has been performed. This system consists of the following main parts; pool open channel for growing microalgae, pre-concentration section, high-rate anaerobic reactor for producing biogas and cogeneration section that biogas is converted into electricity and heat energy. An economic model to investigate the viability of such a system has been given. The present worth of the net profit, the annual equivalent, rate of return, pay-back time are considered as an economic evaluation criteria. In addition, a sensitivity analysis has been performed in order to show the effects of technical and economic parameters on the system economy.
Keywords: Microalgae, anaerobic reactor, biogas, cogeneration, economic analysis

MİKROALG BESLEMELİ BİYOGAZ KOJENERASYON SİSTEMİNİN EKONOMİK ANALİZİ

Özet

Bu çalışmada mikroalg beslemeli bir anaerobik reaktörde üretilen biyogazı yakıt olarak kullanan kojenerasyon sisteminin ekonomik analizi gerçekleştirilmiştir. Bu sistem temel olarak şu alt sistemlerden oluşmaktadır; mikroalglerin yetiştirildiği açık havuz, yoğunluğunun artırıldığı zenginleştirme kısmı, biyogazın ortaya çıktığı yüksek kapasiteli anerobik reaktör, biyogazın elektrik ve ısıya dönüştürüldüğü kojenerasyon. Böyle bir sistemin uygunluğunu araştırmak için bir ekonomik model verilmiştir. Ekonomik değerlendirme ölçütleri olarak net kârın bugünkü değeri, yıllık eşdeğer, geri ödeme oranı ve geri ödeme süresi dikkate alınmıştır. Ayrıca, teknik ve ekonomik parametrelerin sistem ekonomisine etkilerini göstermek için duyarlılık analizi gerçekleştirilmiştir.
Anahtar Kelimeler: Mikroalgler, anaerobik reaktör, biyogaz, kojenerasyon, ekonomik analiz

1 Introduction

The rapid development of the world economy, growing population and rising trend in the living standards of people result in increasing energy use. In addition, while natural resources are rapidly consumed, environmental pollution becomes a major problem. To meet the ever-increasing energy demand and to reduce greenhouse gas emissions, alternative fuel sources are getting important position with each passing day. Microalgae based technologies are seen as one of the promising alternatives. In recent years, microalgae have been taken into attention as a new clean energy sources for producing biodiesel fuel. Generally, biodiesel production from microalgae consists of four process, which are cultivation, drying, extraction and transesterification. Although many studies about the mentioned each process for producing biodiesel from microalgae carried out in the literature, it does not appear to be economical in the current conditions [1]. The main reason is that the producing biodiesel from microalgae requires higher internal energy for realizing some importance process.

As an alternative fuel, biogas production from microalgae biomass with low-cost anaerobic digestion may be considered. The production of biogas with this way also eliminates the necessity of a few steps such as drying and extraction during the biodiesel production [2]. Biogas mainly consists of methane and carbon dioxide. Methanogenic bacteria composes biogas through anaerobic digestion of organic matter. Microalgae contain very low lignin and low cellulose content so that anaerobic digestion can provide high conversion efficiency [3-5]. The produced methane can be converted to electricity, heat or liquid fuels with using different technologies. A portion of the generated electricity and heat energy can be used in internal consumption. In addition, after anaerobic digestion, the remainder can be regarded as fertilizer or animal feed [3].

There is an increasing trend related to produce biogas from microalgae in the literature [1-3, 7-10] some latest studies are summarized below. Brandenberger et al. [7] performed techno-economic analysis of synthetic natural gas production by microalgae supercritical catalytic gasification. In this study, the production of microalgae was carried out in the outdoor pool and tubular-flat panel airlift photobioreactors. The cost of production of synthetic natural gas system with an outdoor pool was 53-90 €/GJ while in the photobioreactor system 30-103 €/GJ was found. Bahutsky and colleagues [2] studied the effects of various pre-transformation strategy for methane production from microalgae in the anaerobic reactor. According to their studies results, alkaline treatment had not a significant effect while thermochemical pre-treatment increase the methane productivity by 30%. Meyer and Weiss [8] carried out the life cycle cost analysis for specially designed photo-bioreactors for microalgae species, which produce hydrogen and methane. They said that the found values was far above the market values. Tartakovsky et al [9] investigated the production of methane from microalgae biomass at a high-rate upflow anaerobic sludge blanket reactor. The purpose of their study is to optimize the operating parameters such as velocity, algal concentration and hydraulic retention time. When hydraulic retention time of 4 days, the organic loading rate of 3.23 gTVS /L-day (corresponding to input concentration of microalgae 12 gTVS/L) were considered, the volumetric methane production rate of 0.6 L/L-days were found. In addition, methane yield were found as 0.18-0.20 liter for each gtvs fed microalgae.

The aim of this study is to perform an economic analysis of a cogeneration system using the biogas produced in an anaerobic reactor feed by microalgae. An economic model has been established to investigate the economically viability of such a system. This economic model of the system can calculate the economic equivalence of initial investment, operation-maintenance costs and potential revenues by considering time value of money over the lifetime at a specific reference date. For realizing the mentioned aim, the present worth of the net profit, the annual equivalent, rate of return, pay-back time have been considered as economic evaluation criteria. In addition, a sensitivity analysis has been performed in order to show the effects of technical and economic parameters on the system economy.

2 Microalgae Based Biogas Cogeneration System

The flow chart of the considered system are given in Figure 1. This system consists of the following main parts; pool open channel for growing microalgae, pre-concentration section, high-rate anaerobic reactor for producing biogas and cogeneration section that biogas is converted into electricity and heat energy.

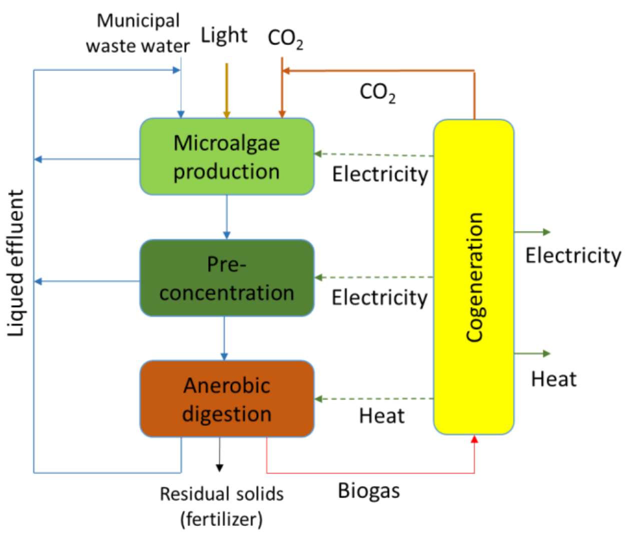

Figure 1. Flowchart of microalgae based biogas cogeneration system

This system has been formed on the basis of the work carried out by Zamalloa et al [10]. Conceptually, in this system, microalgae are grown in the open ponds by using sunlight as a source of light, domestic wastewater as a source of nutrient and using carbon dioxide from the cogeneration system. It is considered that the pool open channel used for microalgae biomass production is constructed on the non-agricultural and non-commercial fields (such as landfill field). The harvested microalgae flow is sent to the pre-concentration section. Here, the flow is concentrated about 100 times. The input stream thus can be obtained with the sufficient chemical oxygen demand (COD) in order to run the anaerobic reactor.

The effluent flow from pre-concentration and anaerobic reactor outputs is fed back into the system. Additionally, CO_2 resulted from the usage of methane in the cogeneration system is taken for the cultivation of microalgae. Therefore, this system is balanced in terms of carbon dioxide production. After the concentration section, the flow enters the anaerobic reactor. To operate at high volumetric loading rates, the UASB reactor was used. The reactor is operated under mesophilic conditions and biogas is produced as a result of the reactions. In the cogeneration system, methane is converted into electricity and heat energy. Some amount of them are used for internal energy consumption, the rest are sold.

3 Economic Evaluation Criteria

Economic analysis identifies the necessary financial resources required for the cash inflows and outflows of a project proposal and aims to determine whether the project proposal is economically feasible in accordance with the evaluation criteria [11]. Economic evaluation criteria are mathematical techniques used to compare the costs and benefits of the project. Many economic evaluation criteria have been developed for both determination of a single project acceptability and making a priority ranking in the case of more than one project based on their acceptability. The methods used for the evaluation of investment projects in the literature can be divided into two groups. The first of these are static methods that don't take into account the time value of money while the second of these is the dynamic methods that takes into account the time value of money. The main features of dynamic methods taking into account the time value of money are as following:

- It covers the whole economic life of the investment
- It is based on the cash inflows and outflows
- Cash input/outputs are converted to the same time level.

For the economic analysis of the considered microalgae based biogas cogeneration system; net present value, annual value, internal rate of return and pay-back time methods, which are based on the dynamic evaluation methods, have been taken into account as economic evaluation criteria.

3.1 Net Present Value Method (NPW)

In the net present value (NPW) analysis, project revenue flows in next years are converted to present value according to the specified discount rate. The net present value of an investment is the difference between the present value of total income and the present value of total expenses and it is calculated by using Eq. (1).

$$N_{PW}=\sum_{t=0}^{n}\left(B_{(t)}-C_{(t)}\right)(1-r)^{-t} \qquad (1)$$

Where, shows the revenue in year of t, represents the costs in year of t, r denotes discount rate, t shows the year, and n stands for the economic life of the project. In order to be economically viable according to this method, the net present value must be greater than zero. In the selecting the best one from alternative projects, the alternative having highest net present value must be chosen. If NPW is positive, the investment it is reasonable to perform; if negative, it is not sensible to perform the investment [11, 12].

3.2 Annual Value Method (NAW)

Annual value (NAW) method has a close relationship with the net present value method. NPW method shows the success of the investment project in total, while the annual value method refers to term success by comparing the cash inflows and cash outflows [11, 12]. Its value can be calculated as following equation.

$$N_{AW}=\left[\sum_{t=0}^{n}\left(B_{(t)}-C_{(t)}\right)(1-r)^{-t}\right]\left[\frac{(1+r)^{n}\,r}{(1+r)^{n}-1}\right] \qquad (2)$$

3.3 Internal Rate of Return Method (IRR)

In this method, the value of discount rate equaling the revenues and the costs of an investment is calculated. This rate is expressed as the internal rate of return (IRR) of investment. It can be calculated by using Eq. (3) [11, 12].

$$\sum_{t=0}^{n}\left(B_{(t)}-C_{(t)}\right)(1-IRR)^{-t}=0 \qquad (3)$$

3.4 Pay-Back Method (PBT)

Payback period (PBT) which is the time period required to recover the project costs. In other words, it is the calculation process resulting the necessary time in order to reobtain a certain money amount equaled to the total costs of a project by means of provided incomes. This value (PBT) can be calculated by Eq. (4) [11, 12].

$$\sum_{t=0}^{PBT}\left(B_{(t)}-C_{(t)}\right)(1-r)^{-t}=0 \qquad (4)$$

4 Economic Analysis and Evaluation

The technical and economical input parameters have been given in Table 1. These parameters used in the analysis have been formed from the literature studies related to biogas production in anaerobic reactors fed by microalgae [1-2, 7-10]. Since microalgae cultivation and biogas production from microalgae are new research topics, the obtained data of technical and economic parameters presents quite variability. Therefore, the used parameters in the analysis have been given as three different scenario. Scenario 1 represents the worst values of technical and economical parameters in the literature. Scenario 3 denotes the best values (depending on technologic improvement in the future) of the considered parameters. Scenario 2 gives the average values. The area of open pond channel, where microalgae is growing, has been considered as 5 km² in all scenarios. The discount rate (can be thought as profit rate) is assumed as 6 %. While the economic evaluation criteria have been computed, the annual revenues and costs in the cash flows have been modelled as uniform series. The obtained technical results according to these values have been given in Table 2. Economic evaluation criteria have been given in Table 3. The sensitivity analysis also shown in Figure 2.

Table 1. Input parameters for technic and economic analysis

Parameters	**S 1**	**S 2**	**S 3**
Microalgae productivity (ton/ha-day)	70	90	110
Volatile solid matter ratio (%)	88	90	92
Fermented volatile solid ratio (%)	73	75	77
Biogas yield (m³/kg)	0.45	0.5	0.55
Biogas energy value (MJ/m³)	25	25	25
Electricity conversion efficiency (%)	35	40	45
Heat conversion efficiency (%)	40	45	45
Economic life (year)	20	25	30
Load factor (%)	85	90	95
Electricity inner consumption (%)	30	27	25
Heat inner consumption (%)	75	70	65
Heat selling price ($/kWh)	0.10	0.112	0.125
Electricity selling price ($/kWh)	0.20	0.225	0.25
CO_2 price ($/ton)	40	45	50

It can be seen from Table 2 that the amount of dry matter derived from microalgae is approximately 96 tons per day for the Scenario 1 while its value is 150 tons per day for the Scenario 3. The values of daily production of biogas and other technical parameters are observed at their highest point in the Scenario 3. For example, daily net generated electricity in Scenario 2 has increased 79% from 47 MWh to 84 MWh. In the scenario 3, it is increased by 190% to reach 137 MWh. The main reason behind of this is that the technical parameters in the Scenario 2 and 3 have better values.

Table 2. Technical analysis results

Parameters	**S1**	**S 2**	**S3**
Dry matter (kg/day)	95890	123288	150685
Volatile solid matter (kg/day)	84384	110959	138630
Fermented volatile solid (kg/day)	61600	83375	106745
Biogas production (m³/day)	27720	41620	58710
Biogas energy amount (m³/day)	693000	104023 9	1467747
Net generated electricity (kWh/day)	47163	84375	137601
Net generated heat energy (kWh/day)	19250	39009	64214

The results of the economic analysis are given in Table 3 for the three scenarios. Annual revenues of the system considered in Scenario 1 become approximately 3 million from the electricity sale, 0.6 million from the heat sale and 0.2 million dollars from carbon sequestration. However, since the initial investment cost and operation/maintenance costs of the system are very high values, the economic evaluation criteria give negative results. The net present value of revenues and costs during the economic life becomes approximately -51 million dollars. In other words, it is understood that the system is getting loss under the conditions given in the Scenario 1., the same comment can be made by investigating annual value of -4 million dollars. Therefore, according to the result of these criteria, making investment to this system is not economically viable. In the Scenario 2, the criteria values turn to positive values. However, it is found that the system payback time is 24 years approximately. This situation would not ever be attractive to any investor. In the Scenario 3, it is observed that the revenues of the system increase significantly due to the change of both technical and economic parameters. The present value of the net profit becomes about 100 million dollars while the annual value of $ 7.3 million has been calculated. In addition, internal rate of return and the payback time are found as 26% and 4.5 years, respectively. Scenario 3 indicates that this system can be economical by getting mature technology for this system.

Table 3. Economic analysis results

Parameters	**S1**	**S2**	**S3**
Revenues			
Electricity selling income ($/year)	2.926×10^6	6.375×10^6	11.93×10^6
Heat selling income ($/year)	0.597×10^6	1.474×10^6	2.783×10^6
CO_2 credits ($/year)	0.207×10^6	0.411×10^6	0.787×10^6
Costs			
Investment cost ($)	34.4×10^6	36.72×10^6	39.04×10^6
Operation/ Maintenance cost ($/year)	5.4×10^6	5.76×10^6	6.12×10^6
Economic evaluation criterion			
Net present value ($)	-51.17×10^6	0.503×10^6	100.9×10^6
Annual value ($/year)	-4.461×10^6	0.039×10^6	7.33×10^6
Internal rate of return (%)	-	6.14	26
Pay-back time (year)	-	24.3	4.5

The results of sensitivity analysis are shown in Figure 2. The sensitivity analysis shows the impact of the considered technical and economic parameters on the present value of net profit and determines the contribution ratio of these parameters are on the results. The limits of value ranges of the investigated parameters have been determined according to the values in Scenario 3 and Scenario 1. With considering the data of Scenario 3 as base case, the influence of the percentage change of the studied parameters on the results have been given as a percentage in this figure. It is clearly seen from this Figure that the most affecting parameter on the present value of net profits is the productivity of dry matter production. When the productivity of dry matter production are changed from 0% to 35%, the present value of net profits varies 67% approximately. It is understood from this information that getting high level productivity of dry matter production in the microalgae cultivation process becomes the vital point. To achieve the mentioned productivity level, the type of microalgae used in the system, the outdoor pool design, its operation, optimization of harvesting becomes crucial processes.

In addition, it can be observed that the curve slopes of the electricity selling price, the electricity conversion efficiency and the load factor (working time rate in one year) is greater than those of other curves. Therefore, it is concluded that the net present value of net profit is more sensitive to the mentioned parameters. It is understood that running the system for as long as possible, converting the produced biogas to electricity with high efficiency and increasing the electricity selling price should be done as initial activities for system economy. This situation will depend on an improvement in the microalgae cultivation technology, the type of the micro-cogeneration technology in the system and the increment price of fossil fuels. Apart from other parameters, it is shown that CO_2 capture income has a lower effect. Therefore, it is understood that, CO_2 taxes must increase even more in order to be more economical of this system.

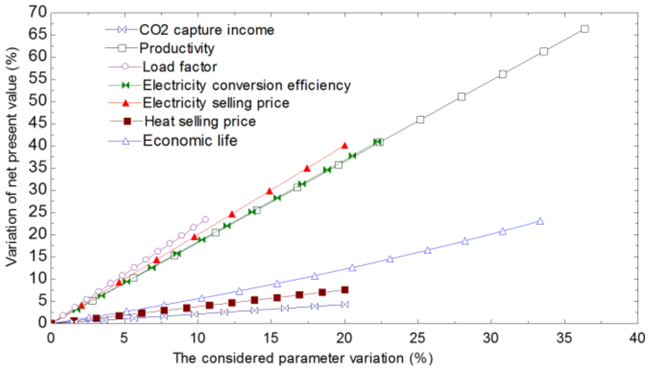

Figure 2. The effect of considered parameters on net present value

5 Conclusion

In this study, economic analysis of the cogeneration system using the biogas produced in the anaerobic reactor feed by microalgae has been performed. In the economic analysis, present value of net profits, annual value, internal rate of return and pay-back time have been used as evaluation criteria. According to the analysis result, the considered system has not yet found economically viable for investment in the current conditions. However, with technological improvement for microalgae productivity and biogas production, this system can reach the level of economically viable. It has been found from the analysis that dry matter productivity, electricity conversion efficiency, electricity-selling price are important parameters affecting mostly on system economics.

In future studies, the effect of different microalgae production systems can be examined in relation to economic analysis. Additionally, pre-processing methods (such as thermochemical method) to increase the portion converted to biogas in the anaerobic reactor can be taken into consideration. Furthermore, in the model development of economic analysis, the revenues and costs flows through the economic lifetime can be formed by the different time series.

6 References

[1] Harun R., Davidson M., Doyle M., Gopiraj R., Danquah M., Forde G., "Technoeconomic Analysis of an Integrated Microalgae Photobioreactor, Biodiesel and Biogas

Production Facility", *Biomass Bioenergy*, 35 (1), 741–747, 2011.

[2] Bohutskyi P., Betenbaugh M.J., Bouwer E.J., "The Effects of Alternative Pretreatment Strategies on Anaerobic Digestion and Methane Production from Different Algal Strains", *Bioresource Technology*, 155, 366–372, 2014.

[3] Vergara-Fernandez A., Vargas G., Alarcon N., Velasco A., "Evaluation of Marine Algae as a Source of Biogas in a Two-Stage Anaerobic Reactor System", *Biomass Bioenergy,* 32, 338-344, 2008.

[4] Schenk, P.M., Thomas-Hall, S.R., Stephens, E., Marx, U.C., Mussgnug, J.H., Posten, C., Kruse, O., Hankamer, B., "Second Generation Biofuels: High-Efficiency Microalgae for Biodiesel Production", *Bioenergy Res.,* 1, 20–43, 2008.

[5] Sialve, B., Bernet, N., Bernard, O., "Anaerobic Digestion of Microalgae as a Necessary Step to Make Microalgal Biodiesel Sustainable", *Biotechnol. Adv.,* 27, 409–416, 2009.

[6] Hidaka, T., Inoue, K., Suzuki, Y., Tsumori, J., "Growth and Anaerobic Digestion Characteristics of Microalgae Cultivated Using Various Types of Sewage", *Bioresource Technology, 170*, 83–89, 2014.

[7] Brandenberger M., Matzenberger J., Vogel F., Ludwig Ch., "Producing Synthetic Natural Gas from Microalgae via Supercritical Water Gasification: A Techno-Economic Sensitivity Analysis", *Biomass Bioenergy*, 51, 26-34, 2013.

[8] Meyer M.A., Weiss A., "Life Cycle Costs for the Optimized Production of Hydrogen and Biogas from Microalgae", *Energy*, 78, 84-93, 2014.

[9] Tartakovsky B., Lebrun F.M., Guiot SR., "High-Rate Biomethane Production from Microalgal Biomass in a UASB Reactor", *Algal Research*, 7, 86–91, 2015.

[10] Zamalloa C., Vulsteke E., Albrecht J., Verstraete W., "The Techno-Economic Potential of renewable Energy Through the Anaerobic Digestion of Microalgae", *Bioresource Technology*, 102, 1149–1158, 2011.

[11] Sabuncu C.Ö., "Biyogaz Üretiminin Teknik, Ekonomik ve Çevresel Analizi", Yüksek Lisans Tezi, Hacettepe Üniversitesi, Fen Bilimleri Enstitüsü, Çevre Mühendisliği Anabilim Dalı, Ankara, 2010.

[12] Baraçlı H., İme M., "Finansal Yönetim", *Alfa Yayınları*, İstanbul, 2013.