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The Production of Biogas from Agricultural and Animal Wastes and Its Utilization in the Integrated Energy System (Biogas)*

Osman YALDIZ[1], Durmuş KAYA[2], H. İbrahim SARAÇ[3], Kamil EKİNCİ[4], Günnur KOÇAR[5], Berk KÜÇÜKKARA[1]
[1]Akdeniz Üniversitesi Ziraat Fakültesi Tarım Makinaları Bölümü, Antalya
[2]TÜBİTAK MAM, Enerji Enstitüsü, Gebze, Kocaeli
[3]Kocaeli Üniversitesi Mühendislik Fakültesi, Kocaeli
[4]Süleyman Demirel Üniversitesi Ziraat Fakültesi, Isparta
[5]Ege Üniversitesi Güneş Enerjisi Enstitüsü, İzmir
yaldiz@akdeniz.edu.tr

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Abstract: The tasks of this research; review of biogas and energy production technologies, system simulations and decision support system (DSS) modeling, design and development of two lab-scale (one for animal waste and one for agricultural waste) and one pilot scale (250 kWe capacity) integrated biogas plant, integration of the pilot plant with energy conversion systems, experimental studies, techno-economical analysis of the biogas production, and life- cycle analysis were determined. The pilot biogas plant consist 2 reactors that have 2089 m3 net volume each and they are connected to each other. The volume of the final manure storage is 1000m3. The retention time at the plant is 47 days; ratio of organic dry matter is 9 % and the fermentation temperature is 35-40^{o}C under mesophilic conditions.
Key words: Biogas, energy, waste

Bitkisel ve Hayvansal Atıklardan Biyogaz Üretimi ve Entegre Enerji Üretim Sisteminde Kullanımı (Biyogaz)

Özet: Bu çalışmada; biyogaz ve enerji üretim teknolojileri için sistem simülasyonu, karar destek sistemi (KDS) modelleme, laboratuar ölçeğinde iki (hayvansal kaynaklı ve tarımsal kaynaklı atıklar için ayrı ayrı) ve 250 kWe kapasitesinde pilot ölçekli bir entegre biyogaz tesisi tasarlanıp imal edilmesi, enerji dönüşüm sistemleriyle entegrasyonu, deneysel çalışmalar, teknik-ekonomik analizler ve yaşam döngü analizleri incelenmiştir. Oluşturulan pilot tesis için 2 adet birbirine bağlı ve her birinin net 2089 m^3 hacmi olan üreteç imal edilmiştir. Nihai ürün deposunun hacmi 1000m^3 olarak seçilmiştir. En uygun bekleme süresinin de 47 gün olduğu tespit edilmiştir. Organik kuru madde oranı 9% ve üreteç içi sıcaklığının mezofil koşullarda 35-40^{o}C'de en uygun olduğu belirlenmiştir.
Anahtar kelimeler: Biyogaz, enerji, atık

INTRODUCTION

The fossil resources which run out day to day cause gradually increasing demand for energy in the world. The use of fossil fuels, foreign dependence, import costs and environmental problems brings significant drawbacks. As a result of these developments, the importance of renewable energy sources are increasing every day and developed countries in this regard is to make large investments in R & D projects. In our country, biogas technology has been tried to apply within the research level and limited knowledge and technology. The first biogas studies in Turkey had been carried out in 1950's (Yaldız O,2000). Since several pilot scale plants built by Soil and Water Institute were not designed properly, these plants did not work successfully. Biogas production took first place in the environment and renewable energy work because of the development of environmental awareness and use of local resources for energy production. Although, development of this regard couldn't increase in

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Turkey. Also manpower, technology and the level of awareness are not needed to be.

Biogas plants constitute an important stage of energy production and environmental protection due to environmentally sensitive. Also, last years it finds place among the economic concept of "Material Flow Management" principles and also should be considered as a requirement. Concept of the "Material Flow Management" is aims to improve efficiency and adequacy of strategies in use raw material and energy across the different sectors. Regional sources of raw material (waste) by establishing inter-sectoral networks to increase their value are also included in this concept. With identification, the waste generated in the sector can be constituted of the raw material for another sector. With this concept, establish the across organization industries will help to create new jobs.

MATERIALS and METHODS

This study was constructed by considering the environmental, economical and social benefits and focus of this study is "The Production of Biogas from Agricultural and Animal Wastes and Its Utilization in the Integrated Energy System (Biogas)." (Anonim, 2010).

The tasks in this study includes: review biogas and energy production technologies, system simulations and DSS modeling, design and development of two lab-scale (one for animal waste and other for agricultural waste) and one pilot scale (250 kW capacity) integrated biogas plant, integration of the pilot plant with energy conversion systems, experimental study, feasibility study including techno-economical analysis of the whole system, life cycle analysis and dissemination of the project results (Kaya et al., 2007 a; Kaya et al., 2007 b; Kaya et al., 2007 c; Kaya et al., 2008 d; Kaya et al., 2008 e; Kaya et al., 2008 f;). In this study, the underlying factors in plant design and input parameters, determining of design parameters, fundamental plant sizes, the methods used in determining the process technique and the calculation results have been presented.

Modeling of biogas production systems and determining the optimum working conditions, Computational Fluid Dynamics (CFD) method was used for the decomposition of animal and vegetable wastes in the anaerobic conditions of the fermenters (Kaya et al., 2007 b) In this model, anaerobic decomposition occurring in fermenter can be explained by chemical reactions equivalence. Material flow and mechanical mixing in fermenters that occur because of the speed, pressure, temperature and concentration profiles produced methane (CH_4), carbon dioxide (CO_2) and biogas. Chemical and physical properties of raw material components have been separately identified with the help of "Anaerobic Digestion Model nr. 1 (ADM1)" modeling (biochemical and physico-chemical processes) of biogas production. A chemical and physical property of the mixture was determined.

In the pilot plant, continually loaded and completely mixed tank reactor was used for the decomposition of vegetable and animal wastes. In this reactor, gas production and at the same time result of the burning of gas will be produced to maximize the energy of the operating parameters were optimized.

Integration of biogas production systems and energy conversion systems: 19 ton/d vegetable and animal wastes were fed to a biogas system and "object oriented" modeling was used. Raw materials, generators, and process parameters that affect the performance of the biogas was determined by this simulation (Kaya et al., 2007 h). When the models were creating, characteristics of the waste material, design parameters of fermenters, operational parameters of fermenters, parameters of energy conversion systems, location features of the facilities were considered.

In the pilot plant, continually loaded and completely mixed tank reactor was used for the decomposition of vegetable and animal wastes. In this reactor, gas production and at the same time result of the burning of gas will be produced to maximize the energy of the operating parameters was optimized. There are many factors which affect the integrated biogas and energy production (Kaya et al., 2008 d). These are;

- Characteristics of the waste material,
- Design parameters of fermenters,
- Operational parameters of fermenters,
- Parameters of energy conversion systems,
- Location features of the facilities.

All these variables will be obtained to the amount of energy production and amount of wastes which is output of the plant. Optimization study, five different dry matter ratio (9.0, 10.1, 11.2, 12.4, 13.6%) and different volumetric flow rates (5, 10, 12.5 15, 20, 25 and 35 m^3/d) were performed. Each simulation was performed for 100 days. Different hydraulic loading rates have occurred depending on volumetric flow and dry matter rate. Biogas, CH_4, CO_2 and H_2 quantities, volatile fatty acids and biomass concentration was investigated in each simulation. Gaussian function was used in the evaluation of simulations. Constant volumetric flow rate of dry matter was investigated. In this research, a constant rate of dry matter and methane production in the total electrical and thermal power generation as well as the maximum rate of dry matter were to be determined. When the rate of dry matter was kept, constant methane production value increased and then reduced with volumetric flow rate increase. Should be emphasized here, that determine the optimum volumetric flow rate value for obtain of maximum methane production rate of each dry matter. As well as material pH during the process changes the methane production. Maximum value of the total electrical and thermal power generation is closely related to maximum methane production. Two different laboratory-scale biogas plant was manufactured for all these parameters to be implemented in pilot plant (Kaya et al., 2008 j). While agricultural wastes were used in one of this laboratory-scale biogas plant, animal wastes (different characters) were used in the other. Also animal and agricultural wastes were used together for the experimental work.

One of these laboratory-scale biogas plant which is at Akdeniz University has 1,2 m^3 gross volume but the net volume of fermentation is 1m^3. It was geometrically designed as the same way with the pilot plant consideration. This mechanism was placed on a platform with wheels. This mechanism consists of a fermenter, water channel which will be using for heating system, two mechanic mixers, material preparation tank and control console. Also there is trolley for the carry out the output material. This laboratory-scale biogas plant is shown in Figure 1. Discharging pipe and charging pipe was mounted on fermanter with 180^0 evacuation. Charging pipe is connected to the sludge pump which is inside the material preparation tank. Discharging clearance made for take out the fermented material from the system. This material is taken to the trolley. Fermenter is mixed with two different mixers to provide effective mixing during experimental station. One of this mixer is paddle mixer. It is mounted up and rotating with 30 min^{-1} and it has 0,75 kW power. Other one placed next to the fermenter and it is convertible rotating with 400 min^{-1}. Rotation speed can be changed on the control panel. It has 0,75 kW power.

Inside the material preparation tank, material derived from fragmentation unit is diluted with water and mixed homogeneously. Material is loaded to the fermenter with mud pump. This unit is manufactured from 304 stainless steel material. The base of the tank has been inclined to reduce deposits. Mixer is placed perpendicularly to ensure homogeneous mixing of the material. Speed of the mixer can be change and the maximum speed reach to 400 min^{-1}, power 0,75 kW. There is a mud pump to load mixed material into the fermenter. Operating time of that pump can be adjusted on the control panel. Working volume of the reactor after filled with agricultural waste, discharged from reactor as a fermented material. This material is taken away from the system with trolley. Produced biogas is taken from the top of the fermenter than is sent to pressure stabilizer. Biogas which comes from water trap is taken into storage (type of balloon) with flexible pipe. Before analyzer biogas is transferred to the flow meter for the examination of the amount of produced gas per day. The biogas from the balloon-type storage is transferred to gas analyzer for determination of the content. Temperature control, mixing and blending cycle time can be adjusted with PLC automation equipment in the system. All system can be controlled on the screen. Taking the data obtained in the experiment can be provided and stored. After the data became stable, experiments are continue with the changing experimental parameters. The laboratory studies using plant materials that achieve the highest production of methane per fermenter; The retention time at the fermenter is 30 days, ratio of organic dry matter is 12% and the fermentation temperature is 35^{o}C under mesophilic conditions and 4 kg/m^3.d material amount entered to fermenter. But, the maximum methane production per raw material obtained by using the same fermentation temperature, 9% organic dry matter content and 30-40 days of retention time.

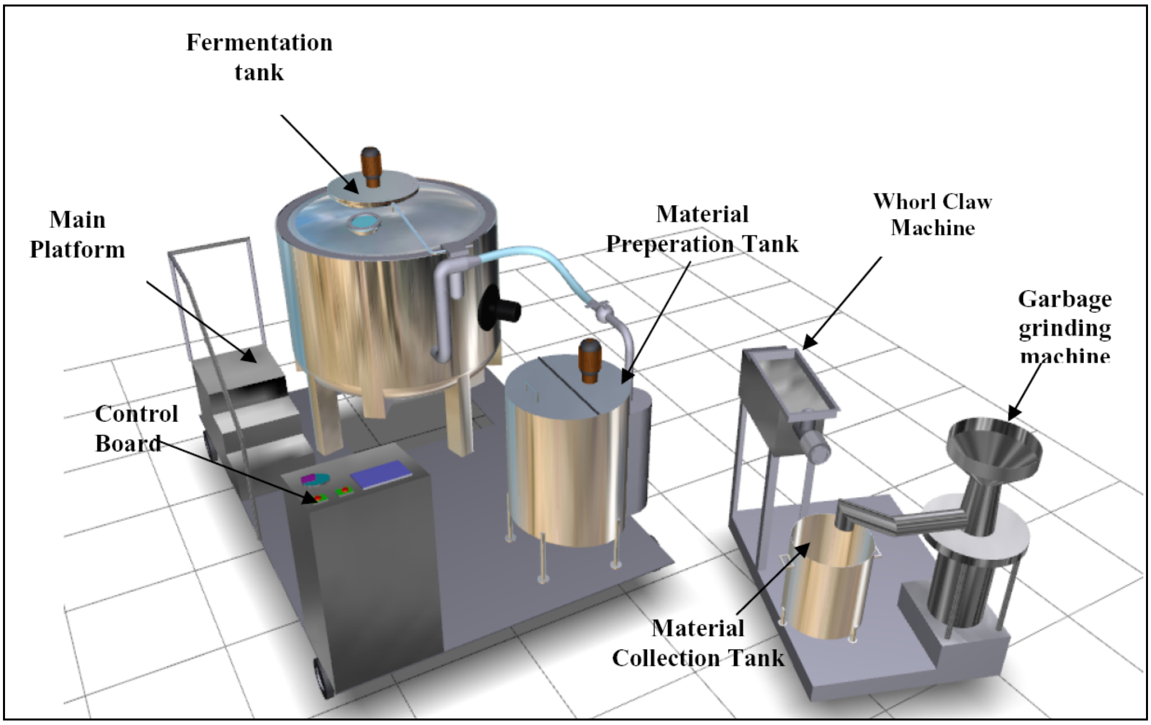

Figure 1. Schematic picture of the laboratory scale biogas system in Akdeniz University

Second laboratory-scale biogas plant which is at Ege University consists of mixer, akuple, material preparation tank, biogas reactor, biogas storage tank and fermented manure discharging tank. Second laboratory-scale biogas plant has 1,2 m^3 gross volume and 1 m^3 net volume. This system consists of mixer, akuple, material preparation tank, biogas reactor, biogas storage tank and fermented manure discharging tank. Maximum working pressure was selected as 700 mbar and the test pressure was selected as 1200 mbar. Mechanic mixing system of reactor has 1.5 kW electric motor with frequency converter. Reactor was isolated with 6 cm rock wool and outside of the isolated material was covered with AISI 304 stainless steel. Gas storage volume is 1m^3. Mixing system was chosen as the binary system. Hydraulic and mechanical mixing was observed to effects on biogas production. Various stages of biogas production were considered when automation system was creating. An advanced control unit which was used in this system is providing reliable data transmission. Also this system helped to solve problems in pilot scale system.

In the system, a type of positive displacement pumps was used for the feeding/discharging and hydraulic mixing. Also this system can be used increase of pressure of cesspool, contaminated water with solids and fibrous particles.

The hydrolic values of pump with 1,1 kW electrical power are flow rate of Q= 1m3/h and manometric height of Hm=20 mSS.

Advanced control systems will provide reliable data transfer and also it will help the problems that may arise in pilot-scale system. The binary system has been chosen as a mixing system, hydraulic and mechanical mixing has been provided effects of biogas production. When the automated systems was creating, various stages of biogas production was considered. For this purpose, the first filling, daily feeding and discharging, the normal working conditions were separately considered, the study scenarios was prepared. Follow-up and changing the parameters is provided with the control unit which has a computer interface.

Design of pilot scale biogas plant was made by using knowledge of literature studies, simulation exercises, laboratory-scale experimental studies and overseas technical visits. Plant installation work has been done in Kocaeli Municipality İZAYDAŞ Inc.s fields Kocaeli Turkey. Plant layout is shown in Figure 2.

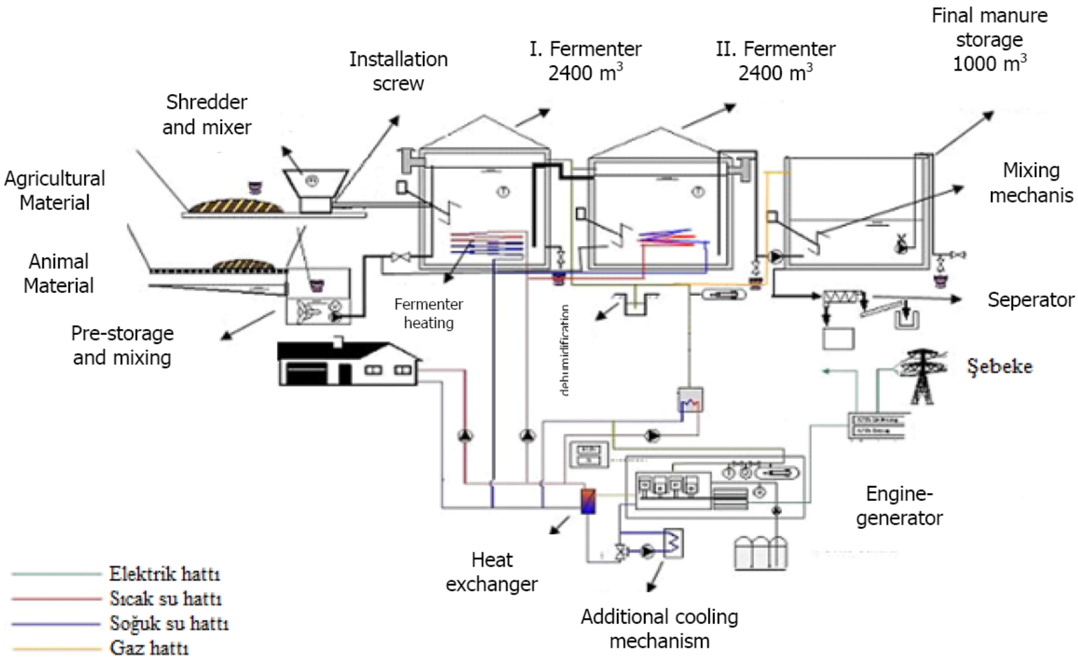

Figure 2: Plant Layout Plan

1) Organic matter / Waste processing systems

The biogas system element which desired size of wastes before sent to the fermenter. Waste preparation system consists of two separately main units. These are; shredder which materials need to fragmentation and feeding unit which materials don't need fragmentation.

2) Fermenters

The pilot biogas plant consists of 2 reactors that have 2400 m^3 gross volume and 2089 m^3 of net volume each, which are connected to each other both in series and in parallel. Construction of fermenters is concrete. Two mixers are placed into fermanters for the material to be fermented in a good way. In addition, heaters are placed into fermanters to keep internal temperature between 35-40 ^oC in the fermenter. Fermenter picture is given in Figure 3. Also Fermanter size in the pilot projects system is shown in Table 1.

Table 1. Technical specifications of the fermenters

Definition	Explanation	Value
Fermenters	Diameter (m)	19,5
	Height (m)	8
	Wall thickness (m)	0,3
Final manure storage	Diameter (m)	16
	Height (m)	5
	Wall thickness (m)	0,3

Figure 3. Pilot-scale plant fermenter

Produced gas continuously delivered to the motor generator group. The gas storage units were mounted separately on the generator in the form of single layer membran and each volume membran is 700 m^3. This volume is enough to store produced gas during 16 hours.

3) Final Product (organic fertilizer) Storage

Fermented end product is sent through the separator by pump. Separator will separate 25-30% solid form and liquid form (≈%3-6 solid) of the final product. After that, separator will pump liquid part into the liquid fertilizer tank.

4) Cogeneration Unit

The content of the biogas which received from fermenter is 50-65% CH_4, CO_2 35-45%, 500-2500 ppm H_2S, very small amounts of other gases and moisture. Biogas obtained from the plant can be used to produce heat and/or power by means of a combined heat and power (cogeneration) system (Fig.4). In that case, heat released during burning can be recovered using an appropriate heat exchanger. Some of the recovered heat can be used to heat the fermenter, and the rest for general heating.

The waste used in the pilot plant consists of store and wholesale food waste (i.e. green vegetable and fruit waste), inner tripe from slaughterhouses, cattle waste from regional farms, grass waste and chicken manure (Table 2). Determination of waste prescribed; maximum amount of chicken manure was used as a raw material because it is creating the biggest environmental problem for the Kocaeli Municipality. Daily and annual amount of wastes are given in Table2.

Table 2. Daily and annual amount of waste used in the plant

Material	Amount (ton/day)	Amount (ton/year)
Grass	16	5.900
Vegetable and fruit	5,6	2.050
Inner tripe	1,17	430
Chicken manure	5,34	1.950
Cattle manure	0,96	350
Total	**29,07**	**10.680**

Figure 4. Cogeneration Unit

Average values of analysis results for five samples taken at different times are given in Table 3.

Table 3. Average values of dry matter (DM), organic dry matter (ODM) and nitrogen (N) analysis results for five samples taken at different times

Type of waste	DM (%)	ODM (%)	N (kg/t)
Grass	26,01	89,91	6
Vegetable and fruit	8,97	91,65	4
Inner tripe	16,81	89,11	6
Chicken manure	71,92	37,10	40
Cattle manure	16,44	75,39	6

Laboratory-scale experiments with a consulting firm that works on the specified materials, the retention time at the plant was chosen 47 days.

The fermentation temperature is 37-38^{o}C under mesophilic conditions. Approximately 31% rates of solids (DM), 31.6 t/d raw material and 9.8 m^3/d water have entered to fermenters.

This fermentation results in approximately 4600 kg/day (with a rate of 55% CH_4) was targeted to produce biogas.

The organic dry fertilizer of 5.100t/y at the dry matter rate of 25% and liquid fertilizer of 8.330 t/y at dry matter rate of 6% at the end of the process were planned.

A total of 876 kW/h of power would be consumed for producing the design amounts of 353 kW of electric power and 361 kW of heat. Plant energy consumption is 60kW. The total energy efficiencies for biogas-fired CHP plant were 81,5%. Mass balance of the biogas plant is shown Figure 5.

The feedback technique consists of feeding back 51.5 m^3 of material taken from the final storage, which is at 6 % solidity and in the form of thin slurry, in to fermenter 1 and 2.

The plant has biological sulfur removal system for removal of H_2S. The system can be considered as biological treatment of hydrogen sulfide (H_2S), where a special wooden system is mounted on the reactor ceiling and certain amount of oxygen (O_2) is supplied in the region.

Investors (who is collecting information) are informing about geographic location of the facility and the amount of material to be used in accordance with the properties with system simulation and decision support system (DSS) modeling (Kaya et al., 2007 e).

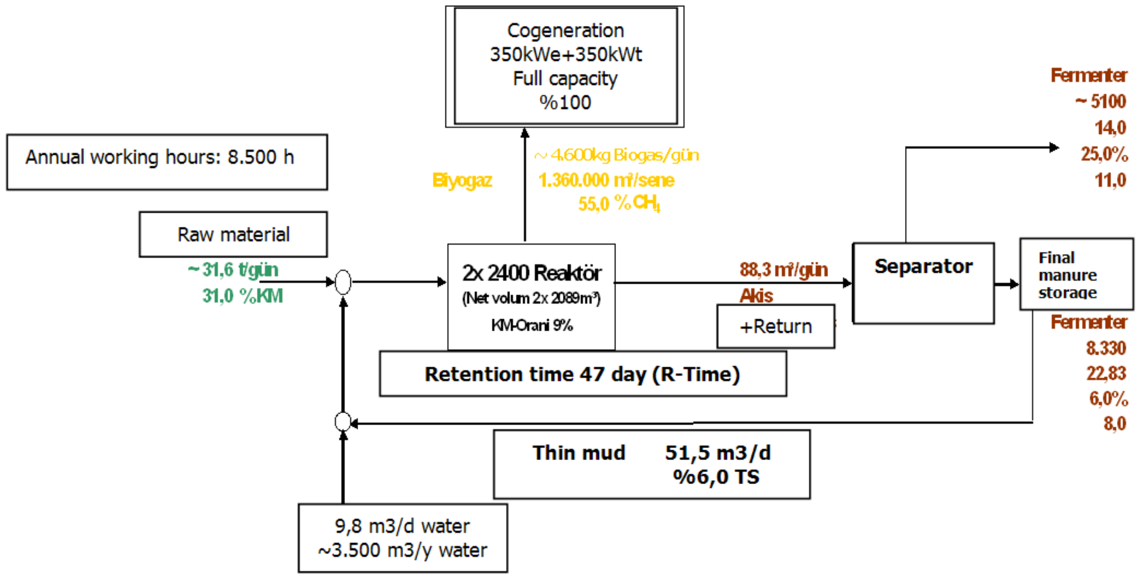

Figure 5. Mass balance of the biogas plant

In this program plant construction area and waste characteristics which will be used plant modeling and using scientific methods;

- The amount of biogas produced from the plant,
- The amount of CH_4 produced from the plant,
- Amount of heat and electrical energy produced from plants,
- CO_2 reduction will be provided at the facility,
- The total cost of the facility (plant units were separated),
- Annual operating expenses of the facility (plant units were separated),
- Eligibility of the facility with the scientific criteria, are obtained as a result.

Different systems from small-size to combine systems will be evaluated for different regions of Turkey. Technical and economical feasibility analyses will be done for each energy production alternatives. (Kaya et al., 2008 f). Plant is operating with different waste characters and measurements are taken for air emissions, water and waste water discharges in order to determine the parameters which are arising from the plant. Environmental effects and environmental aspects of plant will be determined with using measurements datas.

RESULTS and DISCUSSION

The tasks in the project includes: review of biogas and energy production technologies, system simulations and decision support system (DSS) modeling, design and development of two lab-scale (one for animal waste and one for agricultural waste) and one pilot scale (350 kWe capacity) integrated biogas plant, integration of the pilot plant with energy conversion systems, experimental studies, techno-economical analysis of the biogas production, and life-cycle analysis. The waste used in the pilot scale plant were; grass waste, wholesale food waste, chicken manure, cattle manure, inner tripe from slaughterhouses. The retention time at the plant is 47 days; ratio of organic dry matter is 9% and the fermentation temperature is 37-38°C under mesophilic conditions. Approximately 31% rates of solids (DM), 31.6 t/d raw material and 9.8 m^3/d water have entered to fermenters. A total of 876 kW/h of power would be consumed for producing the design amounts of 353 kW of electric power and 361 kW of heat. Plant energy consumption is 60 kW. The total energy efficiencies for biogas-fired CHP plant were 81,5%. The organic dry fertilizer of 5.100t/y at the dry matter rate of 25% and liquid fertilizer of 8.330 t/y at dry matter rate of 6% at the end of the process were planned. Plant configuration was completed. Moreover, Decision Support Systems, simulation and modeling study was also completed.

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