Processing of Biogas Industrial Waste – Application in a Manufacturing Unit

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Abstract: - This study aims at the presentation of dairy waste treatment methods, one of the main industries in Greece with emphasis on biogas production. The industry of dairy products constantly grows due to the increasing demand for milk and its products. Also, the milk production per animal has increased. The dairy industry is one of the largest industrial sources of waste in Europe. A plant can produce over 500 m^3 of wastewater per day. First, there is a demonstration of the production processes of a dairy plant with the requirements of one industry in water and energy to understand the "source" of waste from a dairy factory, showing the significance of having biofuels in reducing environmental pollution, appropriate waste management and various options of their utilization. Then, the waste resulting analysis, of solids, liquids and gases, is studied, giving greater prominence to analysis of wastewater. The quantitative and qualitative characteristics of waste water are examined as well. The liquid wastes in a dairy not only come from production processes but also from pickling premises and mechanical equipment and from milk whey losses and discharges. In addition, analysis of the wastewater treatment methods, with greater emphasis in the anaerobic, treatment is included. Finally, an essential case study based on a real waste data for waste production of a dairy plant, is discussed in details.

Key-Words: biogas production, biofuels, waste treatment, renewable energy.

1 Introduction

In this work we study the treatment of sewage and biogas production in one of the largest dairy companies in Greece. The activity of the plant consists of the production of dairy products. The main categories of products produced by the facility are: cheese production (white, semi-hard and hard cheeses), yogurt production (cow and straw), whey cheese production, milk bottling, and other non-dairy products, etc.

Due to the operation of the installation, the following are created:

- gaseous wastes from combustion of fuels used to meet the operational needs of the installation as well as combustion of sludge in the drying and incineration plants.

- liquid waste arising from the needs of the staff and the production process.

- solid waste that also comes from the needs of the staff and the production process.

In this work the analysis will focus on the treatment of wastewater and the biogas production [1-31].

Urban liquid waste comes from the needs of the personnel and is transported via piping to the biological treatment unit. Industrial wastewater is formed at various stages of production processes, such as:

• Cleaning of parts of machinery, floors, sanitary facilities, refrigeration facilities and tanks.

• Cheese processing (cheese production, brine & lactose production)

• Any leakage of materials

2 Case study – application

An application to a manufacturing unit is analyzing. Its product returns for destruction because it is close to their expiration date.
Waste water from the cleaning of mechanical equipment results from cleaning that takes place at regular intervals for hygiene purposes. Wastewater generated mostly contains water and residues of milk, whey, yogurt, etc.
From cheese processing, whey, salt and lactose are produced as waste. Cheese is used in the production of certain types of cheeses such as myzithra. The remains of this, including the brine and the lactose, which comes from the condensation process during the production of the myzithra, are managed within the plant as waste. The whey, in the form of a waste, carries a high BOD polluting load.
Liquid waste contains material leaks stems from possible leaks or accidental batches of products during the production process.
Finally, returned products are considered those that are placed on the market and returned to the facility for destruction because they are close to their expiration date.
Table A shows the energy consumption in the dairy factory for the basic type of products used.

Table A. Energy consumption in a dairy factory

Type of products	Electricity consumption (GJ / ton of product)	Fuel consumption (GJ / ton of product)
Fresh milk	0.20	0.46
Cheese	0.76	4.34
Milk powder	1.43	20.60
Butter	0.71	3.53

The specific quantitative and qualitative characteristics of liquid waste of waste of the dairy factor are presented below in the Table B.

Diagram A shows a flow sheet diagram of the whole factory.

An example of quantitative data on generated wastewater is presented in the Table 5.

The first part processes the effluent, lactose and municipal waste in an External Circulation Sludge Bed reactor prior to entering the aerobic treatment unit in order to reduce its polluting load, to exploit it for production biogas and significant depletion of the aerobic treatment unit. The External Circulation Sludge Bed reactor consists of a dense anaerobic granular biomass layer where the bioconversion process is carried out at specific temperature and pH conditions at less than 24 hours.
The second section processes the returned products, whey and any other thick residue resulting from the production process in 3 CSTR (slow conversion) digesting reactors to produce biogas. The CSTR-type reactor is a slow-digesting organic biogas system with good mixing conditions and over 20 days of storage in the reactors.
The Aerobic Treatment section is a biological treatment unit with a processing capacity of 3,000 (m^3 / day) or greater if the pollutant load at the inlet is further reduced. This unit is sent to process the output of the anaerobic treatment unit (ECSB). The treated liquid stream is led to a tributary river while the sludge generated enters the sludge drying and incineration plant. It should be noted that the wastewater of the production process and municipal waste are concentrated in a central well from which they are fed to the treatment plant.

Table B. Quantitative and qualitative characteristics of liquid waste of dairy factories

Final product	Waste volume (m3 / ton of product)	BOD_5 (kg / ton of product)	COD (kg / ton of product)	SS (kg / ton of product)
Milk reception station	0.83	0.46	0.84	0.03
Liquid dairy products	3.87	3.21	5.63	1.5
Yoghurt	3.87	3.21	5.63	1.5
Butter	20.9	20.9	36.5	10.4
Cottage cheese (mizithra, etc.) with whey recovery	79.4	137	239	3.4
Cottage cheese (mizithra, etc.) without whey recovery	80.3	609	953	3.4
Fresh cheese with whey recovery	14.8	10.3	16.8	5
Fresh cheese without whey recovery	15.7	482	731	5
Ice cream	1.6	0.8	1.4	0.24
Condensed milk	7.2	3.9	6.8	1.5

It should be noted that the wastewater of the production process and municipal waste are concentrated in a central well from which they are fed to the treatment plant.

The basic mechanical equipment is:

• A regulator tank TO3 in which whey and wash water are collected from the various parts of the plant
• 3 tanks in which lactose is collected from the various parts of the production,
• A regulating tank TO4 which is the ECSB reactor waste water supply,
• A neutralization tank before the ECSB reactor at certain pH and temperature. Also in this tank soda is added when is needed to increase pH when the lysate is acidic. The sewage conditions in this tank are 30°C and pH 6.4.

The ECSB reactor system is accompanied by:

• A preparatory tank TO9 with the CSTR reactors
• 3 CSTR reactors
• A TO8 sludge tank
• One DAF
• A combustion flame for safety
• A biogas storage balloon
• A steam boiler where the biogas produced is converted into steam

3 Process description

Waste from mechanical equipment washing and municipal waste water are collected in the existing pumping station and led to the scraping system consisting of a 1.00 mm gauge and used to remove large solids-debris. Separated solids - usually papers and woods - are stored in a transportable bucket to be disposed of the recyclable materials of the unit. The untreated liquid stream is led through a rotating filter (1.00 mm permeability) to the balancing-acidifying tank.

The tank is metallic, closed type and ensures initial flow equilibration and homogenization of the current to be treated. Essentially, the balancing tank functions, as a damping of flow fluctuations, helps achieve a steady flow. Benefits resulting from normalization of flows are:

• **Stabilization** of incoming wastewater flow to protect the next steps of the hydraulic shock treatment.

• **Homogenization** of BOD5, COD and suspended solids of the content.

Acidification is also carried out in this tank. In particular, complex molecules (carbohydrates, lipids, proteins) are depolymerized into soluble elements, via hydrolytic enzymes (cellulases, semicirinases, amylases, lipases and proteases).

To avoid odor, the balancing tank is covered and vented.

Thereafter, the liquid stream is led to the diluted air flotation unit (DAF).
The flow to the DAF is controlled by an electromagnetic flow meter.
A level indicator resistant to heavy wastewater has also been installed.

Flotation is a function used to separate solid or liquid particles (especially light fractions such as fats and oils) from the liquid phase.
Separation is accomplished by introducing small gaseous bubbles (air) into the liquid phase.
The float is removed to the sludge storage tank and then transferred to the preparation tank for anaerobic digestion.
The effluents from the DAF tank overflow into a second balancing tank where mixing with the filtered whey (lactose) occurs and the acidification process is continued.
Prior to the entry into the reactor, the lithium is led through a heat exchanger into a GRP (Glass Reinforced Polypropylene) tank, where it is prepared by chemical dosing and temperature rise.
This stage is very important for controlling the recirculation of the ECSB reactor. The tank has a NaOH dosing system (to adjust pH), $FeCl_3$ (to improve granulation) and an antifoam dosing system.
Mixing is achieved by means of a venturi stirrer in the tank and two dry-type pumps.
After preparation, the sewage enters the ECSB reactor from its bottom by means of a distribution network (IDS), penetrates a dense anaerobic granular biomass layer where the biotransformation process is carried out and exits its surface.
The collected biogas from the separators is led through an upcoming headspace to the neutralizing tank to be used as a CO_2 gas capture gas.

Anaerobic treated waste and recirculation stream are returned to the neutralization tank.
On the basis of the biomass and design load, the excess biomass must be removed via a connection at the bottom of the reactor to the existing granular slurry storage silos.

The aforementioned process is schematically represented in the following diagram of the ECSB reactor [31] figure 1.

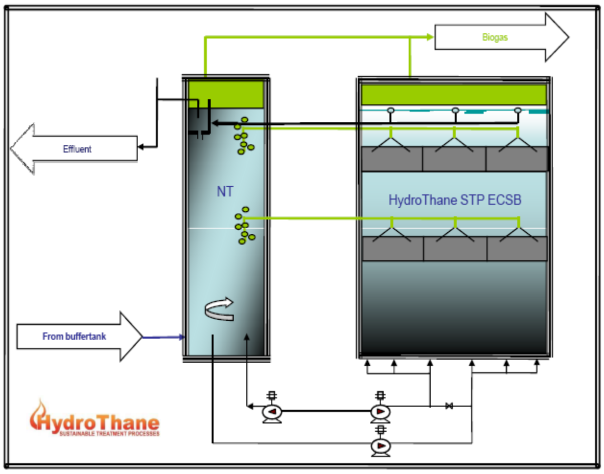

Figure 1. Flowchart diagram of the process.

The ECSB output is intersected by entering the heat exchanger to recover part of the high temperature (above 30 C) of the current. The flow of liquid from the ECSB reactor is introduced into the aerobic system.

Parameters of anaerobic treatment

Anaerobic digestion as mentioned above involves biological processes that can be classified into four distinct phases:

- **Hydrolysis** of polymeric organic compounds (fats, proteins, polysaccharides) with the help of enzymes released from hydrolytic bacteria and their conversion into water-soluble products of lower molecular weight (monosaccharides, amino acids, etc.).
- **Fermentation** of the above soluble products and their conversion into intermediates, such as short organic acids, alcohols, carbon dioxide, hydrogen and ammonia.
- **Acidogenesis**, i.e. production of acetic acid, carbon dioxide and hydrogen from the products of the previous stage with the help of acidogenic bacteria. In this phase, carbon dioxide is the main component of biogas and the pH is 4.5-6.5.
- **Methanogenesis**, where the products of the previous phase are transformed into methane and carbon dioxide from methogenic bacteria and pH ranges from 6.8-7.2.

The speed of the total decomposition process is determined by the slower reaction of the chain. Biogas production reaches its peak during methanogenesis.

Anaerobic digestion can work in a wide range of temperatures, but there are two temperature ranges where its performance is optimized:

- **mesophilic** (approximately 35°C) with a range of 30°C to 40°C, and
- **the thermophilic** range (approximately 55°C) with a range of 50°C to 65°C.

As anaerobic processes are not severely exothermic, organic heat is often insufficient to keep the temperature at the optimum level.

Thus, additional external heat needs to be provided, which can be derived from the combustion of the biogas produced, the amount of which is sufficient both to maintain the desired temperature and to produce excess energy (electricity and / or heat).

Other parameters that determine the performance of anaerobic digestion are substrate particle size, carbon to nitrogen ratio (C / N) and the possible presence of toxic for microorganisms in the substrate.

Particle size: The particle size depends on the degree of biodegradability of the substrate.♣

C / N ratio: For substrates with moderate to high biodegradability, such as waste from the installation under consideration, the optimum C/N ratio is between 25-30. Low C / N values generally result in higher nitrogen emissions in the form of gaseous ammonia, the concentration of which can be toxic to the microbial population. Optimal C/ N values are achieved by the proper mixing of waste components, which requires good planning for the waste that each installation receives, the storage and bioreactor supply.♣

The possible presence of toxic substances in the substrate: The existence of substances that can have a negative effect on the microbial population is possible on a substrate. Some substances (e.g., certain metals such as Cu and Zn) are necessary for the growth of micro-organisms at certain concentrations, but larger ones may be toxic.

Temperature: Anaerobic digestion works at temperatures between 35-55°C, the mesophilic and thermophilic range, respectively.♣

Mesophilic anaerobic digestion is well known and understood as a process, requires less heating for its operation, achieves a greater degree of biodegradation of the organic fraction and is considered more stable / resistant due to the greater biodiversity of the microorganisms involved. However, thermophilic anaerobic digestion is thought to achieve faster biodegradation and more complete sanitization of waste and therefore requires shorter residence times.

The choice of anaerobic digestion system between mesophilic and thermophilic systems depends on specific local conditions (available space, desired degree of stabilization, further processing and use of digested sludge, institutional hygienisation requirements, etc.).

The basic design parameters for anaerobic digestion are reactor volume and heat requirements. These parameters depend on the amount of waste, the residence time, and the reactor temperature.

Anaerobic Low Load Digester

Heavy residues from the above processes as well as wastes which are considered viscous, such as:

- DAF slurry
- excess sludge from the aerobic
- return / expired products
- whey

are harvested in a pre-treatment tank and driven to a three-reactor CSTR system.

CSTR digesting systems convert organic load into biogas by achieving good mixing conditions and staying over 20 days within the reactors.

The outgoing stream is stored in an intermediate storage tank and then dehydrated in a centrifugal separator from which the liquid stream returns to the first neutralizer tank (DEO-1) to recover nutrients and further processing.

Aerobic treatment

The aerobic treatment takes place in the aerobic treatment unit.

- The 1st precipitation is not used and the mixture overflows in the 2nd settling tank.

- B1 ventilation tank is used as a regeneration. All returned sludge enters it and then shares on the two aerobic lines.

The air supply settings are made using a REDOX measuring instrument to achieve healthy denitrification and minimal air use.

The quantities of waste water in the plant and their production in biogas for 12 months for the year 2015 have been studied and recorded.

The following table 2 shows the whey and wash water wastes in m^3 per month for the year 2015.

4 Conclusions

As mentioned above, biogas is a renewable energy source produced by the anaerobic digestion of livestock waste (sewage sludge, blast furnace effluent), industrial waste and sewage, and urban organic waste.

It consists of methane and carbon dioxide and can be used for heat and power generation as well as fuel for internal combustion engines. One cubic meter of biogas replaces 0.66 liters of diesel or 0.75 liters of oil or 0.85 kg of coal.

Nowadays, the application of biogas production from various wastes extends from very small livestock units to very large biological treatment complexes.

More than 700 biogas plants operate in Europe that process animal waste or combine different waste from agricultural sources. Greater growth is seen in central and northern Europe, and in particular in Denmark and Germany. In these countries, 70% of Europe's units are located, mainly small-scale farms.

The strong development of biogas plants in these countries is due to the large concentration of livestock per unit area.
The development of livestock farming has led to the production of huge quantities of animal waste and the creation of difficult problems in processing and disposal in the environment.

The development of biogas technologies has offered a number of advantages and environmental benefits. It has provided money savings for farmers, improved fertilization efficiency, lower greenhouse gas emissions, economically and environmentally acceptable waste recycling, reduced odor nuisance and presence of flies, pathogen reduction abilities.

In this application, the analysis focuses on the treatment of wastewater.
Industrial wastewater is formed at various stages of production processes such as the cleaning of components of machinery, floors, sanitary facilities, cold stores and tanks, cheese processing (whey, brine and lactose production), if any material leaks and product returns for destruction because they are close to their expiration date.

The wastewater treatment plant consists of two sections, the aerobic treatment section and the anaerobic treatment section.

Anaerobic digestion is an anaerobic digestion plant for biogas production.
This unit consists of two separate sections.
The first part processes the wastewater, lactose and urban wastewater before entering the aerobic treatment unit in an ECSB reactor for the purpose of reducing their polluting load, exploiting it to produce biogas and significantly discharging the aerobic treatment unit

The rapid conversion ECSB reactor consists of a dense anaerobic granular biomass layer where the biotransformation process is carried out at specific temperature and pH conditions at less than 24 hours.

The second section processes the returned products, whey and any other thick residue resulting from the production process in 3 CSTR digester reactors to produce biogas.
The CSTR-type reactor is a slow-digesting system for digesting biogas with good mixing conditions and over 20 days of storage in the reactors.

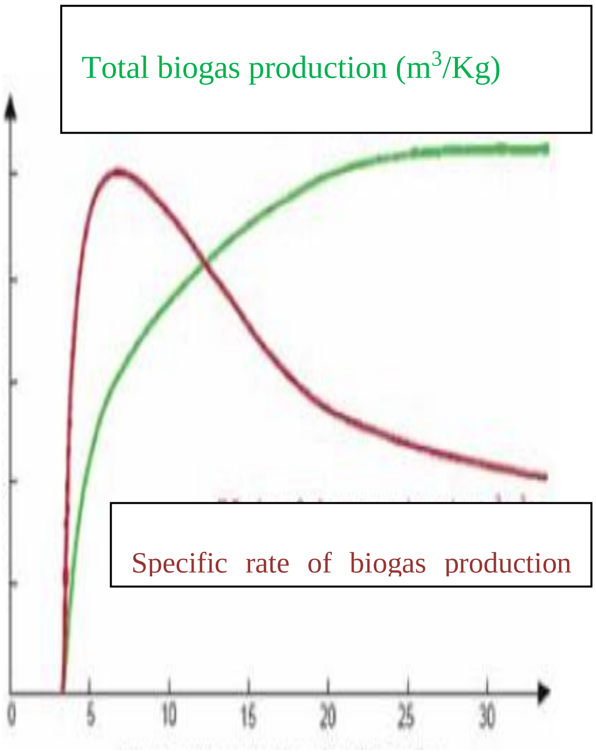

Figure 2. Quantitative rate correlation of biogas production vs residence time per day

Table 1: Amounts of waste generated

A/A	Description	Processed Quantity 2012 (m^3/day)
1	Offshore & Urban Waste	1,419.43 (of which 30.00 m^3 (~) are urban waste)
2	lactose	70.70
3	Cheese (serum)	37.43
4	Returns (before the expiration date)	5.54
TOTAL		**1,533.12**

Table 2: Wastes of whey and washing water in m^3 per month for 2015

MONTH	**2015** **WHEY + WATER SUPPLY**
JANUARY	38,816
FEBRUARY	36,986
MARCH	45,140
APRIL	46,646
MAY	53,814
JUNE	51,212
JULY	52,724
AUGUST	42,563
SEPTEMBER	42,297
OCTOBER	35,647
NOVEMBER	40,492
DECEMBER	51,058
TOTAL	**537,395**

Table 3: Lactose entering the treatment unit in m^3 per month for 2015

MONTH	2015
	LACTOSE
JANUARY	2,298
FEBRUARY	2,762
MARCH	3,981
APRIL	4,451
MAY	5,351
JUNE	4,538
JULY	4,113
AUGUST	3,063
SEPTEMBER	2,886
OCTOBER	3,046
NOVEMBER	2,313
DECEMBER	3,791
TOTAL	**42,593**

Table 4: The supply of the three CSTR in m^3 per month for 2015

MONTH	2015
	CSTR FEED
JANUARY	1,406
FEBRUARY	1,440
MARCH	1,658
APRIL	1,369
MAY	1,640
JUNE	1,222
JULY	1,237
AUGUST	1,286
SEPTEMBER	1,279
OCTOBER	1,016
NOVEMBER	1,147
DECEMBER	1,428
TOTAL	**16,128**

Table 5: Waste values after CSTR in m^3 per month for 2015

MONTH	2015
	CSTR OUTLET
JANUARY	57,429
FEBRUARY	50,378
MARCH	58,656
APRIL	57,734
MAY	75,915
JUNE	71,262
JULY	75,385
AUGUST	77,778
SEPTEMBER	73,607
OCTOBER	58,335
NOVEMBER	53,471
DECEMBER	61,342
TOTAL	**771,292**

Table 6: Supply of ECSB in m^3 per month for 2015

MONTH	2015
	ECSB FEED
JANUARY	41,587
FEBRUARY	39,928
MARCH	49,428
APRIL	51,034
MAY	58,558
JUNE	55,512
JULY	56,961
AUGUST	45,826
SEPTEMBER	45,309
OCTOBER	39,586
NOVEMBER	43,161
DECEMBER	55,139
TOTAL	**582,029**

Table 7: Waste values after CSTR in m^3 per month for 2015

MONTH	2015
	ECSB OUTLET
JANUARY	72,155
FEBRUARY	83,786
MARCH	126,994
APRIL	159,863
MAY	185,777
JUNE	151,617
JULY	142,652
AUGUST	102,240
SEPTEMBER	88,268
OCTOBER	82,055
NOVEMBER	75,627
DECEMBER	114,.359
TOTAL	**1,385,393**

Table 8: Biogas before the steam boiler in m^3 per month for 2015

MONTH	2015
	BEFORE STEAM BOILER
JANUARY	138,758
FEBRUARY	138,824
MARCH	215,998
APRIL	236,361
MAY	292,421
JUNE	196,233
JULY	195,342
AUGUST	158,414
SEPTEMBER	148,463
OCTOBER	134,187
NOVEMBER	118,106
DECEMBER	167,291
TOTAL	**2,140,398**

For the "correction" of pH as we have used NaOH and the quantities used for the year 2015 per month are shown in the table below. Also, the "corrected" pH appears.

Table 9: The quantities of NaOH in Kg used for the "correction" of pH and the "corrected" pH per month.

MONTH	2015	
	NaOH (kg)	**setpoint pH**
JANUARY	60,430	6.3
FEBRUARY	62,800	6.5
MARCH	88,850	
APRIL	166,990	
MAY	181,970	
JUNE	192,660	
JULY	122,610	
AUGUST	67,410	6.4
SEPTEMBER	58,680	
OCTOBER	57,020	
NOVEMBER	72,470	
DECEMBER	148,140	
TOTAL	**1,280,030**	

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Diagram A. Flowchart of the installation