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ENERGY RECOVERY OF WASTE FROM INDUSTRY

PhD Thesis – Summary

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by ing. Ing. Adriana Raluca Avram (married Wächter)
scientific leader Prof.univ.dr.ing. habil Ioana Ionel

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Foreword

The doctoral thesis was developed during the activity submitted within the Research Center for Machinery and Thermal Equipment, Transport and Pollution Control from the Faculty of Mechanics of the Timisoara Polytechnic University. The research focuses on the idea of harnessing the energy potential contained in the biodegradable organic fraction of waste from the food industry and agriculture.

One of the topical problems of today's society is the processing and treatment of organic waste from the food industry. Obtaining food products is carried out with high energy consumption and generates significant amounts of organic waste. The integrated waste management system is meant to deal with this problem.

Under these concerns, energy recovery through the energy recovery of biogas obtained through anaerobic digestion, represents a feasible and sustainable solution for the production of renewable energy from organic waste. In most industrialized countries, the emphasis is on sustainable waste management solutions and on the production of renewable energy from organic waste, a fact that is reflected by European legislation and European funds made available through funding lines promoted at national and European level.

The research work focuses on the concept of "Waste-to-Energy" which offers feasible solutions for the use of organic waste from the food industry as an alternative source of energy. The studied energy recovery processes are based on the action of anaerobic fermentation bacteria, through which organic matter is converted into fuel in the form of biogas with a high methane content (CH4). This process is considered optimal from the point of view of the energy balance, allows the use of a wide range of organic waste, and at the same time constitutes a method of treating organic waste to reduce the impact on the environment. The utilization of biogas takes place in cogeneration groups with the production of heat and electricity (CHP – Combined and Heat Power). In addition, the residues resulting from the anaerobic fermentation process can be used as fertilizer in the agricultural industry.

The addressed research topic aims at the energy recovery of the biogas produced by anaerobic fermentation, using waste from the food industry as raw material. On this demand, two case studies were analyzed for industrial agro-food producers that generate significant amounts of organic waste.

The work is consolidated on a series of experimental researches in the laboratory, for which state-of-the-art equipment was used for the estimation of biogas production by anaerobic fermentation. In order to deepen and fix the theoretical knowledge accumulated from the specialized literature, during my doctoral studies, I attend on-site visits to 3 industrial-scale biogas production stations, in country.

For the measurements, analysis and interpretation of the data, the equipment and apparatus from the Laboratory of Fuel Analysis Ecological Investigations and Dispersion of NOx from the Politehnica University of Timisoara and the Microbial and Industrial Biotechnologies laboratory from the University of Agricultural Sciences and Veterinary Medicine of Banat were used – USAMVB. The obtained results were published in 13 scientific articles, 8 of which are indexed by ISI Web Of Science and 1 by BDI.

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Adriana Raluca Avram
(married Wächter)

CONTENT

1. INTRODUCTION

The topic and the subject that are approach on the PhD thesis research are debated worldwide in research groups, and respond to the energy recovery of waste with organic load generated by the agricultural and food industry. The "Waste-to-Energy" concept uses organic waste as an alternative source of energy, by exploiting the biogas produced by anaerobic digestion.

The thesis is structured in five chapters that cover topics related to integrated waste management, the presentation of three industrial biogas production facilities as well as a series of experimental research carried out on the stand in the laboratory, using the existing infrastructure in the UPT and USAMBV research platforms.

The analysis and interpretation of experimental data was carried out in an interdisciplinary manner with specialists in the field of biotechnology, using two types of state-of-the-art experimental stands in the field of investigating biogas production at laboratory scale.

The introduction chapter highlights topics related to concerns at the European and national level, regarding legislative packages and non-reimbursable funds made available through different funding programs.

The processing and treatment of organic waste from the agriculture and food industry is one of the current problems of contemporary society. Obtaining food products is carried out with high energy consumption and generates significant amounts of organic waste with an impact on the environment.

The finished products of the food industry are characterized by a high value of the ratio between the amount of specific waste and the finished product, it being very difficult to decrease the amount of specific waste while keeping the quality of the product intact. The generation of waste from the food industry is inevitable, their use and storage being hampered by several factors such as: biological instability, pathogenic potential, biological degradation generated by high enzymatic activity (putrefaction), as well as high water content. The stabilization, treatment and storage of organic waste raise special problems both in the field of environmental protection and in that of sustainable development.

The integrated waste management system is meant to deal with this problem. Under this aspect, energy recovery through the energy recovery of biogas obtained from anaerobic fermentation/digestion represents a feasible and sustainable solution for the production of renewable energy from organic waste from the food industry. In most industrialized countries, the emphasis is on sustainable waste management solutions with energy recovery from renewable sources.

The processes of energy recovery from organic waste involve the use of biogas produced following the decomposition of the organic fraction under the action of specific methanogenic bacteria (which produce methane through metabolism). The process of decomposition of the organic fraction under the action of bacteria is known as fermentation or digestion. Depending on the environment in which fermentation takes place, two main types of fermentation are distinguished: aerobic when the decomposition process takes place in the presence of oxygen; and anaerobic when the decomposition process takes place in the absence of oxygen. Each process is characterized by the activity of bacteria specific to the environment in which the decomposition of organic matter takes place.

The anaerobic fermentation process is considered optimal from the point of view of the energy produced/consumed ratio (efficiency); allows the treatment of a wide range of organic waste; it can be fully automated and produces a constant flow of biogas. The fact that the anaerobic fermentation process can be fully automated, so that it produces a constant flow of biogas, has led to the development of several biogas energy recovery technologies applied on an industrial scale. In addition, the residues resulting from the anaerobic fermentation process can be used as fertilizer in agriculture, thus closing the life cycle of food industry products.

The conversion of the organic substance into biomethane is based on the biological activity of methanogenic bacteria cultures found in nature, which consume the biodegradable fraction from the matter, and transform it through metabolism into biogas with a high methane content (55-70%vol). The energy produced by using biogas is considered "renewable energy", so it generates CO_2 certificates that can be traded, according to the Kyoto protocol for GHG reduction.

Unlike fossil fuels, biogas combustion only releases the amount of atmospheric CO_2 that was stored by living organisms (plants or animals) during their growth. Thus, the carbon cycle of the biogas is closed. For this reason, the use of biogas reduces CO_2 emissions and helps to avoid an increase in the concentration of CO_2 in the atmosphere, contributing to the reduction of global warming.

The work is consolidated on a series of experimental research in the laboratory, where several anaerobic co-digestion recipes were calculated and tested for a series of types of organic waste used in the mixture, with the aim of characterizing the energy potential of the resulting biogas.

The investigated co-digestion recipes were established according to the nature and quantity of waste from industrial technological flows, so that the results of the experiments carried out can be used as input technological data for carrying out feasibility studies that provide a vision of the energy recovery potential specific to the addressed sectors in the food and agricultural industry.

The scientific objectives pursued in theoretical, applied and experimental research can be grouped into two main categories:

I. Theoretical research
1. Energy recovery of organic waste from the food industry and agriculture;
2. Biogas production through anaerobic digestion;
3. Constructive types of units for biogas production;

II. Applied and experimental research
4. Investigation of industrial biogas production plants in the Western part of Romania - on-site visits;
5. Investigation of wastewater with high organic load taken from industrial streams – determination of organic load;
6. Calculation and establishment of mixture networks of the investigated substances – calculation algorithms according to standards;
7. Investigation of laboratory-scale on biogas stationary mode production;
8. Investigation of laboratory scale on biogas continuous mode production;
9. Analysis and interpretation of experimental data.

2. BIOGAS PRODUCTION

Energy recovery from organic waste is strongly influenced by the active matter contained in the organic part of the waste, which through bio-chemical processes is converted into methane gas. In order to recover the maximum production potential of methane gas generated by specific bio-chemical reactions, the application of a fermentation/anaerobic digestion process is required.

The process of anaerobic digestion consists in the decomposition of organic matter through the microbiological activity of methanogenic bacteria, which develop in the absence of oxygen and in conditions of high temperature and humidity, found in several natural environments. This process can be reproduced in industrial technological installations, resulting in two final products: biogas and digestate [1,2].

Methanogenic bacteria consume the organic matter from the waste and change its molecular structure through metabolism, transforming the solid and water-soluble organic fraction into a gaseous fraction in the form of methane (CH_4), carbon dioxide (CO_2), small amounts of hydrogen sulphide (H_2S) and ammonia (NH_3). Developing in an anaerobic environment, the rate of multiplication of bacteria is slow, thus only a small part of the organic matter consumed is used for growth and multiplication, most of it being converted by metabolism into methane. In other words, anaerobic bacteria are living organisms that consume significant amounts of organic matter to survive. The biological process of converting solid organic matter into biogas represents the stabilization of organic waste [3,4,20,22].

The conversion of organic matter into biomethane by anaerobic fermentation takes place in four main stages [5,6,16,17]:

- Hydrolysis in which the decomposition of the organic fraction takes place and its passage into the liquid phase under the action of enzymes, which transform carbohydrates, fats and proteins into monosaccharides, fatty acids and amino acids.
- Acidification that takes place under the influence of the metabolism of specific bacteria, through which the liquid phase from the previous stage passes into acids saturated with short-chain carbohydrates, alcohols, hydrogen and carbon dioxide.
- Acetogenesis in which saturated acids and alcohols are transformed by acetogenetic bacteria into saturated volatile organic acids, acetic acid, hydrogen and carbon dioxide.
- Methanogenesis is the last phase that takes place under the action of specific methanogenic bacteria, which assimilate the compounds resulting from the previous phases, and which produce methane gas through metabolism.

Anaerobic fermentation takes place under specific conditions under the influence of bacteria in the phase of acetogenesis and methanogenesis. In other words, the organic fraction contained in waste from the food industry constitutes the "food" for bacteria that produce methane gas. Thus, we come to the conclusion that the higher the content of organic matter in organic waste, the more bacteria reproduce, which leads to an increase in the amount of biogas produced.

Biogas is a mixture of gases consisting mainly of methane CH_4, carbon dioxide CO_2, hydrogen sulphide H_2S and ammonia NH_3. Depending on the anaerobic digestion conditions, the type and nature of the organic matter, the weight of the biogas concentration is 50-85%vol CH_4, 50-15%vol CO_2, the amounts of H_2S and NH_3 being negligible below 1%. In addition to the production of methane gas, a significant amount of very nutrient-rich digestate/sludge results from the anaerobic fermentation process [4,22,23].

Digestate is organic matter processed by bacteria, stabilized in terms of organic and pathogenic load, which lends itself as fertilizer in agriculture. The organic waste used as raw material in the biogas production process has the generic name of co-substrates. The composition of the co-substrates has an important role in the sizing and design of a technological line for biogas production. Organic content, temperature, humidity and pH value are the control parameters for the reproduction, development and lifespan of bacteria.

Based on this aspect and economic considerations, Best Available Technology – BAT indicates two temperature ranges: 35-45˚C for mesophilic fermentation and 55-60˚C for thermophilic fermentation.

In industrial practice, a compromise is made between maximum biogas production and economic profitability. The most important parameters to be monitored in a biogas production process are:

- organic load (5-10 mass %),
- pH value (7.2–8.5),
- fermentation/digestion temperature (35-55°C or 55-60°C).

The technological process of biogas production depends on the nature of the organic waste, the available quantities and the mixing ratio between several co-substrates. Thus, for the correct sizing of a biogas production technological installation, an energetic characterization of the co-substrates is very important, based on which to establish an optimal mixture recipe. Anaerobic digestion of two or more types of co-substrates in mixture is called co-digestion.

The energy characterization of co-substrates refers to the specific yield in methane production generated by the amount of dry matter found in the nature of the substances from which the waste is formed.

The correct estimation of the specific production of methane requires a laboratory analysis, which highlights the organic load of the waste. To determine the organic load, each type of waste requires an individual analysis.

For the profitability/efficiency of a technological flow of biogas production and utilization, it is necessary to maintain a constant flow of biogas to the cogeneration unit (CHP) so that it operates continuously. The main factors influencing biogas production in an anaerobic digestion process are [7,8]:

a. The type/nature of the waste subject to the anaerobic digestion process;
b. Digestate concentration;
c. Digestion temperature;
d. The pH value of the digestate;
e. The presence of inhibitory toxic substances in organic waste;
f. Hydraulic retention time;
g. The organic loading capacity of the digester/bioreactor.

There are several types of technological processes for the production of biogas, which were mainly designed according to the nature of the organic waste generated; and according to the objectives to be achieved regarding the treatment of organic waste. The main objectives of a biogas production plant through anaerobic digestion are:

- Energy utilization (electrical and thermal);
- Mass reduction of organic substance VS contained in organic waste;
- Reduction of odors associated with waste;
- Treatment of waste water in accordance with environmental pollution standards;
- Concentration of nutrients in the form of a product that can be exploited;
- Reducing the pathogenic load associated with organic waste.

From design point of view, biogas production and utilization facilities are distinguished according to the type of digester. By digester or bioreactor is understood the space where the biological process of conversion of organic compounds under the action of microorganisms, and the release of fermentation products, takes place.

The configuration of a bioreactor is a complex process, which is based on engineering principles specific to each constructive type. The choice of the constructive type of bioreactor is closely related to the nature of the organic waste to be recovered/processed in the facility. Depending on the hydraulic retention time HRT of the digestate, digesters with high feed rate (HR - high rate) and low feed rate (LR - low rate) are distinguished. Thus, HR digesters reduce HRT from 20 days to 2-3 hours [9,10,11,16].

3. INVESTIGATION OF INDUSTRIAL FACILITIES FOR BIOGAS PRODUCTION

Three industrial biogas production stations Baia Mare, Seini and Arad were investigated; each having a different technological process applied depending on the type of organic waste used for energy. In this chapter, the approach and implementation of biogas production facilities were highlighted, starting from the resources available in the area.

The biogas production and valorization station from Baia Mare with an installed capacity of 350 kW electricity, Maramureș county uses the waste water and the sludge resulting from the tartar technological process from the treatment plant of the Baia Mare Municipality. From a technological point of view, the treatment plant works after a mechano-biological treatment process that involves advanced biological treatment of nitrogen and carbon, as well as chemical treatment of phosphorus, being designed for a capacity of 163,300 equivalent inhabitants (1450 l/s) [13] .

In the mechano-biological treatment process, a sludge treatment step was introduced with the energy recovery of the biogas resulting from anaerobic digestion. The investment value was 43 million lei (without VAT), being financed from the EU cohesion fund through the Environmental Sectoral Operational Program, in order to fit the emissary related to the waste water treatment station, within the limits imposed by the EU water pollution rules sensitive surface.

The technical solution provided for the use of 4 bioreactors was chosen due to the variation of the water flow entering the treatment plant. The domestic water collection system of the Municipality of Baia Mare takes both the waste water generated by domestic and industrial consumers, as well as the meteoric water, through the same sewage system. Thus, during heavy rainfall, the flow of water taken into the station is very high and very diluted in terms of its organic load. With 4 bioreactors available, these fluctuating high flow rates that may occur in operation can also be taken over.

The operation mode of the biogas station at the Baia Mare treatment plant was designed as a sludge treatment step, the energy recovery of the biogas as electricity and in the form of heat being used in the technological process of the operation of the bioreactors, and not for the purpose its commercialization. For these reasons, energy in the form of heat takes precedence in the energy recovery of biogas, since pathogen stabilization and reduction of the organic load of the sewage sludge are priorities [13].

The biogas production and valorization station from Seini with an installed capacity of 470 kW electricity, Maramureș county uses the manure generated by the animal husbandry activity in the area. The locality of Seini is included in the list of localities vulnerable to nutrients, the amounts of waste coming from agriculture and their impact on the environment, justifying the need to implement measures aimed at improving the social and environmental factors of the locality.

The Ministry of Environment and Climate Change, by signing and implementing the "Integrated Control of Nutrient Pollution" project financed by the GEF/World Bank, the International Bank for Reconstruction and Development and co-financed by the Government of Romania, committed to implement a plan of measures aimed at reducing nutrient pollution nutrients from agriculture. Thus, for the implementation of this Directive, Romania designated in two distinct phases a number of 32 areas vulnerable to nutrients, which represent 60% of the total area of the territory, including 1963 municipalities [12].

Seini being one of the cities designated as areas vulnerable to nitrate pollution, the locality is eligible for the implementation of the investment program to carry out the construction works necessary for the collection, temporary storage and use as organic fertilizer of manure in accordance with the provisions of the "Property Code agricultural practices for the protection of waters against nitrate pollution from agricultural activities", approved by Order no. 1182/22.11.2005 of the M.M.G.A., whose provisions are mandatory in areas declared vulnerable to nitrate pollution.

The main objective of the project is to create a facility that demonstrates the feasibility of treating manure for the purpose of producing electricity and heat, through cogeneration, using the resulting biogas as fuel.

Subsidiarily, the implementation of the project will promote a new institutional concept regarding the management of manure at the level of a territorial administrative unit (UAT) by partially taking over the responsibilities regarding the management of these categories of waste by the public authority.

The maximum installed treatment capacity is 54.79 tons/day mixed organic waste, of which 49.31 tons/day animal manure and 5.48 tons/day plant silage. Based on these quantities, an annual production of 1,527,445 m3/year is estimated, with an indicative composition of 60% CH_4, 39% CO_2 and 1% O_2, CO and H_2S. From the biogas obtained, an electricity production of about 2,967,030 kWh/year is estimated.

Subsidiarily, together with the production of electricity, a thermal energy production of approx. 3,280,564 kW, of which 970,564 kW will be used in the biogas production process (bioreactor heating) and 2,310,000 kW for the fertilizer production facility (drying the digestate) [12].

The biogas production and valorization station from Arad with an installed capacity of 988 kW electricity, Arad County uses biomass in the amount of 48.03 t/day (17,530 t/year), animal manure at the start of the technological process and periodically for fermentation maintenance, and water from boreholes to maintain the optimal concentration of solid matter in the anaerobic fermentation process.

The implementation of the project was based on European promotion legislation in the field, transposed into Romanian legislation through the requirements formulated by the objectives of the Sectoral Operational Program Increasing Economic Competitiveness 2007-2013, of Priority Axis 4 - "Increasing energy efficiency and security of supply, in the context of combating climate change". As a constructive variant, the technological flow implemented in the biogas production facility from Arad opted for the use of a contact bioreactor with two-stage fermentation stabilization.

The advantage of this technological process is that it can process heterogeneous organic waste with different degrees of decomposition. Thus, in the mixture recipe of the co-substrates, organic waste that has cellulose in its composition that requires a long time for decomposition can be integrated, such as in our case the biomass from agriculture. In bioreactors it is a mixture formed from the raw material that enters the process, in this case biomass in the form of corn silage (48.0274 t/day). Feeding of substrates occurs according to a recipe determined by the type and amount of available co-substrates.

Under the conditions of quality and availability of the co-substrates used in the process, the biogas production plant can deliver for sale 822.23 kWel and 755.8 kWth, which in percentages relative to the total energy contained in the biogas is 83.23% electrical energy and 76.35% thermal energy [15].

The daily amount of digestate generated by the biogas production process is 34.08 t/day. The digestate is used in agriculture as fertilizer/fertilizer, it being transported on agricultural land surfaces for 8 months of the year with an average of 52t/day.

4. EXPERIMENTS IN THE LABORATORY

The experimental part carried out in this research work was carried out in the Laboratory of Fuel Analysis Ecological Investigations and Dispersion of Pollutants of the Faculty of Mechanics UPT and the Laboratory of Microbial and Industrial Biotechnologies at the University of Agricultural Sciences and Veterinary Medicine of Banat - USAMVB Timisoara.

The experimental research method was applied on the laboratory stand, using two types of "state-of-the-art" facilities to investigate the potential for biogas production through anaerobic digestion of biodegradable organic substances, both laboratory facilities being provided by Bioprocess Control Sweden AB (https://bioprocesscontrol.com/).

In the USAMVB laboratory, the biogas production facility was used in stationary mode on the Automatic Methane Potential Test System II (AMPTS® II) experimental stand, which investigated the potential for producing methane gas (Biogas Methane Potential - BMP) through anaerobic digestion of waste organic. This type of installation provides information related to the specific production of biogas, and the capacity to convert organic matter into methane gas through anaerobic digestion in laboratory conditions, basic information regarding the energy recovery of organic waste. . Figure 39 shows the experimental stand used in the experimental campaigns carried out in this research for the production of biogas in stationary mode.

In the UPT laboratory, the in-flow biogas production facility with continuous feed was used on the Bioreactor Simulator - BRS experimental stand, through which the continuous production of biogas through anaerobic digestion was investigated, being a faithful copy on a laboratory scale, of the operating mode of an industrial biogas production station. Specifically, this type of installation provides information on the operating parameters of a biogas plant, such as the daily organic loading rate (organic loading rate - OLR) and the hydraulic retention time (HRT). Figure 43 shows the experimental stand used in the experimental campaigns carried out in this research for the production of biogas in flow with continuous feeding.

Two generating sources of organic waste were identified and analyzed, where it lends itself to the implementation of biogas energy recovery facilities; one being the livestock farm from Bacova, Timiș county and the other the Curtici Agro Industrial Combine, Arad county.

In the Bacova livestock farm case study, the possibility of energy utilization of pig manure was investigated. From a zootechnical aspect, it is a breeding farm, with a capacity of 10,000 adults and 267,800 ÷ 272,950 youth, of which 4,277 pigs are delivered annually to the slaughterhouse. In the analyzed case study, the energetic characterization of pig manure does not require the use of high precision values, as they are used at the level of a feasibility study, with the aim of highlighting the economic return and the investment payback time in case of implementation a biogas production and energy utilization facility. For this purpose, specialized literature was used that indicates the characteristic values of biogas production specific to different types of organic substances [47].

These values were used as input data for the specific biogas production calculation and simulation program BioGC developed by WFG Schwäbisch Hall Münzstraße 1 D-74523 Schwäbisch Hall Germany. The advantage of using such calculation programs consists in the fact that the information is obtained very quickly, presents in a concentrated way information related to the sizing of the main equipment, performs economic calculations that provide information about the operating costs and energy consumption of a production facility biogas. The use of calculation programs of this kind is recommended in the early stages of design such as solution studies, pre-feasibility studies or feasibility studies, where the emphasis is on identifying the optimal technical solution to be implemented, which supports the economic feasibility of the investment. The simulation calculation was carried out for mono-fermentation, that is, it involves the use of only one type of substrate, which in our case is represented by pig manure.

In a case study from the Curtici Agro Industrial Complex (CAI Curtici), Macea livestock farm, Arad county, the possibility of energy recovery (BMP) of collected pig manure, cattle manure and slaughterhouse wastewater was investigated. From a zootechnical aspect, the farm practices an integrated system of agriculture and animal husbandry, applying an economy very close to the circular economy. CAI Curtici practices and manages agriculture, animal breeding, animal slaughtering, meat and milk processing, manufacturing agri-food products, sausages and dairy products, as well as selling and marketing them in its own stores.

The experimental campaign was carried out in four main phases aimed at (i) collection and preparation of samples, (ii) calculation and establishment of process parameters, (iii) preparation and commissioning of the experimental stand and (iv) collection and analysis of experimental data.

The sample preparation phase involves taking samples on-site and characterizing the organic matter by determining the content of dry substance TS and volatile substance VS. The collection of samples was carried out according to the protocols indicated in the German standard VDI 4630, the samples being taken from the technological flow before entering the treatment stages, in order to keep the biological characteristics intact, and not to contaminate the samples.

The calculation method used to establish the process parameters was carried out according to the protocols indicated in the German standard VDI 4630, where the quantities and mixing ratios that must be met, for the experimental results to be correct, are specified. Thus, calculation sheets were drawn up for each analyzed sample/recipe, in tabular form, based on the laboratory protocols specific to the laboratory activity for conducting experimental campaigns to investigate organic waste for the production of biogas through anaerobic digestion.

The preparation and commissioning of the AMPTS II experimental stand consisted in the preparation and loading of the 15 bioreactors with co-substrates for 4 types of recipes. Each laboratory sample was run in triplicate, meaning 3 bioreactors are loaded with the same recipe.

After the completion of these phases, the experimental stand is ready for commissioning, following the interconnection phases of the bioreactors with the biogas treatment module where CO2 retention takes place; with the gas flow measurement unit, data recording and processing; respectively with the laptop that ensures the control and monitoring of the stand.

The acquisition and recording of experimental data was carried out for a duration of 21 days, during which the stand operated 0-24. Based on the experimentally determined values and the specific calculation formula for determining the BMP, a biogas production potential value was calculated for each experimentally investigated recipe. The BMP calculations were performed using the resulting value by performing an arithmetic average of the experimental results recorded for each set of bioreactors.

By carrying out the experimental campaign for the production of biogas in stationary mode on the laboratory stand, the way of practical application of the laboratory procedures was highlighted; the investigated co-substrates were characterized in terms of dry substance content TS and organic substance VS; a version of calculation sheets in tabular form for setting the parameters of an experiment was presented; the BMP bio-methane potential and the specific methane production for the investigated organic matter were experimentally determined.

5. CONCLUSIONS AND PERSONAL CONTRIBUTIONS

The applied and experimental scientific research, carried out during the doctoral studies, is based on the energy recovery of biogas produced by anaerobic digestion, using waste from the food industry and agriculture.

In this demand, waste water with a high organic load, generated in the manufacturing process of finished food products from the food industry, was investigated experimentally in the laboratory, on the one hand; and respectively the waste water from animal husbandry/agriculture farms. For this purpose, the pursued objectives were established, presented in subchapter 1.4. All pre-set objectives were fully achieved, through:

- Investigation of 3 biogas production facilities on an industrial scale;
- The approach of two case studies;
- Realization of two experimental campaigns to investigate the production of biogas on a laboratory scale on an experimental stand, in the Laboratory of Fuel Analysis Ecological Investigations and Dispersion of NOx - UPT; in the Laboratory of Microbial and Industrial Biotechnologies – USAMVB.

The investigation of biogas production facilities on an industrial scale was carried out with the aim of understanding the way of functioning and the way of operating the real technological processes, which strengthened the theoretical part assimilated in the first stage of research regarding the current state of knowledge. Each investigated facility used a different biogas production technology, adapted to the nature of the organic matter found in the co-substrates used in the process. In this regard, the following installations were investigated:

1. The biogas production facility at the wastewater treatment plant of Baia Mare Municipality, Maramureș County – uses sewage sludge as a substrate;
2. The biogas production facility in Seini City, Maramureș County - uses manure as a substrate;
3. The biogas production facility in Arad, Arad County – uses a mixture of co-substrates from agriculture

The case studies address:

1. Bacova pig farm, Timiș county - the investigation of biogas production was carried out through a dedicated computer program, using pig manure generated by the operation process of the zootechnical pig breeding farm;
2. Curtici Agro Industrial Combine - Macea farm, Arad county - the investigation of biogas production was carried out on an experimental stand in a stationary regime on a laboratory stand, using the organic waste resulting from the specific activities of meat processing, cattle manure and pig manure available on the agro-industrial platform.

To carry out the experimental research, two types of state-of-the-art experimental stands, manufactured by Bioprocesscontrol, Sweden, were made, as follows:

- In the USAMVB laboratory, the biogas production facility was used in stationary mode on the Automatic Methane Potential Test System II (AMPTS® II) experimental stand, through which the potential for methane gas production through anaerobic digestion of organic waste was investigated - for the case study from the Macea farm.

- In the UPT laboratory, the in-flow biogas production facility with continuous feed was used on the Bioreactor Simulation - BRS experimental stand, through which the method of continuous production of biogas through anaerobic digestion was investigated, being a faithful copy on a laboratory scale, of the method of operation of an industrial biogas production station - for the activity of scientific publication in specialized journals.

The established objectives deal with the most topical issues regarding both the energy utilization of biogas produced by anaerobic digestion; as well as the treatment of waste from the food industry and agriculture, in order to reduce the impact of pollution on the environment. In this sense, waste water with a high organic load, generated in the production process of finished food products from the food industry, was targeted, on the one hand; and respectively the waste from animal husbandry/agriculture farms.

As a result of the theoretical, applied and experimental research carried out during the doctoral studies on the energy recovery of waste from the agricultural and food industry, the following conclusions are drawn:

- The finished products of the food industry are characterized by a high value of the ratio between the amount of specific waste and the finished product, it being very difficult to decrease the amount of specific waste while keeping the quality of the product intact.

- The generation of waste from the food industry is inevitable, their use and storage being made difficult by several factors such as: biological instability, pathogenic potential, biological degradation generated by high enzymatic activity (putrefaction), as well as high water content. The stabilization, treatment and storage of organic waste raise special problems both in the field of environmental protection and in that of sustainable development.

- Waste from the agricultural and food industry has a high organic load and can be energetically exploited very efficiently by using technologies for the production and utilization of biogas through anaerobic digestion.

- The "Waste-to-Energy" concept uses organic waste as an alternative source of energy, by exploiting its potential to produce biogas; and provide feasible solutions for highly efficient industrial-scale implementation.

- Energy recovery processes from organic waste are based on the use of biogas produced following the decomposition of the organic fraction under the action of specific methanogenic bacteria (which produce methane through metabolic activity).

- The process of decomposition of the organic fraction under the action of bacteria is known as fermentation or digestion. Depending on the environment in which fermentation takes place, two main types of fermentation are distinguished: aerobic when the decomposition process takes place in the presence of oxygen; and anaerobic when the decomposition process takes place in the absence of oxygen.

- The anaerobic fermentation process is considered optimal from the point of view of the energy produced/consumed ratio; allows the treatment of a wide range of organic waste; it can be fully automated and produces a constant flow of biogas.

- The fact that the anaerobic fermentation process can be fully automated, so that it produces a constant flow of biogas, has led to the development of several biogas energy recovery technologies applied on an industrial scale. In addition, the residues resulting from the anaerobic fermentation process can be used as fertilizer in agriculture, thus closing the life cycle of products in the food industry.

- From a constructive point of view, biogas production and utilization facilities are distinguished according to the type of digester. By digester or bioreactor is meant the space where the biological process of conversion of organic compounds is carried out under the action of microorganisms, and the release of fermentation products in the form of digestate and biogas.

- Biogas is a gas mixture consisting mainly of methane CH4, carbon dioxide CO2, hydrogen sulphide H2S and ammonia NH3. Depending on the anaerobic digestion conditions, the type and nature of the organic matter, the weight of the biogas concentration is 50-85%vol CH4, 50-15%vol CO2, the amounts of H2S and NH3 being negligible below 1%.

- The digestate is the organic matter processed by bacteria, stabilized from the point of view of the organic and pathogenic load, which lends itself as fertilizer in agriculture, being rich in nutrients.

- The configuration of a bioreactor is a complex process, which is based on engineering principles specific to each constructive type. The choice of the constructive type of bioreactor is closely related to the nature of the organic waste to be recovered/processed in the facility.

- To determine the organic load, each type of waste requires an individual analysis, which involves the determination of the dry substance TS and the volatile substance VS.

- BMP biomethane production potential indicates the methane gas production capacity of a waste, relative to the VS organic substance it contains.

- Sizing and choosing the type of bioreactor for the energy recovery through biogas production of various types of organic waste is based on the methane production capacity of the BMP.

- The high BMP value is not influenced by the amount of organic matter contained in the co-substrates, but by the nature and form in which the organic matter is found in the co-substrates.

- High BMP value indicates that the organic matter in the substrate is found in a form easily assimilated by bacteria, and provides information about the quality of the organic matter contained in the substrate. This aspect is very important in determining and establishing the optimal fermentation recipe for a biogas production process on an industrial scale.

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