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EVALUATION OF BIOGAS QUALITY FROM HOME BIOGAS PLANTS INSTALLED IN CENTRAL VIETNAM

DIPLOMA THESIS

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Statement

I declare that I have developed this thesis on the topic "Evaluation of biogas quality from home biogas plants installed in the Central Vietnam" by myself and independently and I have quoted only from the sources listed in the bibliography. These data I have added by information which were the outcome of my own research.

Prague, 26. 4. 2013 ....

Pavel Štěpánek

Acknowledgement

In this way, I would like to thank the supervisor of his work Mr. doc. Ing. Jan Banout Ph.D., for guidance and important advice during the development of this work and also I would like to thank the Czech University of Life Sciences for financial support during the data collection. I would also like to thank for cooperation and participation on data collection the Department of Foreign Affairs in Hue and the DEKONTA a.s. for borrowing the device.

Special thanks belong to my family, girlfriend and friends for their continuous support and understanding.

Abstrakt

Biomasa respektive bioplyn tvoří podstatnou složku energetických zdrojů využívaných v podmínkách Vietnamského venkova díky své dostupnosti a relativně nízkým pořizovacím nákladům.

Tato práce je zaměřena na kvalitu a kvantitu vyprodukovaného bioplynu z domácích bioplynových stanic. V práci je uveden popis fermentačního procesu, jehož výsledným produktem je bioplyn. Dále jsou v práci popsány typy domácích fermentorů, které jsou používány v rozvojových zemích v tropickém a subtropickém pásu. Je zde popsán způsob hodnocení kvality bioplynu a aspekty, které mohou výslednou kvalitu bioplynu ovlivnit. Jsou zde uvedeny druhy substrátu, který je používán k výrobě bioplynu.

Závěrem práce jsou uvedena doporučení, která mohou napomoci ke zvýšení objemu metanu v bioplynu a tím i ke zlepšení jeho výsledné kvality.

Klíčová slova

Složení bioplynu, využití bioplynu, domácí fermentory, rozvojové země, Vietnam

Abstract

Biomass or biogas, they are an essential component of the energy sources used in the conditions of the Vietnamese countryside due to its availability and relatively low investment costs.

This thesis is focused on the quality and quantity of biogas produced from home biogas plants installed in Central Vietnam. In this thesis is shown the description of the fermentation process, its final product is biogas. The thesis describes the types of home biogas digesters, which are used in developing countries in tropics and subtropics. There is described a method of assessing the quality of biogas and aspects that can affect the final quality of biogas. There are shown the types of substrate, which is used to biogas production.

In conclusion of the work there are indicated recommendations that may could help to increase the volume of methane in the biogas and thus to prove the final biogas quality.

Keywords

Biogas composition, biogas use, household (home) digesters, developing countries, Vietnam

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Preface

Conventional energy sources are usually based on oil, coal and natural gas. At present, there globally exist thousands of oil platforms which provide oil for approx. 50 000 kWh of energy per year. Every year, over 10 billion USD are spent in drilling and searching for new oil fields to secure the oil supply. The main problem of oil fossil fuels is their exhaustibility. The quantity of oil is unfortunately limited, just like any other fossil fuel resource. How will future generations produce the energy when all the oil resources are totally exhausted? (Schulz & Eder, 2004)

The fossil fuels reserves are continuously decreasing and because of that their prices are growing rapidly. The increase in the fossil fuel prices forces us to thing about other energy sources – alternative energy sources. It includes thinking about and searching for new technologies. In the last few years, many new ideas and technologies have been found to produce energy from renewable energy resources more effectively than ever before and to reuse all of its potential as well. In fact, fossil fuels and renewable energy prices as well as the social and environmental costs are heading in the opposite directions, and new economic and policy mechanisms are needed to support the widespread expansion of and sustainable markets for the renewable energy systems.

Because of these developments, market opportunities now exist to both innovate and take advantage of the emerging markets to promote renewable energy technologies, with additional government and population support. It is becoming clear that future growth in the energy sector will be primarily in the new field of renewable energy and, to some extent, also natural gas-based systems, but not the conventional oil and coal sources.

The potential of renewable energy sources is enormous, as compared with the world energy consumption. Renewable energy sources include biomass, wind, solar, hydropower and geothermal energy. These sources can provide sustainable energy services.

In the past 30 years, solar and wind power systems have experienced rapid sales growth. The capital costs and costs of generated electricity have decreased while the technologies have improved their performance characteristics.

Not only solar and wind power systems have experienced rapid growth, but also the systems producing energy from biomass. New ideas and new technologies were put together and now it is possible to use for example even waste water, sewage sludge or agricultural products waste as the initial substrate. This progress has been achieved especially in the developed part of the world, but also in the developing countries, where biomass was used as one of the main energy sources many years before, especially in the form of wood used for cooking. (Herzog et. al, 2011)

Nowadays there are many projects being realized in the developing countries which should help local people to obtain energy for cooking, lighting and heating. Many of them were based on the use of biogas plants. These projects have been realized in Kenya, India, China, Nepal, Vietnam, etc.

1. Introduction

1.1 World energy supply

At present, most of energy is produced by burning oil and other fossil fuels. Small percentage is produced by nuclear power plants. The energy production from renewable energy sources is still insignificant. But it will change thanks to the increase in the prices of oil and other fossil fuels.

Based on their specific climatic conditions and geographical locations, countries are using different technologies to produce the energy. (Deublein & Steinhauser, 2008)

In the past, until the end of 19^{th} century, wood was the only primary energy source used for cooking and heating. Later it was replaced by hard coal for the next 75 years. Then, the era of using petroleum and natural gas began. At that time, the developed world started experimenting with nuclear power technologies, but these were never fully accepted because of the issue of radioactive waste storage and the risk of explosion of the reactor. (Deublein & Steinhauser, 2008)

Primary energy sources

Primary energy sources include oil, natural gas, coal, etc. All of these resources and products are further processed to produce energy. Of course, renewable energy sources are classified as primary energy sources, as well. These include water, sun, wind, geothermal heat and biomass.

Secondary energy sources

Secondary energy sources are defined as products that have been produced by transforming the primary energy carriers into higher quality products by applying processes such as refining, fermentation, mechanical treatment, or burning in power stations. They include, for example, briquettes, coke, petrol, fuel oil, biogas etc.

End-point energy

The secondary energy sources are converted into end-point energy. This kind of energy is the energy used by final consumers. They are available in the form of diesel, petrol, wood pellets and electricity. (Deublein & Steinhauser, 2008)

Renewable energy and renewable energy sources

Renewable energy is a kind of energy obtainable from natural resources such as sunlight, wind, rain, water flows, waves and geothermal heat, but the most important fact is that it is a non-exhaustible resource of energy.

To maintain the current development and quality of life it is now necessary to find out and use new sources of energy. One prerequisite for sustainable development are renewable energy sources. One of the main reasons for our need to find alternative sources of energy is the wasteful management of the natural resources and energy. Nowadays, non-renewable natural resources are very easily accessible. Thanks to modern technologies, they are also much cheaper than energy production from renewable sources. Because of this fact, renewable resources still come second in the production of energy in the developed countries. (In the developing countries, the situation is quite the opposite: one of the primary sources of energy is biomass - wood.) Overall, global infrastructure is based on non-renewable resources and on conventional fuels.

Most of the renewable energy sources have its origin in the solar radiation that reaches the Earth, except for geothermal energy, which is generated in the Earth's core, and also except for tidal power, which results from the gravitational interaction between the Earth and the Moon. There is a huge amount of sunlight on the Earth. Iit is said that in one hour the Earth’s surface is hit by such a big amount of solar energy that it would be able to cover the global energy consumption for one year. The potential of renewable energy sources is limited. For example, if we used all of the arable land, forests and other agricultural land only to produce energy, it would be possible to generate as much as 700 PJ, which is more than half of the total energy consumption. However, we need the land to grow products for food and feeding animals. These are also converted into energy, but the energy statistics do not show it. The same holds true for wood: all of the world's supply of wood cannot be burned just to produce energy as this would cause many industries that are dependent on wood to collapse. Another reason why we cannot burn all the wood are the protecting restrictions from the government (national parks, protected areas and biodiversity protection). The real potential of biomass (wood) is estimated at 276 PJ, which is approximately 40% of the theoretical potential of biomass. Similar restrictions are influencing the wind, water and geothermal energy resources. To install a device to produce energy from these resources, we need to find a location with suitable natural conditions (e.g. sufficient wind speed). It is also necessary to find a place to install the technology and take into account the interests of other subjects (such as disapproval of local population). Another influencing factor is the economy. If a wind turbine was installed on a spot where the wind does not blow, it would soon fail. The only source of energy with almost unlimited potential is the solar energy. The minimum use of this source in these days, is caused mainly by the competition of conventional energy sources. The sun is here for free and is not taxable, but the produced energy is not for free at all. The purchase and installation of a solar power system is still quite expensive. Solar power systems have a limited lifetime and the cost of acquisition and maintenance are reflected in the prices of the energy produced. Currently, however, the prices of energy from conventional sources continue to rise while the prices of energy from renewable sources are declining. If this trend continues, we can expect further significant development of renewable energy sources. The potential of renewable energy is great, but the fundamental problem is the efficiency of energy conversion. Especially in the case of biomass, the efficiency is very low (combustion of biomass for energy production).

Nongovernmental organizations have been trying to support the development of renewable energy sources for a long time. Renewable resources can substantially reduce not only CO^2 emissions but can also decrease other emissions from the energy sector. It might also offer greater reliability of energy supply, diversification and lower our dependence on imports. Developing a processing base for the potentially huge international market can help revitalize some of the declining industrial areas in the world. Employment potential of renewable energy can be five times higher than that of fossil fuels. It can boost local employment and play an important role in the regional development by providing valuable and sustainable source of income for rural areas. Renewable resources can also be advantageous in enhancing peripheral distribution networks.

However, it is necessary to point out that the facilities that use the renewable energy resources must be installed sensibly. The current focus on cost reduction and cost effective solutions for renewable energy can lead to many conflicts, particularly in the sensitive areas of the environment. For example, there are many concerns about the visual impact of wind farms in the picturesque landscape sceneries. There are also concerns about the environmental impact of hydropower and the effects of monoculture energy crops on biodiversity. Insensitive installations and development of renewable sources could be environmentally harmful, for example huge hydro power plants or tidal energy plants. Large scale monoculture biomass crops and some geothermal stations can cause damages to the local environment. To obtain broad public support it is extremely important to involve local people in the planning, development, and encouraging of local investment.

1.2 Biomass

Biomass is a term that is used to describe all organic substances of plant origin (including algae), trees, plants and crops that collect and store solar energy through photosynthesis. Energy from biomass is called bio-energy. This energy is converted into useful forms, such as heat, electricity and liquid fuels.

Biomass comes from plants called energy crops or from residues produced in the processing of crops for food or other products, such as pulp and paper, or waste generated in timber industry. It is extracted from biomass residues, building and construction materials (wood), pure fractions of municipal solid waste (MSW), and fixed pure fractions of wastewater. Furthermore, it comes as a fraction of stable liquid waste (faeces, manure), plant waste and residues from agricultural production (straw, hay, silage). (Malaťák & Vaculík, 2008)

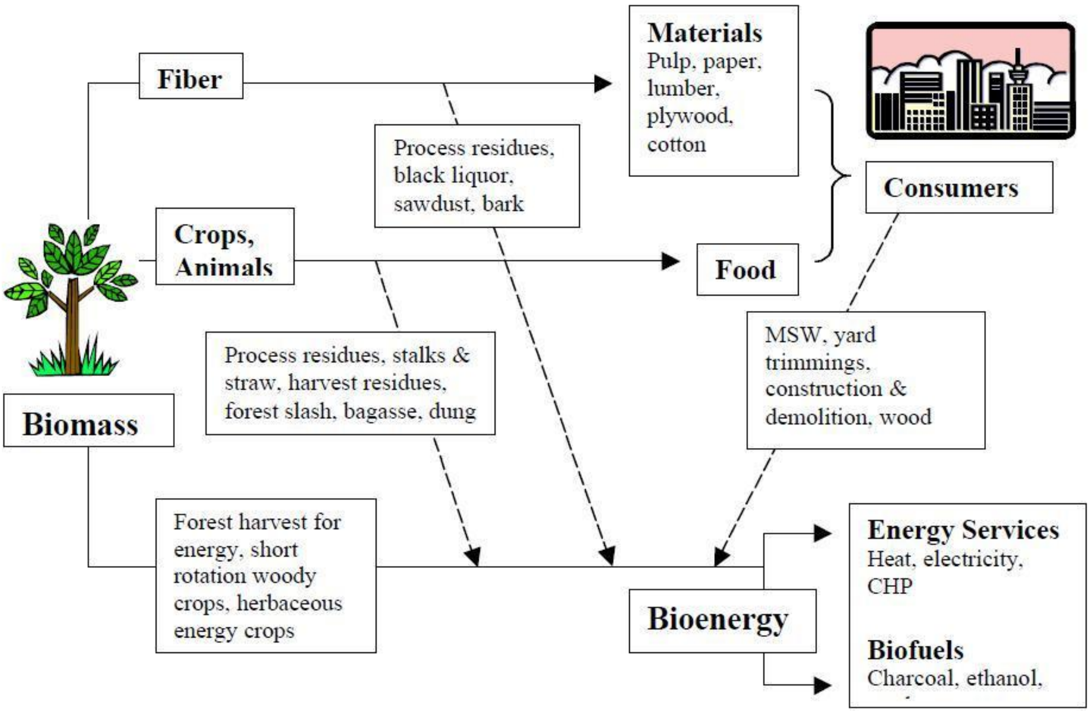

Fig. 1.1: Biomass and bio-energy flow chart *Source: Overend, 2000*

Last century witnessed an improvement in the technologies for extraction and processing of fossil fuels, such as coal, oil and natural gas, therefore bio-energy started to be widely used. To this day, wood is the number one source for bio-energy production, particularly in the developing countries, where it is used primarily for non-commercial purposes. In these countries, biomass provides about a third of the total energy production in the poorest countries, which account for as much as 90% of the total energy. More than two billion people today cook by direct combustion of biomass (wood). (Savita, 2008)

Biomass is usually not recognized and regarded as a modern source of energy because of its widespread use in the developing countries. Direct combustion of biomass fuels is called the “poor man's oil”. Biomass is the lowest rung of the ladder of preferred energy sources with gas and electricity occupying the first place in this chart. (Malaťák & Vaculík, 2008)

Energy from biomass has the potential to expand and be produced all around the world being effectively transferred into more cost-competitive and usable forms, such as gas, liquid or electricity. (Herzog et. al, 2011)

It is assumed that modernized biomass energy will play an important role in the future global energy supply. It is not so much because of the theory, which says that the world will run out of the oil, natural gas and coal reserves, but rather it is because of the threat of global climate change, which is caused mainly by fossil fuels burning.

Biomass fuels are used in the developing countries because they are available at very low cost, or because many people are not able to afford any other type of fuel. As their income grows, people tend to move from biomass fuels to other forms of fuel, especially to natural gas and coal. (Andert et. al, 2006)

Today, the technical potential of biomass energy is estimated to be higher than the current world energy consumption. If the modernization and changes in agriculture in some parts of the world allowed several billion hectares to be allocated for biomass production, it would be able to meet the world's energy consumption needs for the next century. This area would consist of land which is not productively used and surplus agricultural land. (Andert et. al, 2006)

A study by the Intergovernmental Panel on Climate Change (IPCC) examined five options for energy supply to the growing global demand for energy services in the 21 century. In all scenarios, energy from biomass constitutes a significant proportion, helping to meet the emission standard and targets to reduce the greenhouse gas emissions, particularly CO_2. From 1990 to 2100 the cumulative CO_2 emissions should be reduced to less than 500,000 tons of carbon. The results show that in 2050, biomass energy could satisfy approximately one third of the global energy demand. In the developing countries, it could be as much as half of the total energy demand. (Herzog et. al, 2011)

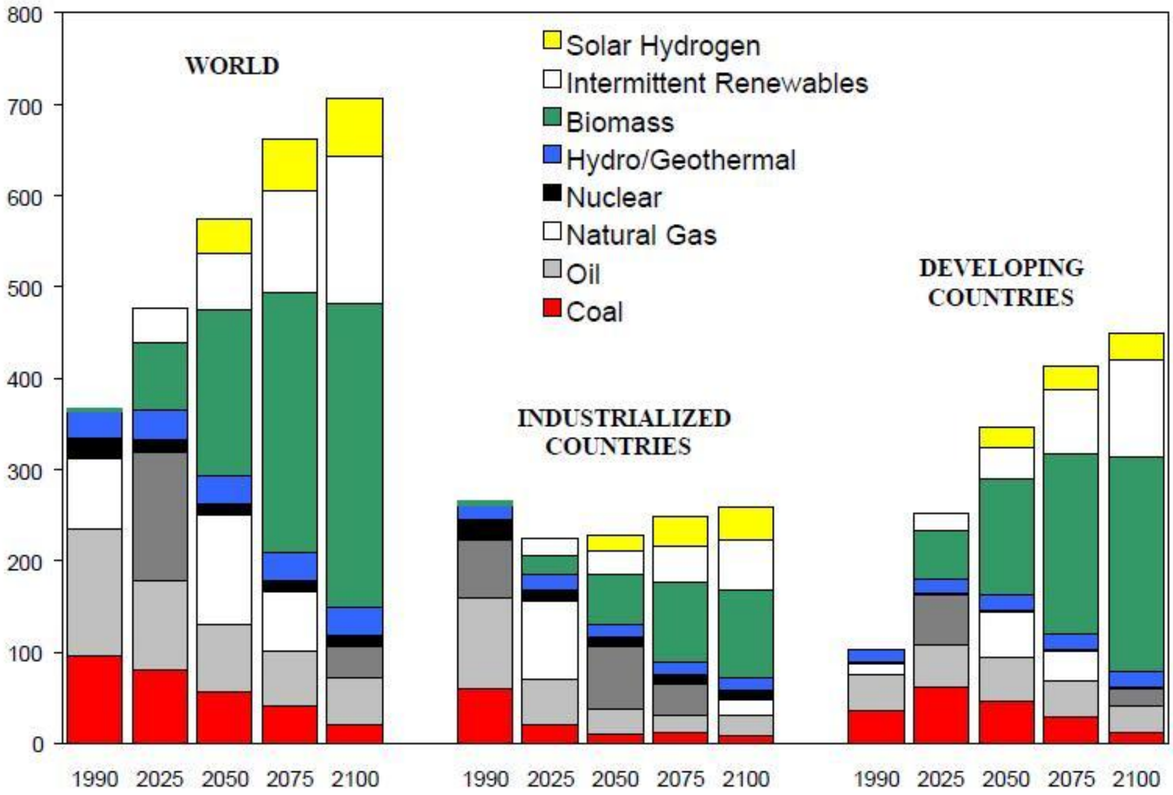

Fig. 1.2: Primary commercial energy use by source for the biomass-intensive variant of the IPCC model *Source: Sivan, 2000*

Such a proportion of biomass to world energy supply could help solve the global threat of climate change, but also remains a concern, due to its unforeseen environmental and socio-economic impacts. These impacts include the depletion of soil nutrients from the soil, due to the removal of agricultural residues, leaching chemicals, which are used for the intensive cultivation of certain plants (fertilizers), or loss of biological diversity, linked to the transformation of land into sections for energy crops growing. (Herzog et. al, 2011)

Significant future role of biomass in the energy supply can be explained in several ways.

a) Fuels from biomass can cover the energy consumption using the existing infrastructure for energy supply, unlike solar and wind energy, whose distribution is more difficult and not as stable.
b) Great energy resource potential.

c) The developing countries recorded the ever-growing demand for energy in the context of population growth and rising living standards. (Deublein & Steinhauser, 2008)

Biomass energy conversion technologies and applications

a) Combustion

The most common technique for converting biomass into electricity and heat is direct combustion. Recently, the development of combustion technologies has allowed more efficient use of the energy potential of biomass. Today, fuel from biomass is burned in automated devices in standardized forms such as briquettes and pellets and the output gas is catalytically cleaned, leading to a reduction of CO_2 emissions. Compared with biomass burning in open fireplaces, this technology is up to 70% more efficient. The costs for the installation of this technology are dependent on the choice of turbines, boilers, and the availability of raw materials. Studies have shown that the use of biomass as a supplementary source of energy during combustion, can replace up to 15% of the fossil fuels. Efficiency and operation of the device is not affected. (Herzog et. al, 2011)

b) Gasification

The technology uses a thermo-chemical biomass gasification process at very high temperatures to produce a flammable gas. Biomass is burned without enough air (that means it is not full combustion), but with an amount of air that is sufficient for the conversion of biomass into gas. The produced gas consists primarily of carbon monoxide, hydrogen, carbon dioxide and nitrogen. Calorific value of the gas is 10 - 15% of the calorific value of natural gas. The manufacture and calorific value of the gas is dependent on the technical features of the gasification device (size, texture, moisture of biomass). After a few modifications it is possible to use the produced gas for cooking or heating or to use it in secondary conversion devices such as internal combustion engines (in the second World War, trucks running on wood gas were used), gas turbines that produce electricity or to drive working shafts.

After the first oil crisis in 1973, there was an expansion of the gasification technology in combination with an internal combustion engine for electricity generation, especially in poor developing areas. Most of these projects have ended unsuccessfully, because of the technical difficulties resulting from the formation of tars and oils produced within biomass gasification. For most devices, which were installed, tar condensed in the downstream equipment and caused problems on the operating system. This fact largely contributed to the abandonment of that technology. Research into new technologies for biomass gasification continues. A new device has been recently invented that cleans and eliminates the smoke responsible to the development of tar and other system problems. Unfortunately, this technology is still more expensive than the technologies for oil, coal and natural gas processing. This is the biggest obstacle to the commercialization of the Bio-Power technology. For commercial purposes, modified combustion engines (mostly, diesel engines) are available, where it is possible to replace 70-80% of the current fuel by the gas from biomass. However, they have little success, due to the high cost of their operation and maintenance. These engines are mainly used in areas where it is not possible to use the natural gas or electricity, mainly for the purpose of heating.

c) Liquid bio-fuels

Bio-fuels are produced by processes that involve the conversion of biomass into multiple forms of energy for further use. In particular, the conversion of solid biomass into liquid, which has the potential to replace the existing fuels based on petroleum that are used primarily for transportation. This theory is difficult to apply in practice, because for bio-fuel to be able to be burned in internal combustion engines of cars it needs to have a similar hydrocarbon structure like the fuel-based petroleum. These products include soybeans, palm oil, seed oil and canola oil. After some treatment, these products can be used as a partial replacement of petroleum fuels. (Andert et. al, 2006)

In Europe and the USA, this fuel is known as biodiesel. Another bio-fuel made from biomass is a class of synthesized hydrocarbons, so called Fischer-Topsch liquids (FT liquids). In this process, hydrocarbon fuels are synthesized, for example, kerosene or LPG from carbon monoxide, hydrogen and iron. These fuels can be used as a sulphur-free diesel fuel. They can also be blended into conventional diesel in order to reduce exhaust emissions. (Malaťák & Vaculík, 2008)

Another type of alternative bio-fuels, capable to replacing the petroleum-based fuels, are alcohols produced from biomass. These alcohols are replacing gasoline or kerosene. Today, the most common is ethanol, produced by biomass fermentation. In the developed countries, ethanol is produced from crops such as maize. In the developing countries, it is produced from sugar cane. Ethanol is used as a substitute for gasoline. Ethanol production to such an extent to satisfy the world gasoline consumption needs is, however, almost impossible. The cost of ethanol production would significantly affect the final price of the produced fuel, which would be higher than the current price of the petroleum fuels. Therefore, ethanol is added to gasoline to enhance its octane levels and to reduce the emissions of exhaust gasses. (Malaťák & Vaculík, 2008)

Other potential bio-fuels for transport are methanol and hydrogen. Both of these fuels are produced from biomass and can be used in the future as so-called fuel cells. Another factor which affects the costs of the ethanol produced is the fluctuating price of commodities (corn, sugar cane). For this reason, attention is now paid to the process of ethanol production from ligno-cellulosic biomass, such as wood, straw and grass. If this technology proves to be successful, ethanol prices could be comparable to the current gasoline prices. (Herzog et. al, 2011)

d) Anaerobic digestion[1]

It is a process of producing a fuel gas from biomass at low temperatures and in the absence of air. “Biogas” is gas that is produced in specially designed biogas digesters or gas that is collected from landfills. Biogas is composed of approximately 60% methane and 40% carbon. Almost every type of biomass

[1] The process of anaerobic digestion is in detail described in the chapter: “Biogas & Anaerobic digestion”

(except lignin) can be converted into biogas, including human and animal waste, excrements, sewage sludge, crop residues, etc. (Kranert et. al, 2003)

1.3 Biogas

At present, biogas is a term that describes a gaseous product, which was produced by the anaerobic methane fermentation of organic matter. In practice, biogas is composed of several different gases and chemicals. The dominant component is methane (CH_4) and carbon dioxide (CO_2). (Bláha, 2012)

Biogas has the greatest importance and potential of all gaseous bio-fuels. The advantage of all methods for biogas production is that it has two indispensable functions:
a) This method processes organic wastes and plant origin residues with high humidity. Organic wastes are often supplemented by animal waste and high-quality organic fertilizers, which have no harmful effects such as fresh manure, sewage sludge or fresh straw manure. (Jelínek, 2001)

b) On average, biogas contains 65% methane, small quantities of sulphur dioxide, which can be easily removed, and a small amount of carbon dioxide. Due to this fact, it is regarded as a very valuable fuel. The calorific value of biogas is about 70% of the calorific value of natural gas. (Jelínek, 2001)

The basic principle of biogas (methane) production is the decomposition of organic matter in several stages, which altogether last approximately one month. The temperature for this process of biogas production is around 37°C and it must be constant. This temperature is also maintained in the digestive tract of ruminants, where we can find the same processes as in biogas production. The most important prerequisite for biogas production is to prevent access of air and oxygen into the reaction. Formation of biogas occurs everywhere where there is no access of air, or there the air and oxygen in the

mass (substrate) has been fully consumed. It leads to the decomposition of the organic matter by the action of microorganisms. (Kára, 2008)
Biogas is a gas which is generated by methane fermentation of organic materials (anaerobic digestion). Methanogenic phase (bio-methanogenic phase) is a set of processes, in which the mixed culture of microorganisms decomposes biodegradable material in the absence of air. Final products are primarily methane and carbon dioxide. (Profeld & Jochová, 2008)

Methane fermentation is a collection of several processes following one after the other. The resulting product is a single group of micro-organisms which works as a substrate for the next groups of microorganisms. Failure of one group can break the whole system. (Schulz & Eder, 2004)

In the first decomposition phase (hydrolysis) are lysed soluble and insoluble macromolecular organic compounds (carbohydrates, lipids, proteins) into the low molecular weight substances, which are soluble in water by hydrolytic enzymes. These enzymes are produced by bacteria fermentation. The resulting low molecular substances are transported into the cells. At this stage, the presence of atmospheric oxygen does not matter as this process can run in the aerobic environments as well; it is not necessary for this part of the process to be anaerobic. For the activation of the process, it is necessary for substrate to contain more than 50% water. (Bláha, 2012)

During the second stage (acidogenic phase), hydrolysis products are lysed into simpler organic substances (acids, alcohols, carbon dioxide, hydrogen) inside the cells. The final reduced products are formed by the fermentation of these compounds. Their individual distribution depends on the composition of the substrate and the conditions of the fermentation process. This process needs full anaerobic conditions. (Schulz & Eder, 2004)

The next phase (acetogenic phase) involves further cleavage of the substrate, except for hydrogen, carbon dioxide and acetic acid. At this stage, propionic acid is catabolised together with other acids that are higher than acetic acid, alcohols and some aromatic compounds. The end-products include acetic acid, carbon dioxide and hydrogen. Because of the presence of hydrogen, this process requires the presence of methanogens and bacteria, which reduce the sulphates and consume hydrogen. If there is not enough of these bacteria in the anaerobic process, it may slow down the process of biogas generation, or it may cause it to stop completely. In an anaerobic process, hydrogen acts as an inhibitor of the biogas production. (Bláha, 2012)

In the last stage, (methanogenesis) methanogenic microorganisms form the final biogas from the substrate made up of mono-carbon compounds (methanol, formic acid, carbon dioxide and acetic acid).

Methanogenic microorganisms are the most important trophic form. They have specific requirements for the substrate and living conditions and they often become a limiting factor of the whole process. According to substrate specifications, they can be divided into hydrogenotrophic, acetotrophic and ambiguous.

Acetotrophic methanogenic bacteria play a very important role in the process. These bacteria generate a substantial portion of methane in the biogas. These bacteria decompose acetic acid and thus producing methane and carbon dioxide. These bacteria also maintain a constant pH of the fermentation medium. These bacteria show a slower growth: in comparison with hydrogenotrophic bacteria, the generation time takes a few days.

Hydrogenotrophic bacteria produce methane from hydrogen and carbon dioxide. They grow faster than acetotrophic bacteria, their generation time is approximately 6 hours. In these processes, anaerobic bacteria work as self-regulating agents. They remove almost all of hydrogen from the reaction. The sensitivity of bacteria to the presence of hydrogen depends on the energy yield of the basic metabolic reactions. (Schulz & Eder, 2004)

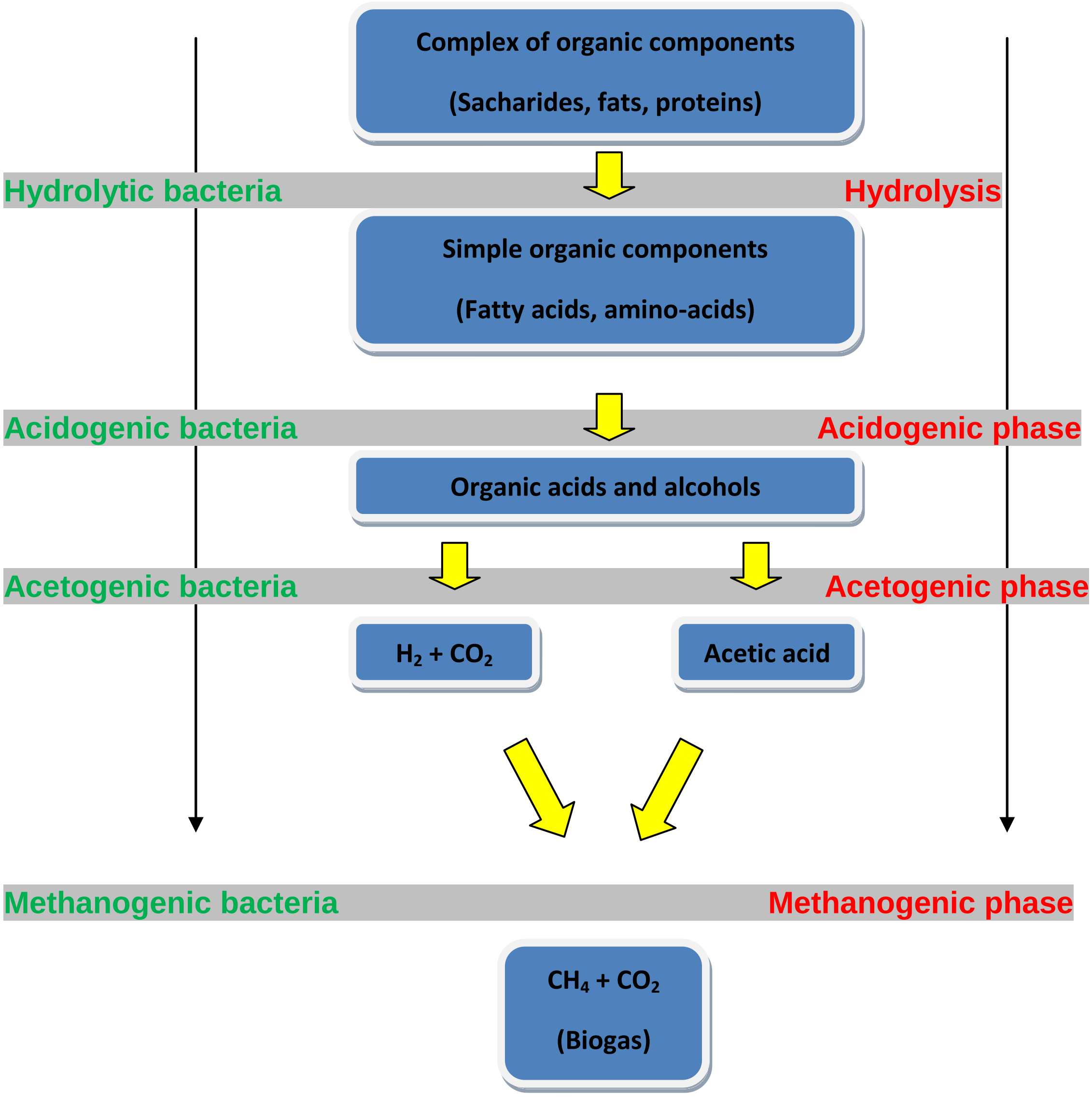

Fig. 1.3: Scheme of biogas production

Source: Malaťák & Vaculík, 2008

Biogas production technologies

The technology of biogas production is rather varied, depending on the characteristics of the processed material. The used kind of technology depends on whether the material is dissolved or in suspension. The limiting factor for the suspension material is the size and concentration of the solid particles inside. From this perspective, it is possible to divide the reactors into three basic groups:

a) Reactors which process dissolved substrates (waste water)

b) Reactors which process the substrate in the form of suspension (dry matter content is approximately 10-12%) such as the sewage sludge and slurry

c) Reactors which process solid materials (dry matter content 10-50%), such as manure (Švec, 2010)

Almost any system designed for the degradation of biomass and biogas production consists of a reactor and a separation section. In industrial facilities, solid particles are most usually separated from the liquid residue by using mechanical equipment (centrifuge, belt press, kato-press, screw press). Reactors are designed for several different principles. Production lines can be composed of one or more reactors, which can be connected in series or in the parallel way. The common feature of the device is a multi-phase collection of biogas and the linear flow of reactive suspension. Two-phase systems includes a separate pre-reactor, which is designed for acidic processes. Gas containing hydrogen is processed separately or in the second phase of the process. (Schulz & Eder, 2004)

An important part of the biogas production is stirring (mixing) and constant temperature throughout the process. From the structural point of view, there are several ways to heat the reactor and mix the substrate. Mixing can be mechanical (mixed, turbine, propeller agitators, pumps). Very often, the substrate is mixed by circulating sludge. Sludge is pumped and injected back into several different places of the reactor thus mixing the substrate. Another method for the substrate mixing is pneumatic mixing. Biogas is pumped from the reactor and then returned back to the reactor at several locations, thereby mixing the substrate. The last method of mixing is mechanical mixing or spraying back raw sludge that disturbs the top layer of the substrate. (Straka, 2010)

Heating of the reactor is carried out in four ways

a) Hot water, steam or heating elements, which are located inside the reactor

b) Hot water, steam or heat exchangers, which are located outside the reactor

c) The injection of steam directly into the reactor or into the stream of re-circulated sludge

d) Using immersion gas burners inside the reactor

In practice, it is achieved by a combination of the mentioned heating technologies, in order to ensure safe operation of the reactor. (Straka, 2010)

Biogas characteristic and its quality

The characteristics of biogas are very important for its use. The most important properties are the calorific value and flammability limits. Calorific value depends primarily on the content of methane. It is a linear function, the more methane contained in the biogas, the higher the calorific value.

The flammability of methane-air mixture is very low, ranging between 6-12%. The ignition temperature of biogas is about 650 to 750°C. Biogas is very dangerous for humans and other animals. It is heavier than air and therefore it settles mainly in various hollows. Further characteristics of biogas depend on the methane content (at least 55%). Another aspect is the content of pollutants in the gas, in particular the compounds of sulphur, chlorine and fluorine. (Ouřada, 2012)

The quality of biogas depends on the properties of the raw materials that have participated in its production. This involves basically the dry matter content in the input material. It is also necessary to take into account the method of operation of the device (biogas plant), the temperature in the digester and the time delay of the material in the production process. The consequence of this is that there is a variance in biogas yield values even for the same input material. (Ouřada, 2012)

Tab. 1.1: Methane content in biogas according to its origin

Biogas origin	CH_4 content (%)
waste-water treatment plant	50-85
sludge stabilization	60-70
agricultural waste	55-75
dumps	35-55

Source: Ouřada, 2012

Source: Ravindranath, 2000

Technological and ecological premises for biogas quality assessment

Technological risks

The most problematic biogas components are the sulphur, chlorine and fluorine compounds. The combustion of these compounds produces aggressive products (SO_2, SO_3, HCl, HF). These products have negative effect on the equipment and fittings. An extremely corrosive effect is caused by hydrogen sulphide. In addition, it can increase the risk of fire and explosion. In the case of combustion of biogas, which contains sulphur and chlorine compounds, it can cause the motor oil quality to deteriorate. Other serious risks in the case of engine combustion are siloxanes and their derivates. These compounds contain highly volatile substances, which are sparingly water-soluble. During combustion, they are converted into hard abrasive material which can form the deposit on the engine inner-walls, boilers and catalytic converters. The effect of these interactions is the decrease of the equipment lifespan and increase of its maintenance costs. The risk of explosion must be taken in consideration as well. Auto-ignition of the biogas can occur due to oxygen infiltration from the air, especially in poorly insulated and poorly operated municipal waste landfills. According to Gaj & Holtra, 2012, the following table shows the explosive properties of selected biogas components.

Tab. 1.2: Explosive properties of selected biogas components

Biogas component	Lower threshold of explosion (% vol.)	Upper threshold of explosion (% vol.)	Auto-ignition temperature (°C)
Methane	4.9	15.4	536.85
Acetone	2.1	13.0	534.85
Ammonia	15.0	28.0	629.85
Hydrogen sulfide	4.3	45.5	289.85
Carbon monoxide	12.5	75.0	804.85
Hydrogen	4.0	75.0	559.85

Source: Gaj & Holtra, 2012

Environmental risks

The biggest environmental issue is the danger caused by uncontrolled biogas emissions, especially methane and carbon dioxide. Carbon dioxide doesn't show any toxic effect, but it can displace oxygen and thereby cause serious health problems to local residents and users (farm and family members). Another risk associated with biogas, in terms of toxicity, are hydrocarbons and their derivatives (including chlorinated hydrocarbons). These substances are well-absorbed by air passages. Some of them could have carcinogenic effect. The biggest risk involved with inorganic substances is associated with hydrogen sulphide, carbon monoxide and ammonia. (Schulz & Eder, 2004)

Some elements are released into atmosphere by the combustion of biogas, including sulphur oxides, nitrogen, carbon, hydrogen chloride and hydrocarbons. Combustion of biogas which contains higher levels of chlorine can cause the emission of dioxins and furans. (Gaj & Holtra, 2012)

The summary of the biogas quality evaluation

According to the way biogas is used, there are many analytical methods for biogas quality evaluation. The most important parameter of biogas as a fuel is the content of methane and associated energy parameters (calorific value, combustion heat and the Wobbe index (ratio of the calorific value of gas per unit volume and the square root of its relative density under the same reference conditions). From the technical point of view, the most important parameter is the content of the corrosive components (oxygen, hydrogen, water, carbon dioxide, hydrogen sulphide, chlorine and fluorine compounds). We have to take in consideration the substances that can cause operation difficulties, as well (dust, oils, siloxanes). (Gaj & Holtra, 2012)

Anyway, for the purposes of this study another biogas quality evaluation criteria was found, which takes in consideration the ratio of methane and carbon dioxide, because of their important role in biogas composition and because these two substances are the major components of biogas. Based on this ratio, biogas quality was measured at each home biogas plant and compared with each other.

1.4 Anaerobic digestion

Anaerobic digesters usually consist of a supply, through which residues and other organic wastes are added into the digester. In this tank, biomass is usually heated, which leads to the acceleration of the decomposition of the biomass and converts bacteria into biogas. Another part is the output, through which biogas is discharged from the tank. Undigested material and sludge are remaining in the tank. The produced biogas is used for direct consumption, i.e. is burning, to provide energy for cooking, heating or to generate electricity. Fermentation has low electrical efficiency, approximately 10-15% and is highly dependent on the kind of the input material and its condition. The sludge from the digester is a concentrated nitrogen fertilizer. (Kranert et. al, 2003)

Anaerobic fermentation is one of the most proven methods for obtaining energy from biomass and is widely used in many countries, above all in the developing countries. But many of digesters are also installed in countries such as India and China. Since the mid 90’s, nearly 2 million home digesters have been installed in India. In China, about 7 million home digesters have been installed. The usual input material is pig manure, food scraps and human excreta. Several thousand home biogas digesters are installed in other countries, such as Vietnam, South Korea, Thailand, Nepal and Brazil. In the developed countries, over 10,000 industrial biogas digesters are installed, particularly around the large farm facilities. (Deublein & Steinhauser, 2008)

a) Dry anaerobic fermentation

A material with the solids ranging between 30-35% is usually used as the substrate in the process of dry anaerobic fermentation. Within this range, the biogas production is the most intensive. It is almost 1.5m^3 of biogas per 1m^3 of biogas fermentation process. In dry anaerobic fermentation, the most often used process is mesophilic fermentation with the temperature ranging between 35-40°C. Thermophilic process with the temperature of 55-60°C is used very rarely. The advantage of this process is the temperature which provides sanitation of the whole process. Thermophilic process is most commonly used in connection with hygienically harmful materials. The disadvantages of the thermophilic process are higher heat losses of substrate. In comparison with the mesophilic biogas production process, the total amount of the produced biogas is higher, but the total amount of methane is lower. Therefore, mesophilic microflora is used in dry anaerobic fermentation. (Bláha, 2012)

b) Wet anaerobic fermentation

Wet anaerobic fermentation process is widely used in biogas production, but it uses complex technological equipment and the overall technological process is more difficult. Dry matter content of the substrate is ideally in the range of 8-10%. With higher solids content (10-15%) of the substrate it is necessary to mix the substrate in the fermenter to avoid sedimentation. If the dry matter content of the substrate is even higher, it is necessary to dilute the substrate, which is usually done by pig slurry, beef manure or sludge from sewage treatment plants. In contrast, when there is a low content of solids in the substrate, a material with a higher solid content is usually added, mostly corn silage, haylage, corn, meal, etc. (Bláha,2012)

c) Co-fermentation

Co-fermentation is the third kind of anaerobic bio-waste processing, in which the substrate is composed of several types of biomass. Each biomass component contained in the substrate has its own reaction requirements, various microbiological processes, varying temperature, pH, etc. It is important to keep these requirements at the constant level to avoid a slowdown or – even worse – an interruption of the whole process. (Bláha, 2012)

Bio-reactions

The first and second as well as the third and fourth phase are linked closely to each other. Therefore, one can accomplish the process well in two stages. In both stages the rates of degradation must be equal in size. If the first stage runs too fast, the CO2 portion in the biogas increases, the acid concentration rises and the pH value drops below 7.0. Acidic fermentation is then also carried out in the second stage. If the second stage runs too fast, methane production is reduced. There are still many bacteria of the first stage in the substrate. The bacteria of the second stage must be inoculated. With biologically difficultly degradable products, the hydrolytic stage limits the rate of degradation. In the second stage, the aceto-genesis possibly limits the rate of decomposition. (Deublein & Steinhauser, 2008)

Hydrolysis

In the first phase (the hydrolysis), undissolved compounds, like cellulose, proteins, and fats are cracked into monomers (water - soluble fragments) by exoenzymes (hydrolase) of facultative and obligatorily anaerobic bacteria. Actually, the covalent bonds are split in a chemical reaction with water. The hydrolysis of carbohydrates takes place within a few hours, the hydrolysis of proteins and lipids within few days. Ligno-cellulose and lignin are degraded only slowly and incompletely.

The facultative anaerobic microorganisms take the oxygen dissolved in the water and thus cause the low redox potential necessary for the obligatorily anaerobic microorganisms. (Deublein & Steinhauser, 2008)

Acidogenic phase

The monomers formed in the hydrolytic phase are taken up by different facultative and obligatorily anaerobic bacteria and are degraded in the second, acidogenic, phase, to short - chain organic acids, C1 – C5 molecules (e.g., butyric acid, propionic acid, acetate, acetic acid), alcohols, hydrogen, and carbon dioxide. The concentra-tion of the intermediately formed hydrogen ions affects the kind of the products of fermentation. The higher the partial pressure of the hydrogen, the fewer reduced compounds, like acetate, are formed.

The pathways of degradation are as follows:

a) Carbohydrates:

Formation of propionic acid by propioni bacterium via the succinate pathway and the acrylic pathway

Formation of butyric acid (butyric acid pathway) above all by clostridium: Acetic acid > 2 - hydroxy butyrate > trans - 2 - butenic acid > butyric acid > butanol

b) Fatty acids:

These are degraded e.g. from acetobacter by β - oxidation. Therefore the fatty acid is bound on Coenzyme A and then oxidizes stepwise, as with each step two C atoms are separated, which are set free as acetate.

c) Amino acids:

These are degraded by the Stickland reaction by Clostridium botulinum taking two amino acids at the same time – one as hydrogen donor, the other as acceptor – in coupling to acetate, ammonia, and CO_2. During splitting of cysteine, hydrogen sulphide is released. (Deublein & Steinhauser, 2008)

Acetogenic phase

The products from the acidogenic phase serve as a substrate for other bacteria – those of the acetogenic phase. The acetogenic reactions are endergonic. In the acetogenic phase, homoacetogenic microorganisms constantly reduce exergonic H_2 and CO_2 to acetic acid.

Acetogenic bacteria are obligatory H_2 producers. The acetate formation by oxidation of long-chain fatty acids (e.g., propionic or butyric acid) runs on its own and is thus thermodynamically possible only with very low hydrogen partial pressure. Therefore, acetogenic bacteria can get the energy necessary for their survival and growth only at very low H_2 concentration.

Acetogenic and methane-producing microorganisms must therefore live in symbiosis. Methanogenic organisms can survive only with higher hydrogen partial pressure. They constantly remove the products of metabolism of the acetogenic bacteria from the substrate and so keep the hydrogen partial pressure, pH at a low level suitable for the acetogenic bacteria.

When the hydrogen partial pressure is low, H_2 , CO_2 , and acetate are predominantly formed by the acetogenic bacteria. When the hydrogen partial pressure is higher, predominantly butyric, capronic, propionic, and valeric acids and ethanol are formed. From these products, the methanogenic microorganisms can process only acetate, H_2 and CO_2. About 30% of the entire CH_4 production in the anaerobic sludge can be attributed to the reduction of CO_2 by H_2, but only 5 – 6% of the entire methane formation can be attributed to the dissolved hydrogen. This is to be explained by the “interspecies hydrogen transfer”, by which the hydrogen moves directly from the acetogenic microorganisms to the methanogenics, without being dissolved in the substrate.
The anaerobic conversion of fatty acids and alcohols goes energetically at the expense of the methanogenics, where these, however, in return, receive the substrates (H_2, CO_2, acetic acid) needed for growth from the acetogenic bacteria. The acetogenic phase limits the rate of degradation in the final stage. From the quantity and the composition of the biogas, a conclusion can be drawn about the activity of the acetogenic bacteria.
At the same time, organic nitrogen and sulphur compounds can be mineralized to hydrogenic sulphur by producing ammonia. The reduction of sulphate follows for example the stoichiometric equations below. Sulphate - reducing bacteria such as Desulfovibrio, Desulfuromonas, Desulfobulbus, Desulfobacter, Desulfococcus, Desulfosarcina, Desulfonema and Desulfotomaculum participate in the process, which uses the energy released by the exergonic reaction. (Deublein & Steinhauser, 2008)

Methanogenic phase

In the fourth stage, the methane formation takes place under strictly anaerobic conditions. This reaction is categorically exergonic. As follows from the description of the methanogenic microorganisms, all methanogenic species do not degrade all substrates. One can divide substrates acceptable for methanogenesis into the following three groups:

CO_2 type: CO_2, $HCOO^-$, CO

Methyl type: CH_3OH, CH_3NH_3, $(CH_3)_2NH_2^+$, $(CH_3)_3NH^+$, CH_3SH, $(CH_3)_2S$

Acetate type: CH_3COO^-

Long-chain hydrocarbons are involved, such as methanofuranes. Corrinoids are molecules which have four reduced pyrrole rings in a large ring and can be represented by the empirical formula C 19, H 22, N 4. When the methane formation works, the acetogenic phase also works without problems. When the methane formation is disturbed, overacidification occurs. Problems can occur when the acetogenic bacteria live in symbiosis instead of with a methanogenic species with other organisms, using H_2. In waste water technology, symbioses can occur with microorganisms which reduce sulphate to hydrogen sulphide. Therefore they need hydrogen and compete with the methanogenics. The methanogenics get less feed and form less methane. Additionally, hydrogen sulfide affects the methanogenics toxically. All methane-forming reactions have different energy yields. (Deublein & Steinhauser, 2008)

1.5 Home biogas digester types used in developing countries

Biogas production is quite simple and the process can run under any conditions. Biogas energy for rural areas is sustainable, affordable and without negative effects on human health and environment, if handled properly. It is much cheaper and simpler in comparison with commercial biogas plants. These plants are unavailable for poor farmers in the developing countries, so farmers have adopted this more available technology for energy production. (Savita, 2008)

There are currently over 20 million home digesters in China, almost 4 million in India, 200 thousands in Nepal, 60 thousands in Bangladesh, almost 30 thousands in Vietnam and over 3 thousands in African countries (unfortunately only few of them are operating). (Savita, 2008)

Usually it is difficult to find just one type of digester suitable for household purposes. The design of the digester is changing according to the climatic conditions, geographic location and availability of the substrate. For example, the digester used in mountainous areas is designed to have less gas volume to avoid gas losses. On the other hand the digester for tropical and subtropical areas it is preferred to have the digester tank underground due to the geothermal energy. Of all the different digester types developed, the fixed dome model developed in China and the floating drum digester developed in India have continued to perform until today. (Ravindranath, 2000)

The main difference between the basic home biogas plants, can be found between batch and continuous plants. The batch plants are completely filled and also completely emptied after the retention time. For batch filling it is possible to use every design and every fermentation substrate. The continuous plants are filled and emptied continuously (regularly), usually every day. These plants are emptied by the overflow. These plants are more suitable for rural areas, because of their easy maintenance and constant biogas production. There are three main types of simple domestic biogas plants. (Mödinger & Giovanni, 2010)

Fixed dome digester type

This plant type is composed of an enclosed digester with a non-moveable gas holder, mixing tank with an inlet pipe, compensation and removal tank and gas-pipe. Biogas is stored in the upper part of the digester. When the volume of the produced biogas is bigger than the volume of space for biogas storage, the slurry is pressed into the compensation tank by the pressure inside the digester. After the gas is released, the substrate flows back into the digester immediately. The pressure inside the digester is increasing accordingly to the amount of produced biogas. If constant pressure is needed (for example for engines) it is better to use floating gas holder (or pressure regulator). Engines require a great amount of gas and that's why large gasholders are used. The gas pressure can become too high if no floating gasholder is being used. Advantages of this digester type are low construction costs, no rusting steel parts, long service life (usually more than twenty years), underground construction (wind and cold protection, space saving) and can provide local work opportunities. This type has also some disadvantages, for example porosity and cracks causing gas leaking, high gas pressure inside the digester and low digester temperatures. For the construction of fixed dome biogas plants, experienced staff is required. The top part of the digester, which works as the gasholder must be absolutely gastight. It is usually constructed using masonry and cement. These materials are not gastight at all and that's why the surface of the top part of the digester is usually painted by an elastic gastight material (latex, synthetic paints). The same paint is used for the digester walls. Fixed dome plants produce as much biogas as floating drum plants only if they are gastight. (Blank & Brockmann, 2009)

This type of digester is also called the Chinese or hydraulic digester. This type is the most common type, which was developed and is used mainly in China. The digester is filled through the inlet pipe until the level of substrate reaches the bottom level of the expansion chamber. These digesters are usually constructed underground and their size depends on the location, number of connected households and the amount of substrate, which is available every day. (Zhang, 2003)

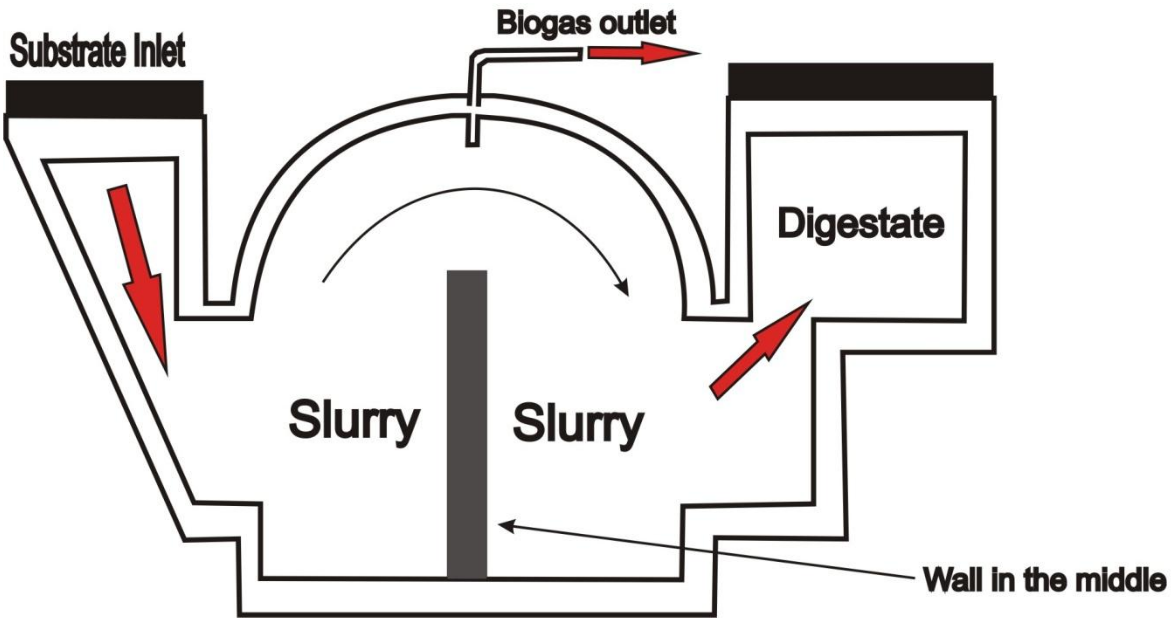

Fig. 1.4: Janta fixed home biogas digester (scheme)

Source: Sasse, 1988

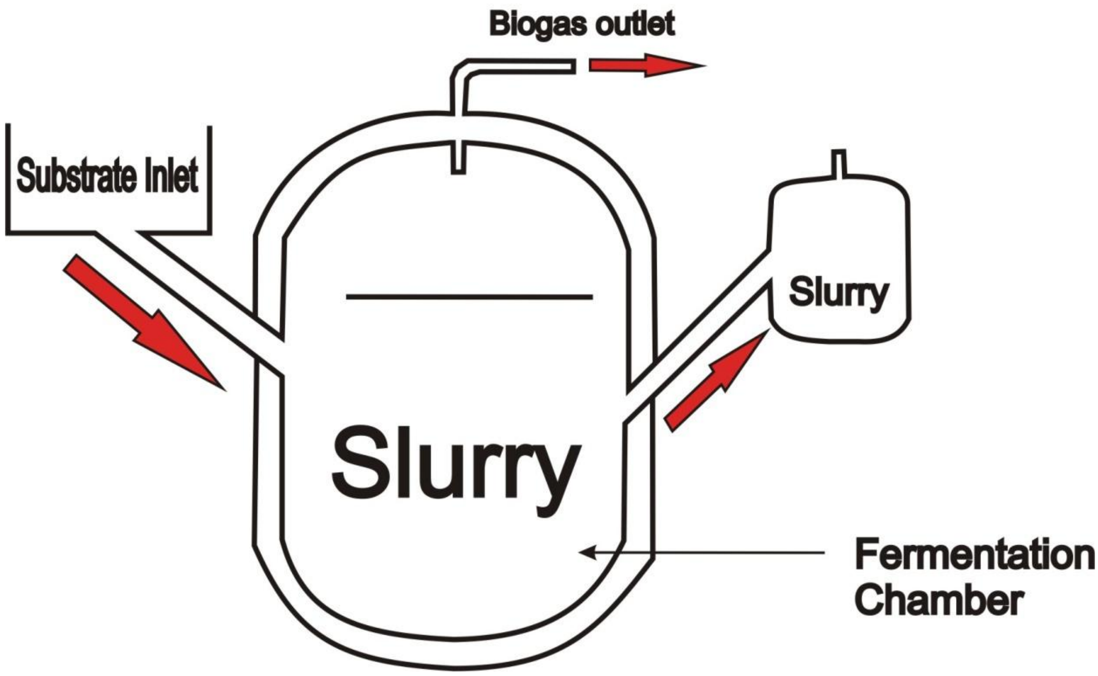

Fig. 1.5: Modified model with less biogas storage (scheme)

Source: Sasse, 1988

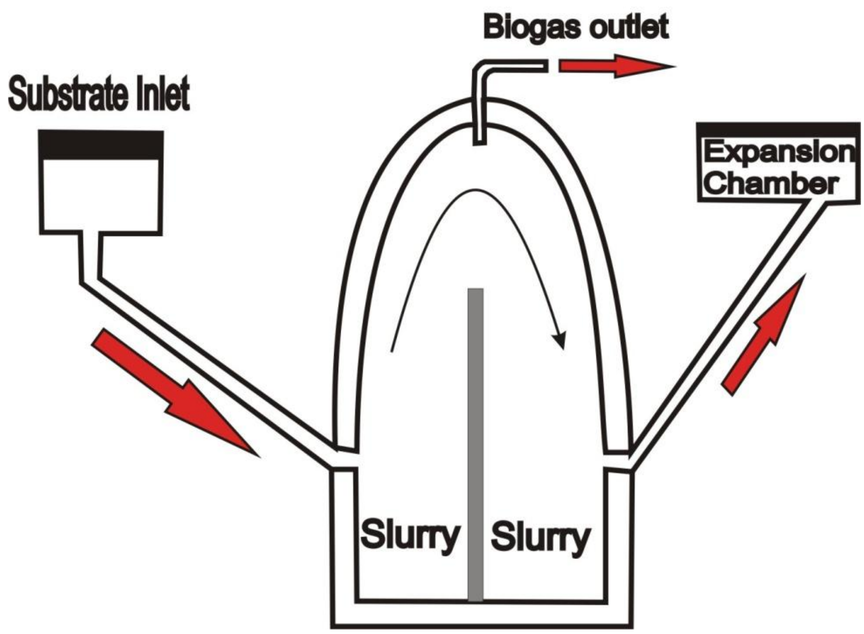

Fig. 1.6: Modified bell-shaped dome scheme

Source: Sasse, 1988

Floating drum digester types

This type of home biogas digester is very old. It was developed as early as in 1962. The original name of the floating drum digester model is Khadi and Village Industries Commission (KVIC). It is the most common model especially in India. Floating-drum plant is composed of a digester, moveable gasholder, mixing tank with inlet pipe, overflow and outlet pipe. The gasholder floats either directly on the fermentation slurry (substrate). The produced biogas is collected in the floating drum, which rises up and down according to the volume of the produced biogas. The main advantage of this digester type is that it provides biogas under the constant gas pressure and the volume of the produced biogas is visible thanks to drum rising. Thank to the inverted drum position it is pretty easy to detect the total amount of biogas inside the digester and it is also easier to clean the digester in comparison with the fixed dome digester type. The floating drum plant construction is usually more expensive in comparison with other types, especially because of the drum. There are also many steel parts, which are prone to corrosion. Another disadvantage is the short service life of the drum. Because of the corrosion of the drum, another option has been developed: a drum, which is made from glass-fibre and high-density polyethylene. However, these materials increase the total construction costs. For this digester type, many experiments have been carried out with other materials to be used, for example PVC, but the main problem of this material is its non-resistance to UV radiation. (Zhang, 2003)

The floating drum usually consists of 2.5 mm steel sheet, which is used for the sides, and 2 mm steel sheet for the cover. It has to be protected against corrosion, which is done by coating products, such as oils, synthetic paints and bitumen paints. Of course, the final surface treatment is done by painting. There have to be at least two primary paintings and one top-painting. In the case of oil paint, the painting must be repeated almost every month. In the case of bitumen or plastic painting, it is recommended that the painting is repeated at least once a year. Biogas production is higher if the drum is painted in black or red colour (from the outside). Because of this, the digester temperature will be increased by solar radiation. The gas drum should have a sloping top to avoid rainfall water trapping (it can cause corrosion). Another important part of the construction is the guide frame for the drum. (Sasse, 1988)

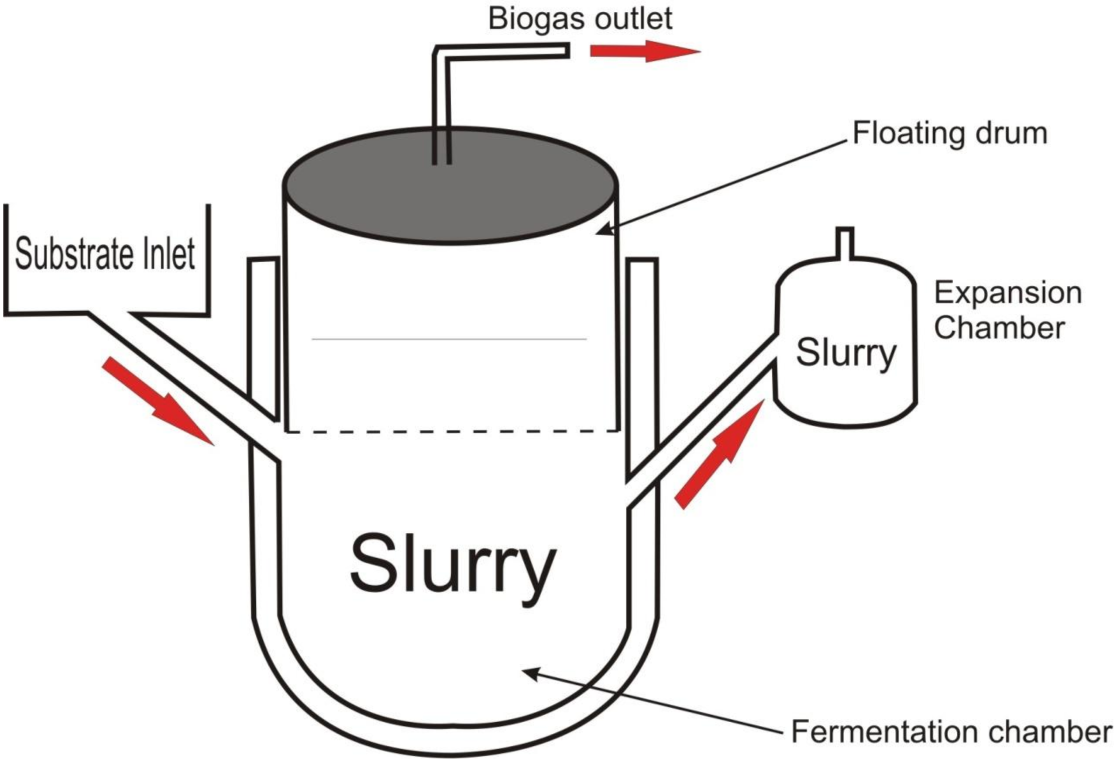

Fig. 1.7: Floating drum digester (scheme)

Source: Sasse, 1988

Plug flow biogas digester model

The plug flow plant contains a plastic or rubber digester bag, which is in the upper part, where the produced biogas is stored. The inlet and outlet is on the opposite sides and they are attached directly to the balloon. When the space for biogas storage is full, the whole plant works as the fixed dome biogas plant. The slurry inside the balloon is agitated by the movement of the balloon skin. It has a positive impact on the digestion process. The material used for balloon construction has to be UV resistant. The main advantages of this digester type are low costs, easy transport (it is not fixed to the ground), high digester operating temperature, easy maintenance, easy cleaning, easy filling and emptying. Disadvantages on the other hand include short service life (+/- five years), that fact that it can be easily damaged and that it does not create work opportunities. This type of home biogas plant can placed almost anywhere where it is not likely to damage the balloon skin. (Mödinger & Giovanni, 2010)

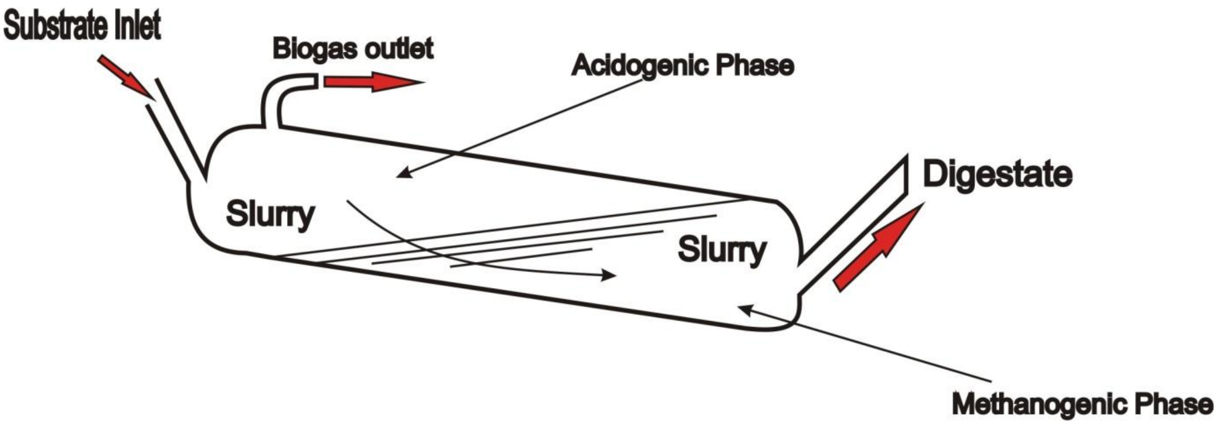

Fig. 1.8: Plug flow (balloon) digester (scheme)

Source: Sasse, 1988

Factors and parameters influencing the biogas production process

One of the most important factors is the material used as the digestion substrate. Only the organic (dry/wet) can be used. Other considered parameter is the digester loading which indicates how much organic material per day has to be supplied to the digester or has to be digested. It is calculated in kilograms of organic matter per cubic meter of the digester capacity per day (kg ODM/m^3/day). For domestic biogas plants the digester loading is 1-1.5 kg/m^3/day. If this amount is exceeded it will cause an increase in the pH value (in the case of small scale household plants). Another important indicator is the retention time (RT or t). It indicates the time period spent by the substrate in the digester. The retention time is appreciably shorter than the total time needed for the whole digestion process. Another very important parameter is the biochemical oxygen demand (BOD). It indicates the degree of pollution of the effluent liquids. The BOD is measure of the amount of oxygen consumed by bacteria in biological purification. Another biogas production limitation is the temperature. Ideal temperature for biogas production is in approximately 33°C.

The ideal conditions for biogas production are uniform temperatures (33°C) + long retention time (+/- 100 days) and thorough mixing. (Zhang, 2003)

2. Objectives

The main objective of the thesis is to evaluate the quality of biogas produced in the household biogas plants installed in the central part of Vietnam by comparing the influences of chemical and physical parameters. The first part of this objective is focused on trying to find out what kind of material (pig slurry, chicken litter, etc.) is used as the primary substrate in the home biogas plants and facilities that are connected to the digesters (including stable, shed, lavatory, etc.) and their effect on biogas composition. The second part of the study objective is to compare the quality and quantity of the biogas produced, according to the construction parameters of the digester (KT1, KT2). The results of this study will be used as an output of the project “Renewable energy resources for rural areas in Thua - Thien Hue”.

3. Materials and Methods

3.1 Overview of study area

The area of this study was situated to Thua – Thien Hue in the central part of Vietnam. As a consequence of the war in Vietnam, most people still live in poverty in this region.

The total area of Thua - Thien Hue province is 5,062 km^2 and the population is over one million inhabitants (1,090.9 x 1000 inhabitants in 2011). The capital of this province is the city of Hue. The province consists of seven districts, namely: Phong Dien, Quang Dien, Huong Tra, Phu Vang, Phu Loc, Nam Dong and A Luoi. There are five ethnic groups in this province: Viet (Kinh), Ta Oi, Co Tu, Bru Van Kieu and Hoa. (Villavicencio, 2011).

The Thua Thien Hue Province is located in the central part of Vietnam, about one hundred kilometres north of Da Nang. On the north, the province borders with the province of Quang Tri. This province was probably the hardest hit area during the Vietnamese War. On the west, it borders with Laos. The climatic and environmental conditions create a specific atmosphere in the whole province. The surface of a relatively narrow perimeter rises from the sea coast to the high mountains on the border with Laos. The mountains reach the height of up to 1600 meters above the sea level. The average annual temperature is around 25°C. The average annual rainfall is around 3000 mm per year. Precipitation and temperature varies depending on the altitude. The province is located in an area where there are frequent floods, mainly in autumn. As a result of these floods there is a decrease in total production, environmental damage, property damage and often loss of human lives. During these floods, the life in the province is almost paralyzed and the mountain districts and communities are cut off from the outside world.

The main part of the province economy is agriculture and tourism. There are differences between poor areas, where people are mostly working in agriculture, and the areas around the city of Hue, which is quite famous for tourists, and along the Ho Chi Minh Road, which connects the city of Hue with the capital city of Vietnam on the north and with the second largest city in

Vietnam, Ho Chi Minh City. Thank to the development of the province there are some negative environmental impacts, especially the decrease in biodiversity, usage of chemicals and inorganic fertilizers in agriculture, increase in the total amount of waste produced by urban and suburban province areas. On the other hand, there are huge protected territories in the province, too (national parks and reservations).

The research was carried out in two districts. The first one was the Huong Tra district. Huong Tra is a rural district in the north part of the central coast of Vietnam with the population of over 120 thousand inhabitants. The district covers an area of 521 km^2. The capital of the district is the village of Tu Ha. The second one is the Phong Dien district. It has a population of over 105 thousand inhabitants and it covers an area of 119 km^2. (Villavicencio, 2011).

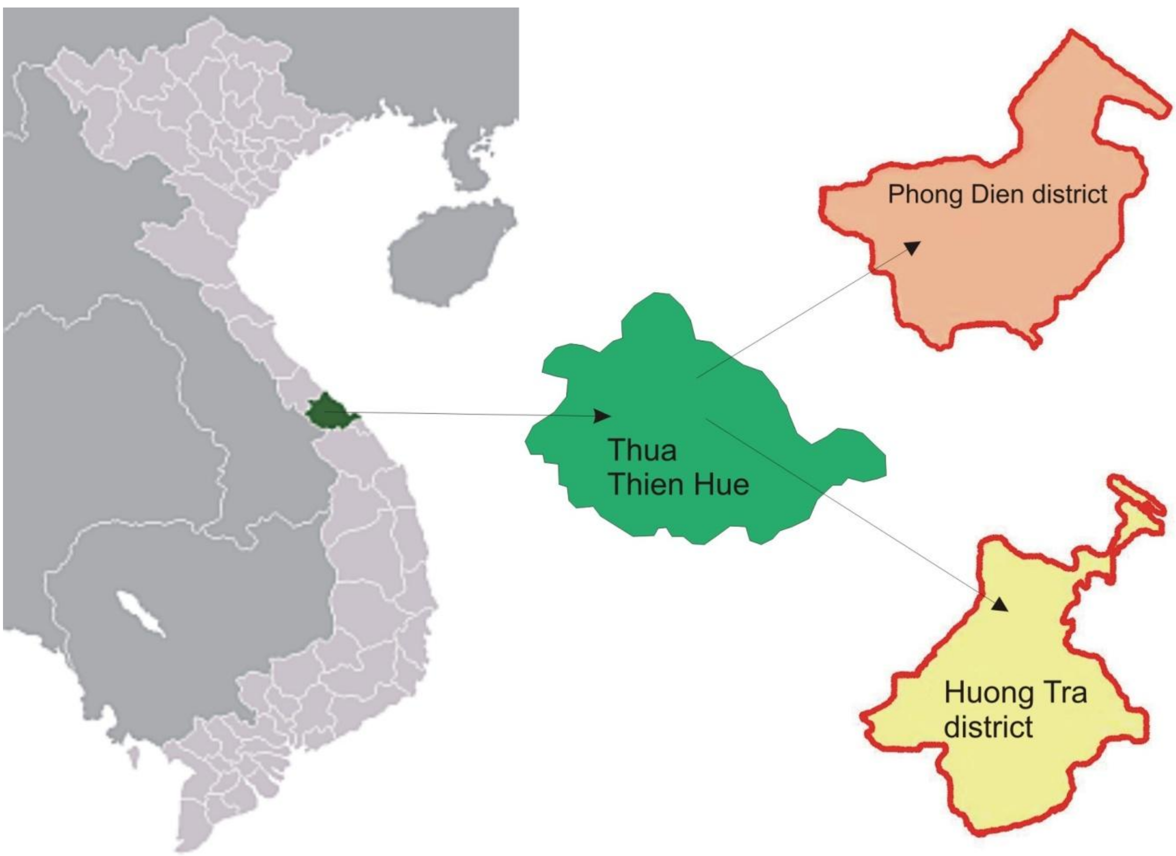

Fig. 3.1: Map of target area location

Source: Chicago, 2012

The target group of the study is the group of the residents of the rural areas in the target districts of Phong Dien and Huong Tra in the province of Thua Thien-Hue. In total, the measurements were carried out in 107 households in 14 villages, which correspond to 20% of total amount of installed biogas plants in target area. These people have a direct benefit from the constructed home biogas plants within the project "Renewable energy for rural areas in Thua - Thien Hue" realized by the Faculty of Tropical AgriSciences of the Czech University of Life Sciences in Prague.

3.2 Data collection

Data field collection was carried out from June to July 2012. Biogas composition was measured by the multifunctional portable gas analyzer Geo Tech GA5000. The measurements were taken upstream the H_2S filter, to eliminate measurement inaccuracies. In total, the measurements were carried out in 55 KT1 digesters and 24 KT2 digesters installed by CULS and in 26 KT1 and 2 KT2 digesters installed by SNV, a Dutch development organization (detailed description of the construction of each digester type is shown below).

Measured parameters by gas analyzer Geo Tech GA 5000

- CH_4 (0-100%)
- CO_2 (0-100%)
- O_2 (0-25%)
- H_2S (0-5000 ppm)
- NH_3 (0-1000 ppm)
- Flow rate (l/hour)
- Relative pressure (mbar)
- GPS position

Fig. 3.2: Gas analyzer Geo Tech GA 5000

Device description

This device measures the biogas composition in percentage, with different typical accuracy for each element after calibration (the specific data are shown in the following table). It measures CO_2 and CH_4 by the dual wavelength infrared sensor with reference channel. O_2, CO, H_2S, NH_3 and H_2 are analyzed by the internal electrochemical sensor. This equipment was also used to measure the GPS locations of each plant, relative pressure, flow-rate and temperature.

Tab. 3.1: Typical accuracy, range and response time of each measured parameter

Measured element/facility	Range	Typical accuracy (+/-)	Response time (s)
CH4	0-100%	0.5%	< 10
CO2	0-100%	0.5%	< 10
O2	0-20%	1.0%	< 20
CO	0-2,000 ppm	2.0%	< 30
H2S	0-50 ppm	1.0%	< 30
Temperature	-10°C to +75°C	0.5°C	-
Flow rate	0-20 l/hour	0.3 l/hour	-
Relative pressure	+/- 500 mbar	4 mbar	-
Barometric pressure	500 - 1500 mbar	5 mbar	-

Source: Geotechnical instruments Ltd.

The standards used for biogas composition are shown in following table:

Tab. 3.2: Standardized biogas composition

Element	Volume (%)
Methane - CH_4	40 - 75
Carbon dioxide - CO_2	25 - 55
Water vapour	0 - 10
Nitrogen - N_2	0 - 5
Oxygen - O_2	0 - 2
Hydrogen - H_2	0 - 1
Ammonia - NH_3	0 - 1
Hydrogen sulfide - H_2S	0 - 1

Source: Murtinger & Beranovský, 2006

3.3 Supporting data collection by questionnaire survey

The data were collected using a questionnaire. The questionnaires contained a combination of close-ended and open-ended questions. Total amount of respondents was 107 they were the home biogas digesters owners and users.

Used questions

- capacity of the digester (m^3)
- investor of the construction (SNV or CULS)
- digester type
- digester connection
- used kind of animal stable
- digester cleaning period (years)
- biogas primary feedstock materials
- no. of animals
- average weight of animals (kg)
- time of biogas use (hours per day)
- no. of other applications powered by biogas (if any)
- usage of digestate

The implementation of the survey was divided into two parts. The first part of the survey involved collection of data by the gas analyzer (to analyze the biogas it was necessary to disconnect the biogas outlet pipeline and connect the analyzer to the digester). And the second part of survey involved data collection by means of questionnaires with the help of an interpreter.

3.4 Types of evaluated biogas digesters

As the most suitable technology for this project, two main biogas digester types were chosen because of their tradition in the target area. The most common home biogas digester types used in the central Vietnam are the KT1 and KT2 models. Both digesters are based on the Chinese digester type. They are fixed dome digesters. The volume of these digester usually ranges between 4.2 m^3 and 48.8 m^3. These models were developed according to the biogas industrial standard no. 10 TCN 499-2002, issued by Ministry of Agriculture & Rural Development of Vietnam in 2002.

KT 1 digester model

- this type is applied when there is a good ground structure, easy deep digging and limited construction space

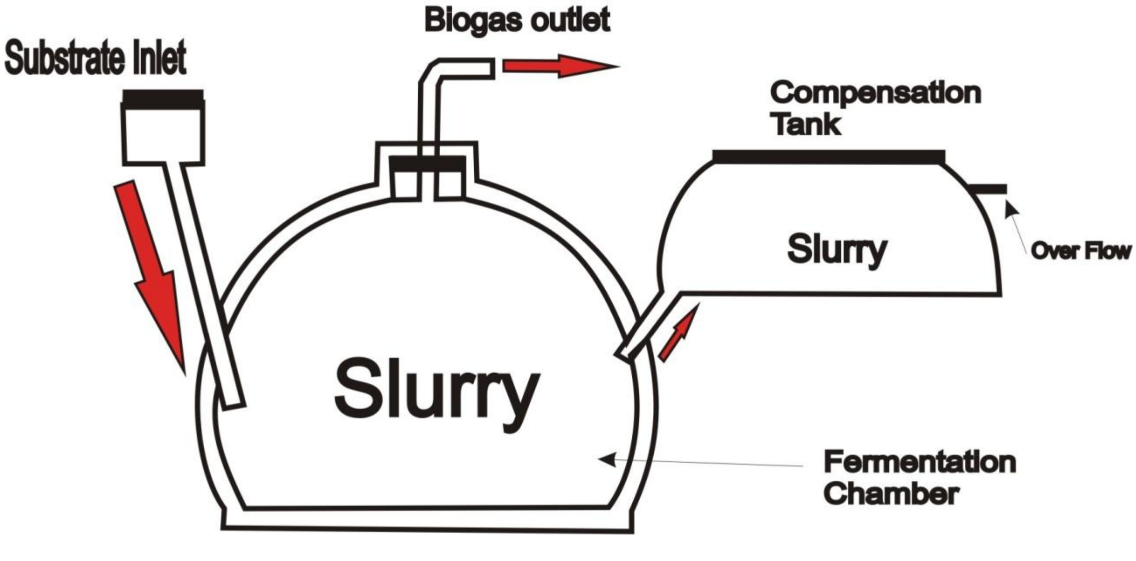

Fig. 3.3: KT 1 digester scheme

KT 2 digester motel

- that type is applied when there is a complicated ground structure, abundant underground water, difficult deep digging and wide construction space
-

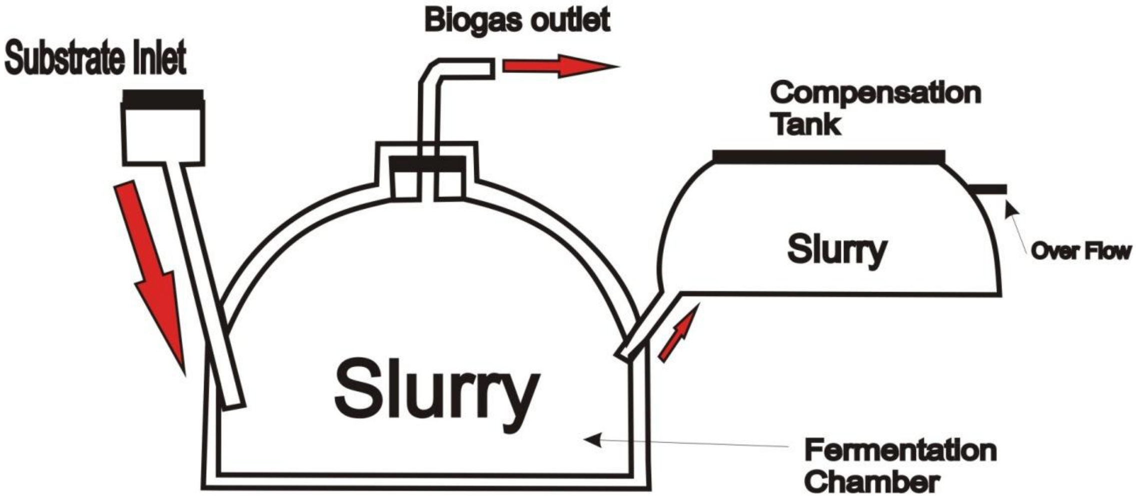

Fig. 3.4: KT 2 digester scheme

3.5 Collected data analysis

Fig. 3.5: Data collecting – field work

The measured data were summarized into tables and compared for each commune. The main target parameter of the study was the produced biogas composition. On the basis of the measured data, it was possible to determine the calorific value of the produced biogas. The data were statistically analyzed by the use of the Microsoft Office Excel software. Pearson correlation coefficient was calculated to confirm or disprove the relation between the target parameters. The data taken into consideration involved the types of the used digesters, digester capacity, age of biogas plants, what kind of material was used as the primary substrate and the average daily time of using the biogas. On the basis of the collected data, graphs were developed according to the indicator the study was focused on. The Pearson correlation coefficient and the calorific value were calculated by the formulas which are shown below.

$$\rho_{X,Y} = \frac{E(XY) - E(X)E(Y)}{\sqrt{E(X^2) - E^2(X)}\,\sqrt{E(Y^2) - E^2(Y)}}$$

Pearson correlation coefficient formula

X= data field 1 (e.g. flow rate)

Y= data field 2 (e.g. type of the used digester)

E= arithmetic mean

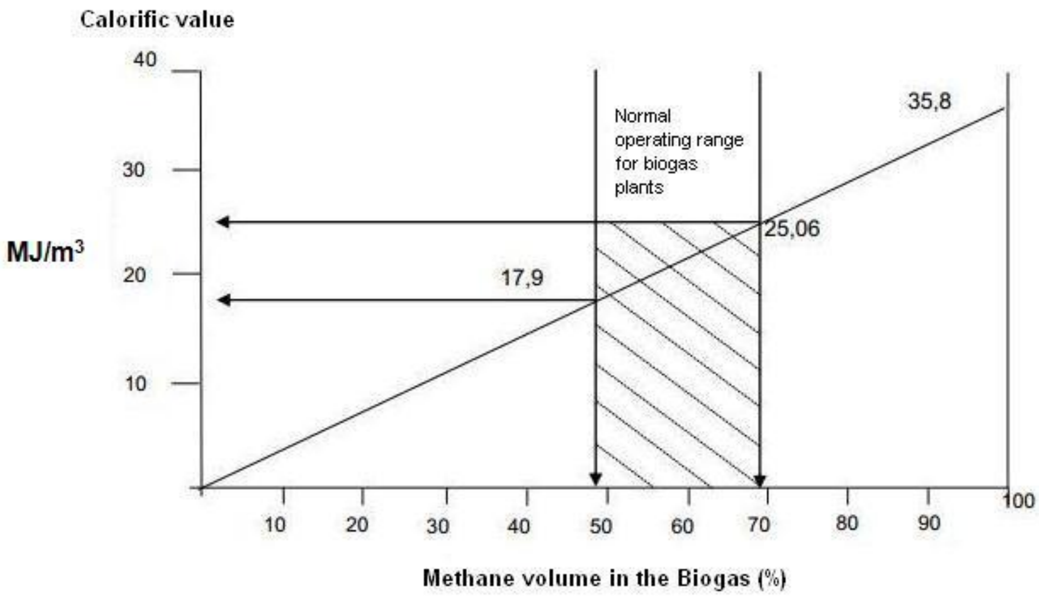

Fig. 3.7: Calorific value calculation according to Jelinek 2001

4. Results and Discussion

From the evaluation of the questionnaires, it is possible to obtain relevant information about the materials used and connectivity of different sources to the digester. As shown in figure 4.1, every family have used pig slurry as the main source of biomass for biogas production, 36% of families have added human excreta, 29% of families have added chicken manure into the digester.

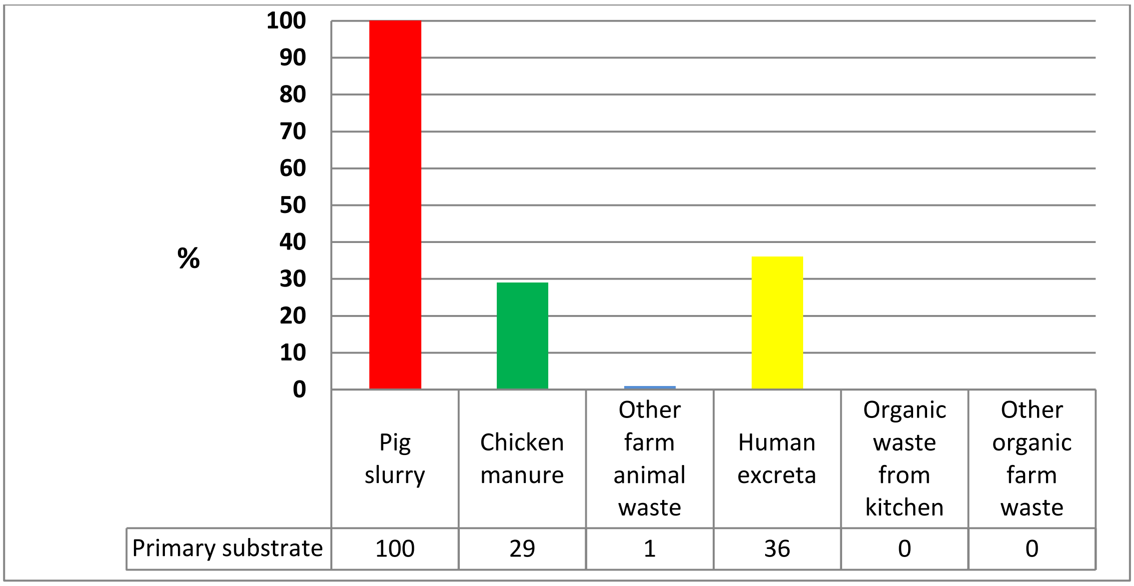

Fig. 4.1: Primary substrate used for biogas production

Every family have their pig stable connected into the digester but only 37% of them connected toilets outflows into the digester. Only one family has their chicken shed connected into the digester.

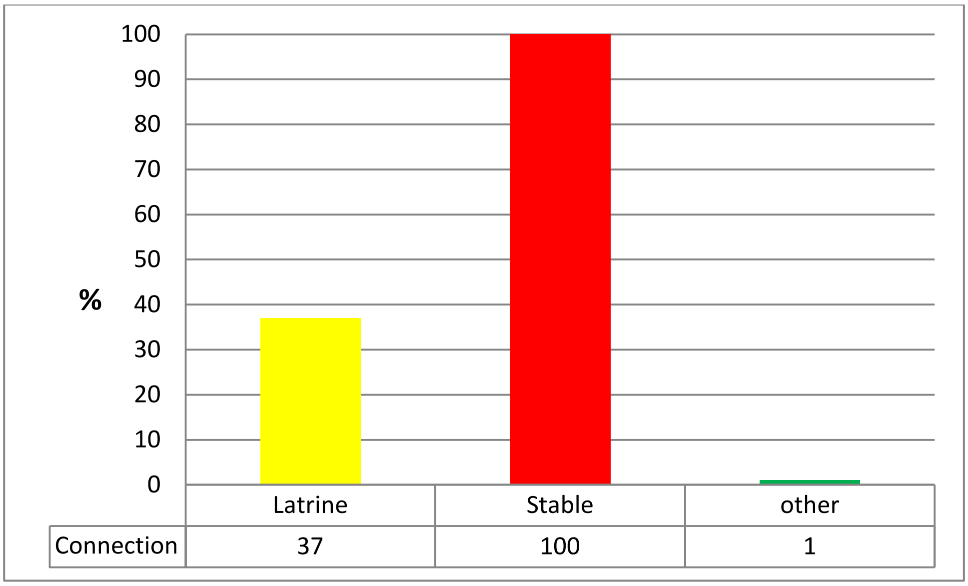

Fig. 4.2: Connection into the digester

The gas analyzer Geo Tech GA 5000 showed a difference in the quantity of biogas components between the KT1 and KT2 digester types. This analysis revealed that the KT2 digester type has demonstrated a higher production of methane and, at the same time, lower production of carbon dioxide. Nitrogen, Hydrogen and Water vapour are collectively marked as Bal.

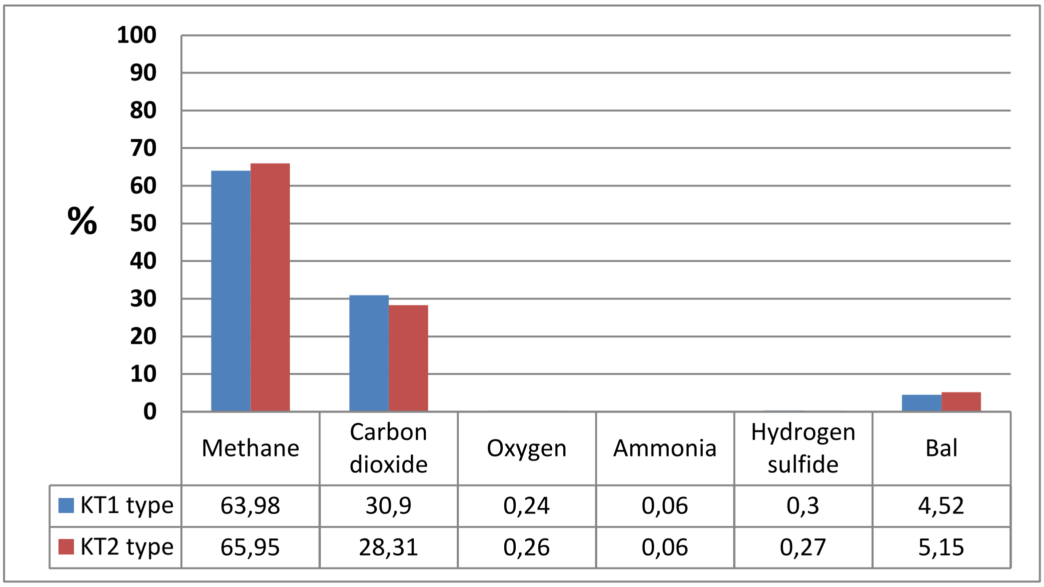

Fig. 4.3: Biogas composition according to the used biogas digester type

With the help of Pearson correlation coefficient, the study looked into the dependency or independency of selected variables. Negative values represent independence, zero represents a neutral relation between variables and positive values represent the dependence. The selected variables included: digester capacity, material used as a substrate for the digester, digester type, age of biogas plant and the average daily use of biogas (especially for cooking). The final results have shown that there is no significant dependency between the flow rate and the selected variables. It means that the selected variables do not affect the quantity of the produced biogas.

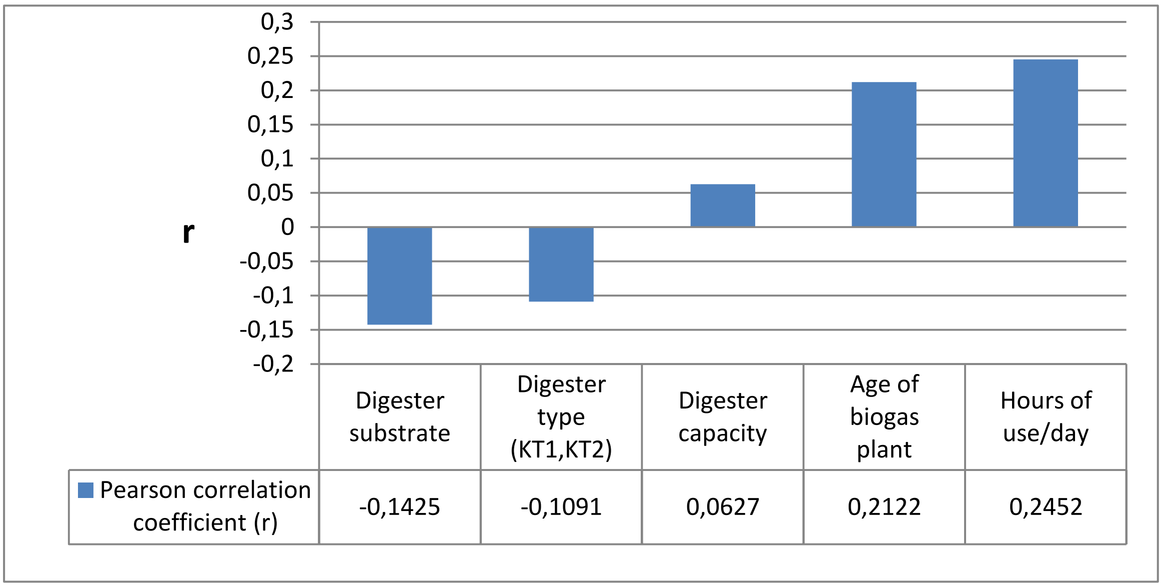

Fig. 4.4: Correlation between flow rate and individual variables

The qualitative indicator (CH_4 – CO_2 Index) was used to find the positive or negative correlation between the index and the selected variables. On the base of measured data the final results did not demonstrate any significant dependency between the index and the selected variables. According to our correlation coefficient it can be considered that the selected variables did not significantly influence the quality of the produced biogas.

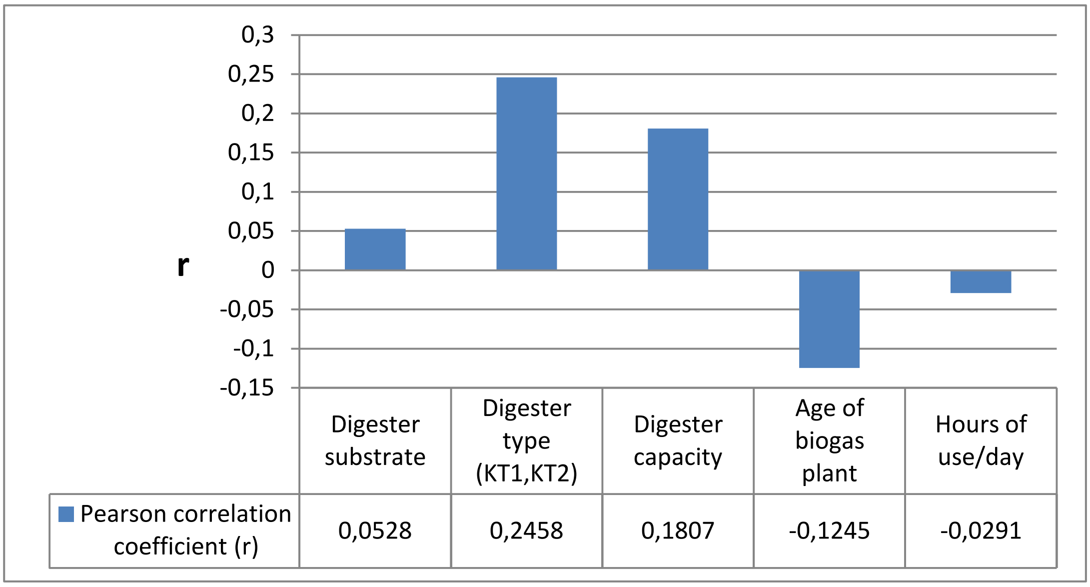

Fig. 4.5: Correlation between CH_4-CO_2 Index and individual variables

In the first commune where the research was carried out, it is possible to see that the KT2 type prevails as the most effective digester type. Here, the measurements have shown a significantly higher volume of CH_4 and they have a higher calorific value in comparison with the KT1 digester types.

Tab. 4.1: Biogas composition and quality in Huong Toan Commune

No. of biogas plant	Digester type	Digester capacity (m^3)	Constructed by	CH_4 (%)	CO_2 (%)	NH_3 (%)	H_2S (%)	Flow rate (l/hour)	$CH_4 : CO_2$ Index	Calorific value (MJ/m^3)
1	kt 2	6.2	CULS	69.4	27	0.09	0.06	19	**2.57**	**23.5**
4	kt 2	6.2	CULS	69.1	28	> 0.1	0.50	17.3	**2.47**	**23.4**
2	kt 1	8.1	SNV	67	28.1	> 0.1	0.33	16.9	**2.38**	**22.6**
5	kt 2	6.2	CULS	66.5	28.9	> 0.1	0.28	18.5	**2.30**	**22.5**
6	kt 1	9	CULS	65	28.9	> 0.1	0.27	18.5	**2.25**	**22.0**
3	kt 1	6	CULS	63	33.5	> 0.1	0.28	9.1	**1.88**	**21.3**
7	kt 1	6	CULS	62.4	33	> 0.1	0.28	5.3	**1.89**	**21.1**

In this commune it was difficult to compare the KT1 and KT2 digester types, because there was no presence of the KT2 digester type in the measurements. In this commune, the highest index was calculated at the plant with the largest capacity of the digester, but on the basis of the Pearson correlation coefficient it was not possible to prove any significant relation between the digester capacity and the CH_4 – CO_2 index value.

Tab. 4.2: Biogas composition and quality in Phong Son Commune

No. of biogas plant	Digester type	Digester capacity (m^3)	Constructed by	CH_4 (%)	CO_2 (%)	NH_3 (%)	H_2S (%)	Flow rate (l/hour)	Rel. pressure (mb)	CH_4 : CO_2 Index	Calorific value (MJ/m^3)
15	kt 1	13	SNV	68.5	28.3	0.07	0.21	23.6	108.4	**2.42**	**23.2**
9	kt 1	6	CULS	67.9	28.6	0.05	0.14	9.6	27.56	**2.37**	**23.0**
10	kt 1	9	SNV	67.6	36.7	> 0.1	0.39	16	59.57	**1.84**	**22.8**
14	kt 1	9	CULS	67.6	28.8	0.08	0.25	0.3	4.07	**2.35**	**22.8**
20	kt 1	7.2	SNV	67.3	28.3	0.07	0.28	-0.6	3.73	**2.38**	**22.7**
19	kt 1	9	SNV	67	28.5	0.08	0.32	15.2	57.7	**2.35**	**22.6**
12	kt 1	9	SNV	66.5	30.8	> 0.1	0.30	18.2	70.24	**2.16**	**22.5**
28	kt 1	9	CULS	66.1	30.5	0.04	0.17	18.1	69.38	**2.17**	**22.3**
11	kt 1	9	CULS	65.5	31.9	0.10	0.29	5.2	3.32	**2.05**	**22.1**
8	kt 1	12	CULS	65.2	33.3	> 0.1	0.45	14	46.82	**1.96**	**22.0**
17	kt 1	6	SNV	64.2	30.4	> 0.1	> 1	5.1	13.6	**2.11**	**21.7**
16	kt 1	9	SNV	63.7	32.7	0.09	0.35	12.6	40.48	**1.95**	**21.5**
21	kt 1	6	CULS	63.2	33.5	0.08	0.30	18.1	69.82	**1.89**	**21.4**
22	kt 1	6	CULS	63.1	32.9	0.07	0.28	14.7	50.87	**1.92**	**21.3**
25	kt 1	9	CULS	63.1	33.5	0.07	0.30	9.8	29.51	**1.88**	**21.3**
26	kt 1	6	CULS	62.8	33.4	0.06	0.25	18.1	69.24	**1.88**	**21.2**
13	kt 1	9	CULS	62.7	33.8	0.08	0.24	3.4	8.29	**1.86**	**21.2**
29	kt 1	9	CULS	62.6	33.4	0.06	0.28	15.6	55.95	**1.87**	**21.2**
23	kt 1	6	CULS	62.4	33.7	0.07	0.25	16.4	60.76	**1.85**	**21.1**
27	kt 1	6	CULS	61.1	34.7	0.08	0.41	12.1	37.74	**1.76**	**20.7**
24	kt 1	6	CULS	61	34.6	0.07	0.28	12.1	46.68	**1.76**	**20.6**
18	kt 1	9	SNV	60.3	36.3	0.06	0.21	18.8	73.98	**1.66**	**20.4**

In the Phong Xuan commune, the results measured at the biogas plant no. 32 (KT1) with the largest capacity of the digester have shown the lowest volume of CO_2 and the highest CH_4 – CO_2 index and it is possible conclude that the plant was very well constructed without any leakages.

Tab. 4.3: Biogas composition and quality in Phong Xuan commune

No. of biogas plant	Digester type	Digester capacity (m^3)	Constructed by	CH_4 (%)	CO_2 (%)	NH_3 (%)	H_2S (%)	Flow rate (l/hour)	Rel. pressure (mb)	CH_4 : CO_2 Index	Calorific value (MJ/m^3)
32	kt 1	11	CULS	76.4	17	0.03	0.12	1.9	23.81	**4.49**	**25.8**
34	kt 1	9	CULS	72.9	21.4	0.05	0.18	2.3	6.42	**3.41**	**24.6**
31	kt 1	9	CULS	71	23.9	0.09	0.43	6.5	17.1	**2.97**	**24.0**
33	kt 1	9	CULS	69.2	23.7	0.07	0.37	19.8	80.38	**2.92**	**23.4**

45	kt 2	9.2	CULS	68.6	24.2	0.04	0.14	8	23.93	**2.83**	**23.2**
39	kt 1	9	CULS	67.2	26.5	0.07	0.29	14	43.14	**2.54**	**22.7**
49	kt 2	9	CULS	65.9	28.4	0.07	0.46	13.1	43.01	**2.32**	**22.3**
35	kt 1	9	CULS	65.3	28.7	0.06	0.29	13	42.47	**2.28**	**22.1**
38	kt 1	6	CULS	64.8	28.5	0.05	0.09	-1.5	1.79	**2.27**	**21.9**
48	kt 2	6	CULS	64.1	28.9	0.03	0.14	9.9	29.94	**2.22**	**21.7**
50	kt 1	6	CULS	63.9	29.3	0.06	0.39	5	13.63	**2.18**	**21.6**
41	kt 2	7.5	SNV	63.7	29.1	0.08	0.34	1.6	7.5	**2.19**	**21.5**
36	kt 1	6	CULS	63.6	31	0.04	0.14	17.1	64.31	**2.05**	**21.5**
37	kt 1	6	CULS	63	31.3	0.06	0.26	8.6	25.15	**2.01**	**21.3**
42	kt 1	6	CULS	62.6	30.8	0.07	0.33	17.3	65.14	**2.03**	**21.2**
46	kt 1	6	CULS	61.7	31.2	0.05	0.19	5.7	15.55	**1.98**	**20.9**
47	kt 2	6	CULS	61.4	32.9	0.04	0.16	9.1	26.04	**1.87**	**20.8**
30	kt 2	9.2	CULS	60.8	34.7	> 0.1	> 1	14.6	49.51	**1.75**	**20.6**
44	kt 2	9.2	SNV	60.8	32.6	0.09	> 1	23.5	107.5	**1.87**	**20.6**
40	kt 1	6	CULS	57.8	36.7	0.02	0.04	4	9.34	**1.57**	**19.5**
43	kt 1	7	SNV	57.7	36	> 0.1	> 1	24.7	117.9	**1.60**	**19.5**

Compared with the previous commune, the measured results were very similar, which means that the digester with the largest capacity had the lowest volume of CO_2 but it was the KT2 digester type. It is necessary to take in consideration the flow rate which was below zero in this case, which could be caused by previous cooking or measurement inaccuracy.

Tab. 4.4: Biogas composition and quality in Huong Xuan commune

No. of biogas plant	Digester type	Digester capacity (m^3)	Constructed by	CH_4 (%)	CO_2 (%)	NH_3 (%)	H_2S (%)	Flow rate (l/hour)	Rel. pressure (mb)	$CH_4 : CO_2$ Index	Calorific value (MJ/m^3)
69	kt 2	9.2	CULS	74.8	17.1	0.03	0.15	-0.4	0.93	**2.13**	**25.3**
70	kt 2	6.2	CULS	71.3	22	0.05	0.31	7.6	20.52	**1.70**	**24.1**
62	kt 1	6	CULS	71.1	24.6	0.05	0.21	15.6	55.88	**2.29**	**24.0**
63	kt 2	6.2	CULS	68.7	24.7	0.06	> 1	7.3	18.7	**2.27**	**23.2**
58	kt 1	6	CULS	68.6	25.9	0.04	0.24	19.1	77.03	**2.54**	**23.2**
72	kt 2	6.2	CULS	68.6	26.5	0.05	0.32	11	32.81	**1.54**	**23.2**
64	kt 2	6.2	CULS	67.5	26.5	0.07	> 1	10.2	29.22	**2.24**	**22.8**
51	kt 2	9	CULS	67.1	31.2	0.08	0.27	16.5	71.59	**4.37**	**22.7**
57	kt 1	7	SNV	66.7	27.1	0.05	0.29	16.1	60.12	**2.56**	**22.5**
68	kt 2	6.2	CULS	66.6	26	0.04	0.29	8.8	25.2	**2.15**	**22.5**
53	kt 2	6.2	CULS	66.1	29	0.09	> 1	8.1	23.23	**2.89**	**22.3**
59	kt 1	7	CULS	65.6	27.2	0.05	0.38	16.1	60.12	**2.46**	**22.2**

65	kt 1	7	SNV	65.6	27.7	0.06	> 1	16.8	62.58	**2.21**	**22.2**
71	kt 1	6	SNV	65.1	28.4	0.06	0.48	22.1	100.1	**1.54**	**22.0**
60	kt 2	6.2	CULS	64.9	28.9	0.05	0.36	3.1	7.9	**2.41**	**21.9**
56	kt 1	6	SNV	64.6	29.2	0.04	0.28	15	53.63	**2.58**	**21.8**
52	kt 1	6	CULS	64.4	30.2	0.09	0.39	14.1	48.28	**3.24**	**21.8**
55	kt 1	6	SNV	64.2	29.3	0.06	0.42	12.7	41.12	**2.64**	**21.7**
66	kt 1	6	SNV	64.1	28.9	0.04	0.27	9	25.68	**2.21**	**21.7**
61	kt 1	6	CULS	58.7	34.5	0.07	> 1	17.4	64.71	**2.36**	**19.8**
54	kt 1	9	CULS	57.3	37	0.05	0.36	2.8	6.7	**2.78**	**19.4**
67	kt 1	6	SNV	56.7	36.8	0.04	0.27	18	68.6	**2.19**	**19.2**

In this commune, no significant difference was found between the measured biogas plants, but it can be concluded that the KT2 digesters are above the average values in every parameter measured for the whole commune.

Tab. 4.5: Biogas composition and quality in Phong An commune

No. of biogas plant	Digester type	Digester capacity (m^3)	Constructed by	CH_4 (%)	CO_2 (%)	NH_3 (%)	H_2S (%)	Flow rate (l/hour)	Rel. pressure (mb)	CH_4 : CO_2 Index	Calorific value (MJ/m^3)
86	kt 1	6	SNV	66.7	26.9	0.04	0.32	11.1	34.3	**2.48**	**22.5**
78	kt 2	9.2	CULS	66.4	27.3	0.03	0.20	14.1	46.63	**2.43**	**22.4**
81	kt 1	6	SNV	65.4	28.9	0.04	0.26	6.1	21.01	**2.26**	**22.1**
74	kt 2	9.2	CULS	65.3	31.5	0.06	0.39	11.9	16.62	**2.07**	**22.1**
79	kt 2	9.2	CULS	65.1	28.2	0.04	0.28	12.2	38.13	**2.31**	**22.0**
87	kt 2	9.2	CULS	64.3	28.5	0.05	0.29	8.7	23.93	**2.26**	**21.7**
77	kt 2	9.2	CULS	63.8	31.5	0.05	0.41	22.1	96.07	**2.03**	**21.6**
80	kt 1	6	SNV	63.8	29.7	0.06	> 1	16.5	60.47	**2.15**	**21.6**
84	kt 1	9	SNV	63.6	30.7	0.05	0.40	12.6	40.33	**2.07**	**21.5**
85	kt 2	9.2	CULS	63.6	29.4	0.04	0.25	6.7	17.32	**2.16**	**21.5**
73	kt 1	9	SNV	62.8	34.3	0.07	0.31	16.8	60.6	**1.83**	**21.2**
75	kt 1	6	SNV	61.1	34.1	0.04	0.23	16.2	57.94	**1.79**	**20.7**
76	kt 1	9	SNV	61.1	33.5	0.05	0.40	7.6	20.16	**1.82**	**20.7**
82	kt 2	9.2	CULS	60.2	33.1	0.02	0.11	10.9	31.74	**1.82**	**20.3**
83	kt 1	6	CULS	59.5	34.2	0.06	> 1	15.5	54.05	**1.74**	**20.1**

In the Huong An commune, no significant difference was found between the measured parameters. The best results were measured at the biogas plant with the smallest digester capacity. This fact confirms the above-mentioned Pearson correlation coefficient, which has shown that there is no significant relation between the digester capacity and the amount of biogas produced. This commune has had the lowest values of the CH_4 – CO_2 index in comparison with other communes.

Tab. 4.6: Biogas composition and quality in Huong An commune

No. of biogas plant	Digester type	Digester capacity (m^3)	Constructed by	CH_4 (%)	CO_2 (%)	NH_3 (%)	H_2S (%)	Flow rate (l/hour)	Rel. pressure (mb)	$CH_4 : CO_2$ Index	Calorific value (MJ/m^3)
97	kt 1	6	CULS	68.3	27.3	0.05	0.36	19.6	85.48	**2.50**	**23.1**
104	kt 1	6	CULS	67.3	28.5	0.05	0.43	7.6	20.24	**2.36**	**22.8**
103	kt 1	9	CULS	66.8	27.5	0.07	> 1	19.2	76.04	**2.43**	**22.6**
95	kt 1	8.1	CULS	66	27.2	0.05	> 1	12.4	63.25	**2.43**	**22.3**
88	kt 1	6	SNV	65.7	31	> 0.1	> 1	17.4	64.12	**2.12**	**22.2**
107	kt 1	6	CULS	64.7	28.2	0.05	0.47	4.7	10.35	**2.29**	**21.9**
96	kt 1	6	CULS	63.8	30.7	0.05	0.40	3.6	6.88	**2.08**	**21.6**
98	kt 1	8.1	CULS	63.8	29.5	0.05	0.44	15.9	56.72	**2.16**	**21.6**
94	kt 1	6	CULS	63.4	32	0.04	0.37	19.3	77.05	**1.98**	**21.4**
99	kt 1	8.1	CULS	62.8	31.5	0.02	0.16	11	32.41	**1.99**	**21.2**
106	kt 1	6	CULS	62.7	30.4	0.05	0.44	1	2.8	**2.06**	**21.2**
101	kt 1	8.1	CULS	61.9	32.9	0.03	0.30	17.1	63.42	**1.88**	**20.9**
92	kt 1	6	SNV	61.7	32.3	0.05	0.46	23.2	75.86	**1.91**	**20.9**
91	kt 1	8.1	CULS	61.5	32.9	0.01	0.09	22.1	94.96	**1.87**	**20.8**
93	kt 1	6	CULS	60.1	33.2	0.05	> 1	10.7	38.87	**1.81**	**20.3**
102	kt 1	6	CULS	59.3	34.5	0.05	0.45	15.5	54.61	**1.72**	**20.0**
89	kt 1	8.1	CULS	58.6	37.4	0.06	0.33	12.5	38.82	**1.57**	**19.8**
100	kt 1	8.1	CULS	58.5	35.1	0.05	0.38	21.1	88.36	**1.67**	**19.8**
105	kt 1	6	CULS	57.9	35.9	0.03	0.29	9.7	26.58	**1.61**	**19.6**
90	kt 1	8.1	CULS	56.9	38	0.05	> 1	15.6	54.8	**1.50**	**19.2**

On the base of the CH_4 – CO_2 index, it is possible to assume that the biogas plants in Phong Xuan and Huong Xuan are constructed and connected better than the others, because of the lower CO_2 volume in the produced biogas. The volume of CO_2 is mainly affected by the presence of oxygen inside the digester. If any improvements were made to the digester inlets, the presence of oxygen inside the digester would decrease and the index would increase and the quality of the produced biogas would be better.

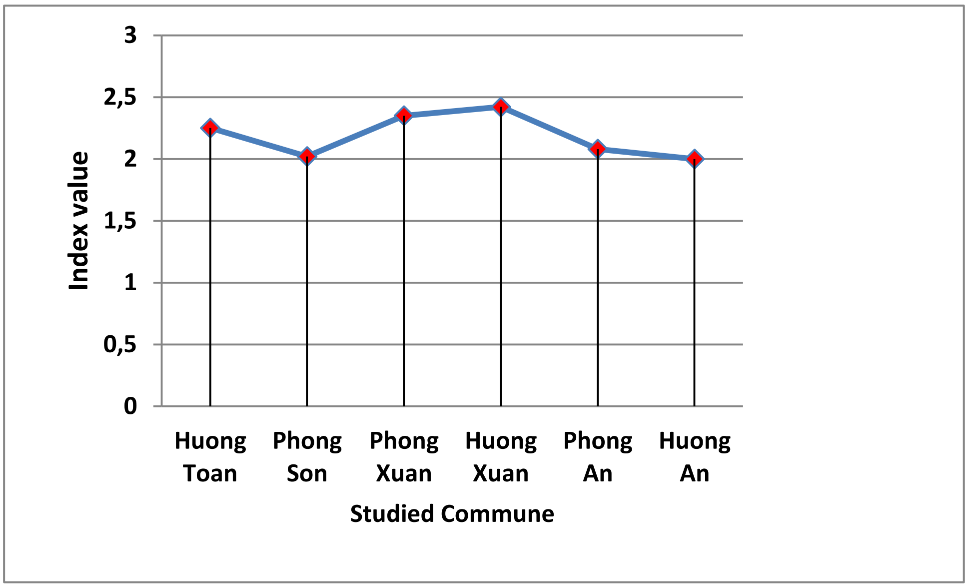

Fig. 4.6: Comparison of values of CH_4 – CO_2 index in communes under study

On the basis of measured and researched data was found out that the average methane content in biogas was over 60%. This value is comparable with the value which states Rajendran (2012) in review of Household biogas digesters in Africa. There was used as the primary substrate for biogas production the pig slurry as well and the methane content in biogas was also 60%, within use of cattle dung as the primary substrate the value of methane content was around 50%. Wargert (2009) state that the similar home biogas digester type with the digester capacity of 6m^3 installed in Nepal is able to produce around 2.7 m^3 of biogas per one day. According to our measured results was calculated the average daily biogas production it was around 0.299 m^3 per day. The difference between average daily biogas production could be explained by Sasse (1988), he states, that fixed dome biogas digesters can annually leak around 55% of methane and the production of biogas is also dependent on the temperature of substrate.

According to measured data was calculated the average calorific value of home biogas plants used in Central Vietnam. It was 0.30 MJ/m^3. Heegde et al. (2009) from SNV state by the review of Tanzania Domestic biogas program the average calorific value of biogas around 1.14 MJ/m^3. In contrast to the Vietnamese project, in Tanzania, there was used the floating drum biogas digester and cattle dung as a substrate. Similar calorific value state Kamara et al. (2010) in the review of Uganada domestic biogas programme. The average calorific value in Uganda was around 1.61 MJ/m^3 within use of the similar fixed dome digester types with the similar range of digester capacity like in Vietnam and as the digester substrate was used pig slurry as well. Very similar calorific value state Chen et al. (2010) in Renewable and sustainable energy reviews. By the project realised in China within use of similar fixed dome biogas digesters with the capacity range between 6 up to 10 m^3 and within use of the same substrates the average calorific value was around 1.08 1.61 MJ/m^3. All of these projects were realised by SNV. However data measured on home biogas digesters installed by SNV in Vietnam were similar in compare with data measured on home biogas digesters installed by CULS.

Other topics for broader discussion could include leakages of the digesters, which can result in a higher level of oxygen inside the digester and thereby higher volume of the produced carbon dioxide.

6. Conclusions

According to all the measured and calculated data was the average content of methane in biogas from home biogas digesters installed by CULS 64.60%. The average value of CH_4 – CO_2 index was 2.22. The average calorific value of biogas produced by plants installed by CULS was 21.8 MJ/m^3. The average content of methane in biogas produced by plants installed by SNV was 64.04%. The average value of CH_4 – CO_2 index was also a little bit lower it was 2.09. The average calorific value of plants installed by SNV was 21.6 MJ/m^3. On the basis of these data it can be considered, there is not any significant difference between biogas produced from home biogas plants installed by CULS and plants installed by SNV.

On the basis of researched data was found that the most used digester substrate was the pig slurry. The second most used digester substrate was the combination of pig slurry with human excreta. The most common digester connection was the connection with stable. The second most common digester connection was connection with latrine together with stable.

According to calculated Pearson correlation coefficient no assumed dependence of the variables has been demonstrated. It can be concluded that there is no significant relation between the selected variables. It is recommended to continue the research and to focus more on the constructions and performance of the digesters to eliminate the presence of oxygen inside the digester in order to decrease the total amount of the produced carbon dioxide, which is decreasing the CH_4 – CO_2 index and can also account for the lower calorific value of biogas. It is also recommended to try to increase the proportion of oil plants or oil plants residues in the digester substrate to increase the final CH_4 production and to increase its quality.

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