Module 04 : Planning operations

Week 03B: Technologies for energy recovery from organic waste

Resource Recovery and Reuse
(RRR) Entrepreneurship

Week 3.B module 4: Technologies for energy recovery from organic waste

“Welcome to week 3.B of module 4: Technologies for energy recovery from organic waste”. This week we are going to look at selected treatment technologies that convert organic solid waste into biogas, non-carbonized and carbonized briquettes, as well as pellets.

Remember that in week 2 we learnt that the options for waste treatment could be biological, physical and chemical, and that also these last two could be combined into physico-chemical and thermo-chemical treatment. Right?

Now, we are going to learn about 3 differ types of processes, covering many of these treatments, namely: Anaerobic digestion, densification and pyrolysis, also called carbonization.

Let’s start with anaerobic digestion for biogas production. A wide range of different biomasses can be used as substrates for biogas production. Anaerobic digestion’s feedstock includes sewage sludge, animal manure, food industry waste, energy crops and harvesting residues and the organic fraction of municipal solid waste.

Notice that every organic feedstock comprises dry material and water. Dry material could be inorganic and organic. This last, composed of proteins, carbohydrates and lipids, is of interest for anaerobic digestion.

What is important for you is that, knowing the Total Solids Content and the Volatile Solids Content of your substrate, you can adjust the moisture for optimal gas production. Keep in mind that usually anaerobic digestion occurs in an aqueous environment, which means with low-solids concentration. However, dry digestion, with a total solids’ concentration higher than 15%, is currently under research and development, as it offers many benefits over wet anaerobic digestion, such as smaller reactors size, lower energy inputs, etc.

What I can recommend you is to mix different types of solid and liquid wastes, which results in a homogenous mixture increasing the stability and performance of the process.Keep in mind that you will need to carry out a number of pilot tests to find out the optimal composition of your feedstock to maximize the gas production.

Like any RRR process, anaerobic digestion is composed of three steps: pre-treatment, principal treatment and value addition. The pre-treatment needed will depend on the characteristics of the substrate. If municipal organic solid waste is going to be used, you might need to sort out the plastics and other inorganic fractions. Strong lignified substances, like energy crops or crop residues will require a mechanical treatment, such as grinding and extrusion, to reduce the particle size. For co-digestion, which means when you are introducing different subtracts to the digester, you might need to mix the materials. And finally, in case you need to adapt the moisture level, you might need to water the substrate. Keep in mind, that sometimes, especially when the moisture content of your substrate is more than 60%, you might not need any pre-treatment.

The principal treatment is where the actual anaerobic degradation actually happens, and as a result, biogas and digestate is produced. Digestate is the mixture of solids and liquids of partially digested sludge discharged by the digester.The main types of anaerobic digestion in low- and middle-income settings are:

-Fixed-dome digester
-Floating-dome digester and
-Tubular digester

In the fixed dome, the volume of the reactor is constant. As gas is generated it exerts a pressure and displaces the slurry upward into an expansion chamber. When the gas is removed, the slurry flows back into the reactor. The pressure can be used to transport the biogas through pipes. In a floating dome reactor, the dome rises and falls with the production and withdrawal of gas. A tubular digester expands like a balloon as the biogas is being produced.

Each of these technologies has its advantages and disadvantages. For instance, a fixed dome has the advantage of the absence of moving parts and rusting steel parts. If well-constructed, fixed dome plants have a long-life span. Its disadvantages are mainly the frequent problems with the gas-tightness of the brickwork gas holder; therefore, they are only recommended where construction can be supervised by experienced biogas technicians. Floating drums have a simple and easily understood operation, since the volume of stored gas is directly visible. Its disadvantages are the high material costs of the steel drum and the susceptibility of steel parts to corrosion. The advantages of balloon digesters are the low cost, simple construction and easy operation and maintenance. However, they have a relatively short life span and high susceptibility to damage.

The decision on the type of the reactor is based on the local context, technical parameters and the experience of the operators.

Usually, biogas reactors have hydraulic retention times of at least 15 days in hot climates and 25 days in template climates. The production of biogas will depend on:

-the operation mode: batch, single or multi-stage reactor
-Concentration
-C:N ratio
-pH among other.

However, the single most important parameter is the type of feedstock. This table shows the typical biogas yield according to different feedstock. As you can see, sewage sludge produces very little biogas, and therefore it should be mixed with other inputs.

Once biogas is produced it can be used for various purposes, including:

1) production of heat and steam,
2) electricity generation, and
3) vehicle fuel

The most straightforward use of biogas is for thermal (heat) energy. In areas where fuels are scarce, small biogas systems can provide the heat energy for basic cooking and water heating. Gas lighting systems can also use biogas for illumination.

You can also obtain electricity by using a gas-based generator required to convert the chemical energy found in biogas into electricity. The equivalent of 6 kWh of heating energy is contained in each cubic meter of biogas. About 2 kWh of useable electricity can be obtained when biogas is converted to electricity. The remaining biogas is converted to heat which, can then be used for heating applications.

Gasoline vehicles can use biogas as a fuel provided the biogas is upgraded to natural gas quality in vehicles that have been adjusted to using natural gas. Most vehicles in this category have been retro-fitted with a gas tank and a gas supply system in addition to the normal petrol fuel system.

Going back to our typical configuration of an anaerobic digestion system, after the production of biogas, we need a further step of value addition. This is needed for two reasons:

(1) to increase the heating value of biogas, and

(2) to meet requirements for some gas appliances (engines, boilers, fuel cells, vehicles, etc.).

Usually, we will need to remove CO2 to increase the heating value and quality of the biogas. This can be done economically through absorption or adsorption. However, for many of the simpler biogas applications such as heaters and generators, CO2 removal is not necessary.

Straight from the digester, biogas will be saturated with water vapor. Besides reducing the energy value of biogas, water can react with hydrogen sulfide to create sulfuric acid, which is corrosive to metals. Refrigeration or sensible pipe-work design can condense and remove the water. The biogas is normally compressed before cooling to achieve high dew points.

Hydrogen sulfide in biogas needs to be removed for all but the simplest burner applications. Hydrogen sulfide in combination with the water vapor in raw biogas can form sulfuric acid (H2SO4), which is very corrosive to engines and components. At concentrations above 100 parts per million by volume (ppmv), H2S is also very toxic.

Finally, you need to keep in mind that anaerobic digestion also produces slurry, also called sludge or digestate. This end-product is rich in organics and nutrients, almost odourless and the pathogens it contains are partially inactivated.

As the goal of RRR based businesses should be full resource recovery from all end-products, disposal at landfills is not advocated. In any case, the sludge has to comply with local regulations and post- treatment technologies have to be implemented. I recommend you look at the module 3A, in which the system for nutrient recovery of sludge, for instance through drying and co-composting, is explained

Now that we have learned about anaerobic digestion, it is time to look at the physico-chemical treatments that include chemical reactions or the application of physical, mechanical force.

The first of them is the densification.

The low density of herbaceous and woody biomass limits their application in energy production, as it makes the material difficult to store, transport and use. Therefore, prior to use in energy applications, these materials need to be densified to increase their bulk densities.

Densification involves the compaction of biomass by applying mechanical force or sometimes binding agents to create inter-particle cohesion, resulting in homogenous briquettes or pellets with consistent shapes and sizes, and bulk densities. The improved consistent physical properties improve fuel quality and make the densified biomass suitable for many residential and industrial applications.

Biowaste used for densification can be divided mainly in two types of lignocellulosic residues: crop wastes and agro-industrial residues.

Crop wastes include the residues which remain in the field after harvesting, for instance, paddy straw, bean straw, soya straw, maize straw and wheat straw. Agro-industrial residues on the other hand are generated during the processing of crops or logwood, and include rice husk, coffee husk and soybean husk, bagasse, sawdust and other wood processing products.

There are other types of feedstock used such as groundnut shells, mustard stalks, cotton stalks, coconut fibers, palm fruit fibers and urban solid biowastes such as leaves, grass, tree trimmings and waste paper. However, for waste to be densified, moisture content should be as low as possible, generally in the range of 10–15%.

Like any RRR process, densification is composed of three steps: pre-treatment, principal treatment and value addition.

Pre-treatment of the raw biomass includes:

-Grinding: which is the mechanical fragmentation of raw materials by crushing machines.
-Drying of the crushed materials when the moisture content is too high for briquettes production.
-Pre-heating, which improves the efficiency of the principal treatment.

The principal treatment for biomass densification can be classified according to their working principle. It can be extrusion, pelletizing and briquetting.

An extruder brings the smaller particles closer, providing more strength to the densified bulk material. During extrusion, the biomass moves from the feed port, with the help of a rotating screw, through the barrel and against a die, resulting in significant pressure. The combined effects of wall friction, internal friction in the material, and high rotational speed of the screw, increase the temperature in the closed system and heat the biomass. This heated biomass is forced through the extrusion die to form the briquettes or pellets with the required shape.

A pelletizer consists of a perforated hard steel die with one or two rollers with cylindrical shaped press channels. As the figure indicates, by rotating the die and/or rollers, the feedstock is forced through the channels to form densified pellets. Heat is generated from the high friction between the biomass and the press channel walls.

In the briquetting process, the biomass is compressed under high pressure and temperature, allowing biomass particles to self-bond to form high-density briquettes.

In a briquetting roller press, the feedstock falls in between two rollers rotating in opposite direction and is compacted into pillow-shaped briquettes. Briquetting machines can handle larger-sized particles and higher moisture contents without the addition of binders compared to pelletizers.

As summary, you need to keep in mind that an extruder and a pelletizer produce pellets, while a briquetting roller press produces briquettes, which are bigger and have different characteristics. Briquettes and pellets can both be used for domestic heating, cooking and as industrial fuel, thereby replacing wood-based fuels and fossil fuels. If you want to learn more about these three technologies, I recommend you read the article: A review on biomass densification technologies for energy applications.

Going back to our typical system, the last step of densification is the value addition. The value addition processes of densification include cooling, screening and packaging.

Now, it is time to learn about the thermochemical treatments, which apply heat to induce chemical reactions as a means of extracting and creating energy carriers as products. These include pyrolysis.

Pyrolysis, also called carbonization, is an anaerobic decomposition process at high temperature, in which biomass is "burned" in the absence of oxygen. This decreases the volatile matter and moisture content of the raw material, and results in high carbon content of the carbonized material and thus higher energy content than when non-carbonized.

Carbonized briquettes can be made out of any biomass material, although the choice of feedstock can determine its heating potential as a fuel. The available biomass resource consists primarily of:

- Wood
- Agricultural Waste (field residues and process residues)
- Agro-industrial waste
- Animal Manure
- Municipal Solid Waste (Household and Food Processing Wastes)
- Fecal sludge

To ensure a high-quality product, pre-treatment of the input waste is an important step.

Pre-treatment depends on the type of input, so if you are having municipal solid waste, you will need to sort the material. If you are using fecal sludge or animal manure, you will need to mix with other woody material. In case of agro-industrial or agricultural waste, you need to shred to ensure a consistent small particle size. In order to reduce the demand of energy during carbonization, raw materials need to be dried with a moisture content below 15%.

Once the material is ready, it is time for the carbonization process, also called slow pyrolysis. Carbonization is often carried out in batch reactors, and is mostly affected by temperature, pressure and reaction time. Methods of carbonization in developing countries largely follow traditional charcoal making techniques, which achieve conversion efficiencies of less than 10%. This is the case of the earth pit/mound kilns. Some improved processes have been developed for small scale char production, with improved efficiencies of up to 30%. Brick and steel kilns can be used in low-scale briquette production, with a retention time of hours and yield of 25-30%.

Large scale plants as well as drum retorts are applied in large- scale production, as allow for continuous operation and yields of 30-40%.

After carbonization, the produced charcoal needs to be grinded into powder form. This can be done manually by crushing, chopping or by using mechanized milling machines. It is often then sieved to ensure consistency in the powder.

Binding is the process of sticking together the compacted material. Due to loss of binding elements in raw materials during carbonization, a binder with high binding property needs to be used to create a solid form with the densification into a mold. Common binders include cassava flour, molasses, wheat flour, fine clay and red soil.

Once the charcoal is ready, it is possible to start forming the carbonized briquettes.

Briquetting technologies can be classified in the following categories based on the mechanical features and equipment involved:

-Piston press densification,
-Screw press densification,
-Roll press densification and
-Manual presses.

Mechanical piston presses are usually applied for large scale production (e.g. 200 to 2,500 kg/h). They are relatively large machines in which a heavy piston forces biomass material through a tapered die.

Screw presses use a screw action to extrude a briquette through a die. Biomass is fed into the machine from a hopper into the screw chamber. Powered by an electric motor, the screw forces the material through a die and out of the machine as a continuous (usually cylindrical) briquette.

Roller Presses are also commonly used to make charcoal briquettes. They involve two adjacent counter-rotating rollers with indentations in the shape of the desired briquette. Powder is fed from above, which falls into the indentation and is compressed as the rollers turn. The briquette then exits the machine as a single pillow shaped lump. The level of compaction achieved by a roller press is relatively low compared to a piston or screw extruder and so is suited more to briquetting of wet powders containing a binding agent. However, production rate of a roller press can be very high, reaching 1.5 tonnes per hour.

Manual presses are frequently used in low- and middle-income countries. There are various types of manual presses, with the advantages of low investment and operation cost and low levels of required skills. Manual presses mold the feed stock with lower pressure with high moisture content which should be dried after shaping into briquettes. The dried briquettes have low strength and can be crumbled easily.

Once the briquettes are obtained, these need to be dried to less than 10% moisture content.

The most common method for doing this in tropical countries is through sun-drying due to the favorable climate. This is usually done by laying the briquettes out on polythene or iron sheets or a wire mesh. Sun-drying can take up to 3-4 days to dry the briquettes completely. Even large companies continue to use sun- drying methods for finished briquettes.

Other low-capital solutions for drying include solar driers, heated fans or tunnel ovens.

Depending on the customer’s requirements, briquettes should be packaged in convenient formats for its distribution and sale.

Today, charcoal is still one of the primary cooking fuels in many low- and middle-income settings, with 80–90% of urban households in sub-Saharan Africa depending on it. Apart from cooking, charcoal is used for heating, in industrial processes requiring heat, and as soil amendment.

You have now learnt about technologies to produce biogas and briquettes from waste for energy recovery.

When assessing which technologies are most appropriate for your waste to energy system, you need to ask yourself the following questions. You may download the worksheet below to record your findings.

-What should be the treatment objectives in terms of caloric value and energy recovery?
-What suitable technologies and machines are available locally? What has been the experience with them?
-What is the level of performance and efficiency of the different technologies?
-Are there resource constraints related to labour, land, energy or other factors of production?
-If there is a break-down in the plant, are capacities and resources available for the timely repair and maintenance?

To learn more about carbonized and non- carbonized briquettes, I would recommend you to read the following articles:
-Briquettes Businesses in Uganda, by Hamish Fergunson.
- As well as the Resource Recovery and Reuse Series 7: A review on Production, Marketing and Use of Fuel Briquetting by IWMI.

Now that you have learnt about the different technologies for energy recovery, it is time to plan your own technology system for biogas recovery or for production of briquettes.

Record your findings in the worksheet below.

In module 2, you have calculated your sales volume, which is the amount of biogas or electricity to be produced, or the number of briquettes expected to sell.

By using the expected sales volume in units/day, you are able to estimate the capacity of the system. For instance, the volume of the biogas reactor, and the number of kilns and presses for the production of briquettes.

You can also estimate the time of a production cycle, which includes the time it takes to prepare the feedstock from the moment the waste arrives until biogas is produced or briquettes are ready to sell. Here, you will need to make some assumptions, for instance how long it would take to sort, mix and prepare the waste.

With this new information it is time for you to describe the specifications of each treatment step: what is the type of technology, the capacity of each step and the list of all equipment needed. Record your findings in the worksheet.

In week 4, I will guide you through the planning of your resources. That’s why it is very important to know the specifications of your system.

I will see you there!”

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Graph sources:

- Unless otherwise noted, all graphics and case studies from OTOO, M. (Editor), DRECHSEL, P. (Editor) (2018): *Resource Recovery from Waste. Business Models for Energy, Nutrient and Water Reuse in Low- and Middle-Income Countries.* International Water Management Institute (IWMI). Routledge
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Palm fibre: https://www.flickr.com/photos/torquay-palms/19595467716/in/photolist-9hqZPF-avDpEi-vRzTRE-dfkdGf-9hqZVc-6U27V2-9gMM53-5rnbTw-9hu8dw-8G6Kxa-8otmiM-PSkXYq-m5t5gH-NQdNM-bBTLv4-r83bsp-9q6SMF-422rkZ-6HpXZ6-WG6dgz-bgBErx-9q6NvB-9q9WMQ-9qa1hY-9q9SLS-WG6dgK-CidGMt-BAxenE-wfsy7b-s5zrfN-bgBKba-5wGVkz-fWXjv5-5wMhSj-Cy3s3x-NGcUvK-eSpAgy-PSkYYm-NGcFYF-NGcT6R-P3Q6H
Urban waste: https://www.flickr.com/photos/mezuni/2205003791/in/photolist-4mRdNK-ezVD2d-4T3AJj-4UbrMn-9CqEAw-664Wq7-gkC8zP-6zjdb9-2hkSzk-2EKQr1-gkCabp-5MyseL-5tpR6i-5xQxvo-7wBMVG-tkFfD-dt4MPs-7wBRzy-6EgY6d-djp5ZX-6Lc6JY-4LfZRU-dXSQ8v-LScht-26RRvyK-66n76y-5mgVdH-br8s7L-9LgXsS-3tThKG-28YRUY3-68oFgz-6EcC6T-TN5mx2-6LccaS-gkCBjK-5mAhGh-9uYA3J-6EcyV2-eQDCCw-9GqJwC-6Ed1ge-89Yg4B-8a2vV9-6Eh5XW-4fTRUt-cez7SJ-pRdwLN-7GMzSq-6EcUbD
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66TeJB-8P5n5W-fPeHde-fPw93Q-62XdiV-aUbePe-fPeENg-qSq6ZW-8P2gvi-aUberP-aUbfot-6EdGns-rCrdQ5-TcNfkH-dFq3G-2dNE5dH-7VDeWX-GPProi-agdxdW-S9Xfcp-2drVxWm-2aKP7C1-2dwnp8T-2aKP7K5-2aKP7QL-zJqsKG-2gFS1FN-h8nha7-2gzFVh8-8LDHMW
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*Information and data were compiled to our best knowledge, but mistakes remain possible. In such a case we apologize and kindly ask for feedback to correct them.