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More than garbage at the Doña Juana Landfill

Más que basura en el Relleno Sanitario Doña Juana

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This article details the mismanagement of organic waste and other residues of different kinds that arrive at the Doña Juana Landfill. Bad procedures and bad decisions have been identified in the problem due to the area where it is located and the design of the landfill. The recognition of all types of waste that arrive at the sanitary landfill should be done, and based on the conflicts that have been generated inside and outside the landfill, a better solution should be sought, so that the environmental impact is as small as possible, and the quality of life of the families that live in the periphery should be improved.

Keywords: Doña Juana Landfill, environmental impact, organic waste

Este artículo detalla el mal manejo de los residuos orgánicos y otros residuos de diferente índole que llegan al Relleno Sanitario Doña Juana. Se han identificado en el problemas, malos procedimientos y malas decisiones debido a la zona donde está ubicado y al diseño del mismo. Debe realizarse el reconocimiento de toda la clase de desechos que llegan al relleno sanitario, y con base en los conflictos que se han generado dentro y fuera del relleno, se debe buscar una mejor solución, para que el impacto ambiental sea lo menor posible, y mejorar la calidad de vida de las familias que habitan en la periferia.

Palabras clave: Impacto ambiental, Relleno Sanitario Doña Juana, residuos orgánicos

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Introduction

This article has been created with the intention of giving information to the reader about the events that occurred due to a bad management and distribution of the waste thrown in the Doña Juana Landfill. We will tell the story, how it was originated and all the problems that it has caused, for example, giving rise to the generation of diseases in the inhabitants of the areas and the flooding of pests like flies and rats. Even landslides that caused the stream that passed through this place was contaminated ceasing to be useful for agriculture that was carried out there, besides this also make known a possible solution for the use of these with alternative energy as it has been biogas which brings many advantages both environmental and economic in a community, besides being something aesthetic view of the inhabitants.

Of course, it is not only the fault of the people in charge of the landfill, since all these problems also derive from another hand that is the same inhabitants of the department of Cundinamarca due to the lack of culturalization and appropriation of the land, there are still many people who in spite of knowing the consequences of not recycling and following the campaigns that have been made on the classification of the garbage in industries as well as in homes, still make the mistake of not doing it, which makes things difficult when the waste arrives to the garbage trucks and from there to the dump, It is clear that we cannot leave aside the need to consume and produce food and even technology since this is what moves trade and the world, and this is where biogas comes in as the alternative energy we need since with this we can take advantage of organic waste to light homes, industries, heat and fuel for the different machines that have already been and will be created by the human being, of course you have to know how they work and how to obtain this, and what you get, and this is what we will show here, a mantle of concepts and knowledge of which you were probably unaware and could change your way of thinking about the waste coming out of your company or home.

What is a landfill?

A sanitary landfill is understood as a facility for the final disposal of solid waste that cannot be recycled or used, designed to minimize environmental impacts and reduce the health risks potentially generated by such waste (Arias & Buitrago, 2012).

The safe and reliable final disposal of non-recyclable and non-usable solid waste is a fundamental component in the integral management of solid waste, made up of four elements whose hierarchical order is reduction at source, use and valorization, treatment and transformation and finally controlled final disposal. For this purpose, it is important to develop the stages of planning, design, construction, operation, decommissioning, adaptation and final use that the adequate management that a sanitary landfill implies (Arias & Buitrago, 2012).

The selection of the method to be used for the operation of a landfill should be made based on the topographical, geotechnical and hydrogeological conditions of the site selected for the final disposal of the waste. The stratigraphic profile of the soil and the level of the groundwater aquifers must be established.

Stratigraphic profile and groundwater level

Stratigraphy is a branch of geology that studies rocks taking into account the temporal sequence and the materials that constitute them; therefore stratification is the way sedimentary rocks are deposited according to the agent and the sedimentary environment (Pasotti, 2017).

The stratigraphic profile (Fig. 1) is the one made from drilling data, geophysical prospecting data, or natural or artificial terrain cuts that show the rocks that make up the stratigraphic column, through which the subsoil stratigraphy can be reconstructed, according to the depth required by the project (Galvis, 2016; Sanjuan, 2012).

The phreatic level (Fig. 2) is a fundamental concept in hydrogeology, which is the branch of geology dedicated to the study of surface and underground water cycles. The phreatic level (water table) is the geometric location of the points where the water pressure is equal to the atmospheric pressure. The phreatic level is defined by the levels reached by the groundwater in observation wells. When water moves through pores and voids under the effect of gravity and meets an impermeable layer, it can be stored, leading to the formation of aquifers (*Nivel freático del suelo*, 2017).

An aquifer is a body of saturated rock through which water can easily move, according to the Idaho Museum of Natural History. Water moves through the pores of the rock. Aquifers can be considered confined or enclosed. The bottom of a free aquifer is a layer of porous rock, which restricts water flow, creating a barrier to the aquifer. The phreatic level is the upper layer of the unconfined aquifer (Quiroz, Martínez, & Massone, 2012; Varni, Zeme, Weinzettel, & Dietrich, 2014).

Suggested methods to be used

Trenching method. This method is used in flat regions and consists of periodically digging trenches two or three meters deep with a backhoe or a crawler tractor. The solid waste is deposited and accommodated within the trench and then compacted and covered with the excavated soil (Fig. 3).

Special care should be taken during rainy periods as water may flood the ditches. Therefore, perimeter channels must be built to capture and divert the water and even provide the ditches with internal drainage. Its slopes or walls must be cut according to the angle of rest of the excavated soil.

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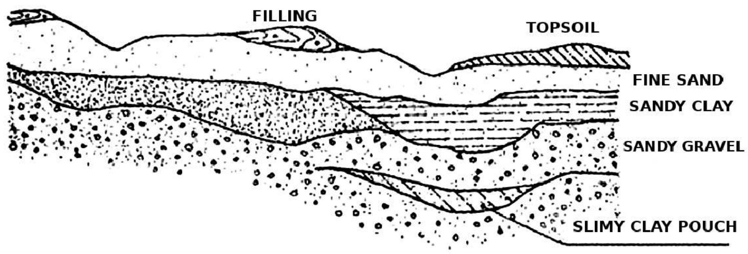

Figure 1. Stratigraphic soil profile.

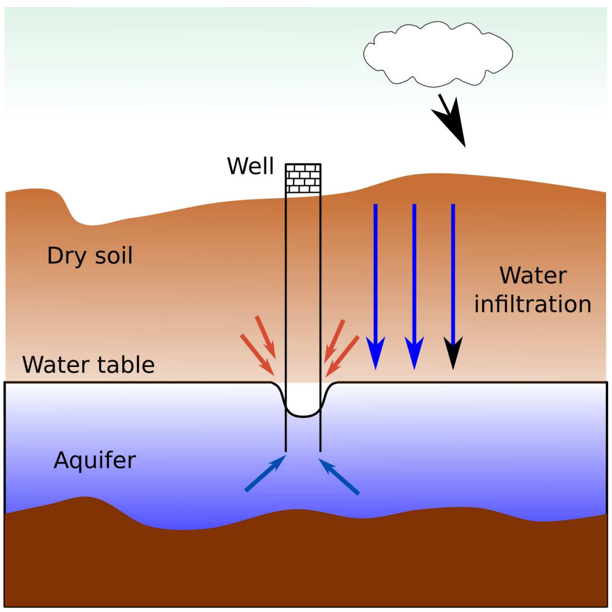

Figure 2. Phreatic level.

Trenching requires favourable conditions with regard to both the depth of the water table and the type of soil. Soils with a high water table or very close to the surface are not suitable because of the risk of contaminating the aquifer. Rocky soils are also unsuitable because of the difficulties of digging (Pagano, 1964).

Area method. In relatively flat areas, where it is not feasible to dig pits or trenches to bury the garbage, it can be deposited directly on the original soil, which must be raised a few meters, after waterproofing the ground (Fig. 4). In these cases, the covering material should be transported from other sites or, if possible, removed from the surface layer. The pits are built with a gentle slope on the slope to prevent slippage and to achieve greater stability as the fill is raised (Pagano, 1964).

It is also used to fill in natural depressions or abandoned quarries a few meters deep (Fig. 5). The covering material is excavated from the slopes of the land or, failing that, from a nearby place to avoid the costs of haulage. The operation of unloading and construction of the cells must be started from the bottom up.

The landfill is built by supporting the cells on the natural slope of the land, i.e. the waste is dumped at the base of the slope, spread out and pressed against it and covered with a layer of soil every day. The operation is continued by advancing on the land, maintaining a gentle slope of about 18.4 to 26.5 degrees on the slope, i.e. the vertical/horizontal ratio of 1:3 to 1:2, respectively, and 1 to 2 degrees on the surface, i.e. 2 to 3.5% (Pagano, 1964).

Combined method. Since these two methods of landfill construction have similar operating techniques, it is possible to combine both to take advantage of the land and cover material (Fig. 6).

For medium and low levels of complexity, the landfill must be reached by a public access road, which must be a main road of permanent use and must meet acceptable design conditions.

For high and medium-high levels of complexity, the layout of the internal routes must take into account the dimensions of the cells, sub-modules and modules, the operating methodology and the climatic conditions, such that the waste must be received under all conditions.

External roads must meet at least the following specifications: Access to the landfill must be on a public road, must be of permanent layout and must guarantee transit at any time of the year for all types of vehicles that come to the landfill.

With the creation of a sanitary landfill it is important to take into account the environmental quality criteria related to the disposal of solid waste since it is necessary to follow them up in detail. Among them are:

- The impact of gas emissions on the greenhouse effect.
- Uncontrolled generation of leachates, producing surface and ground water contamination.
- Risks and threats caused by instability of the filling.
- Uncontrolled escape of gases that can migrate away from the landfill site, producing bad odors and potentially dangerous conditions.
- Reproduction of sanitary vectors due to inadequate operation of the landfill, with risk to health (Arias & Buitrago, 2012).

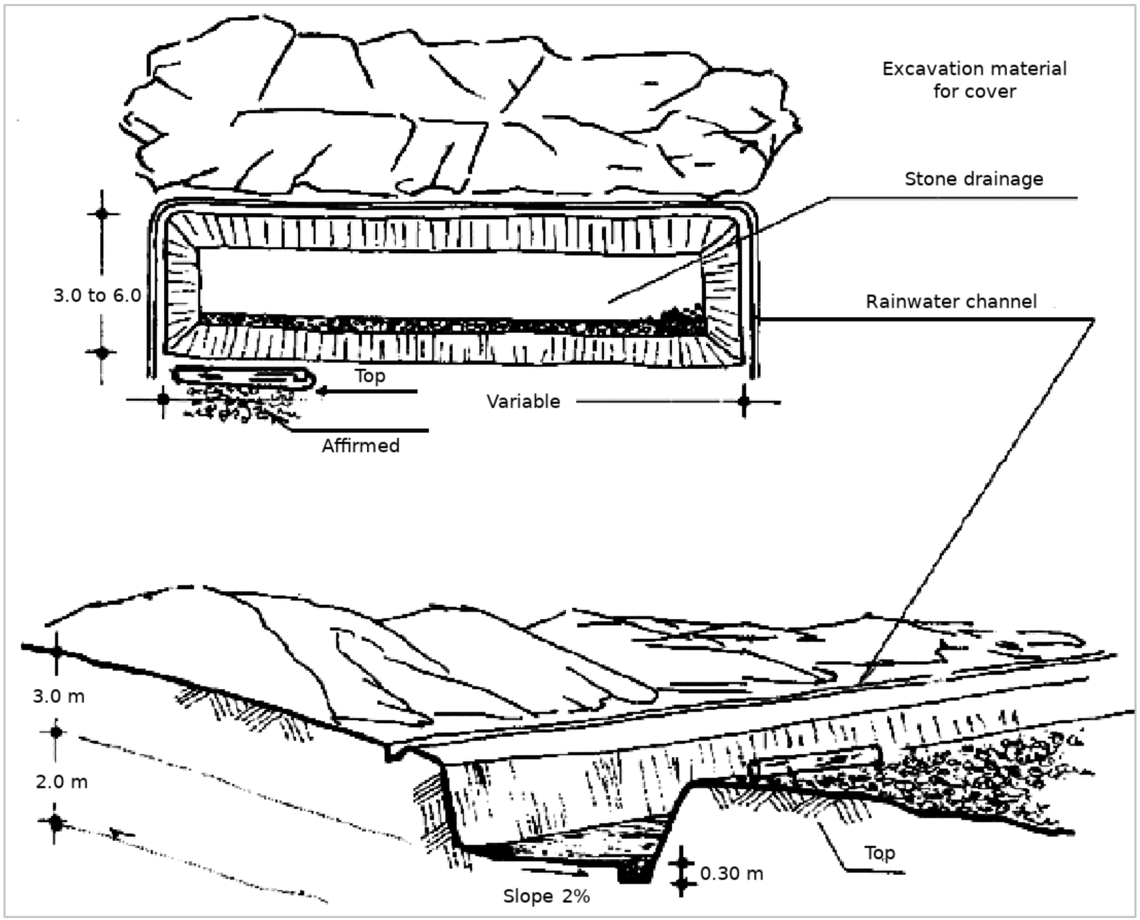

Figure 3. Trenching method for building a landfill.

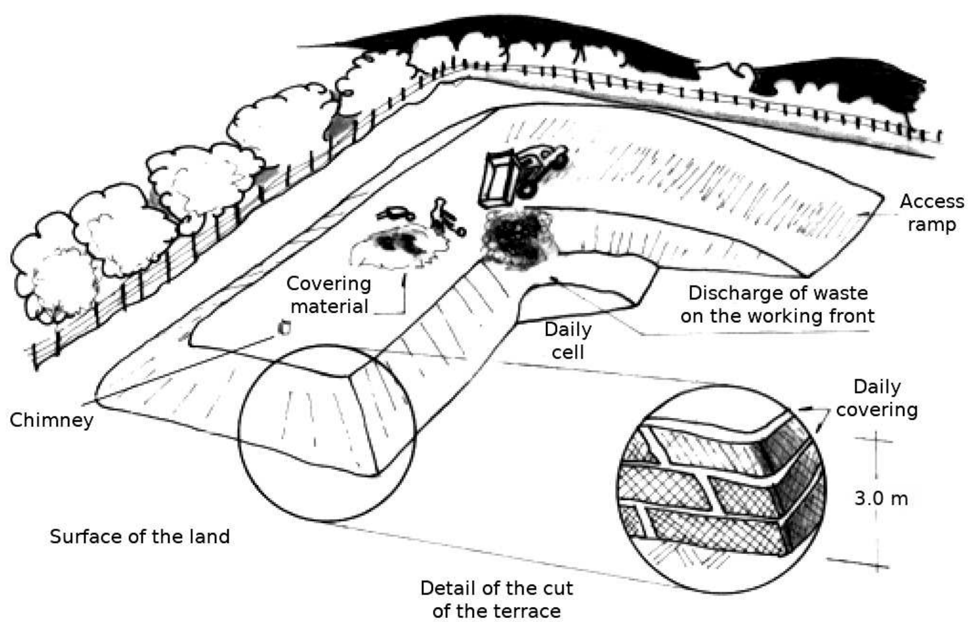

Figure 4. Area method for building a sanitary landfill.

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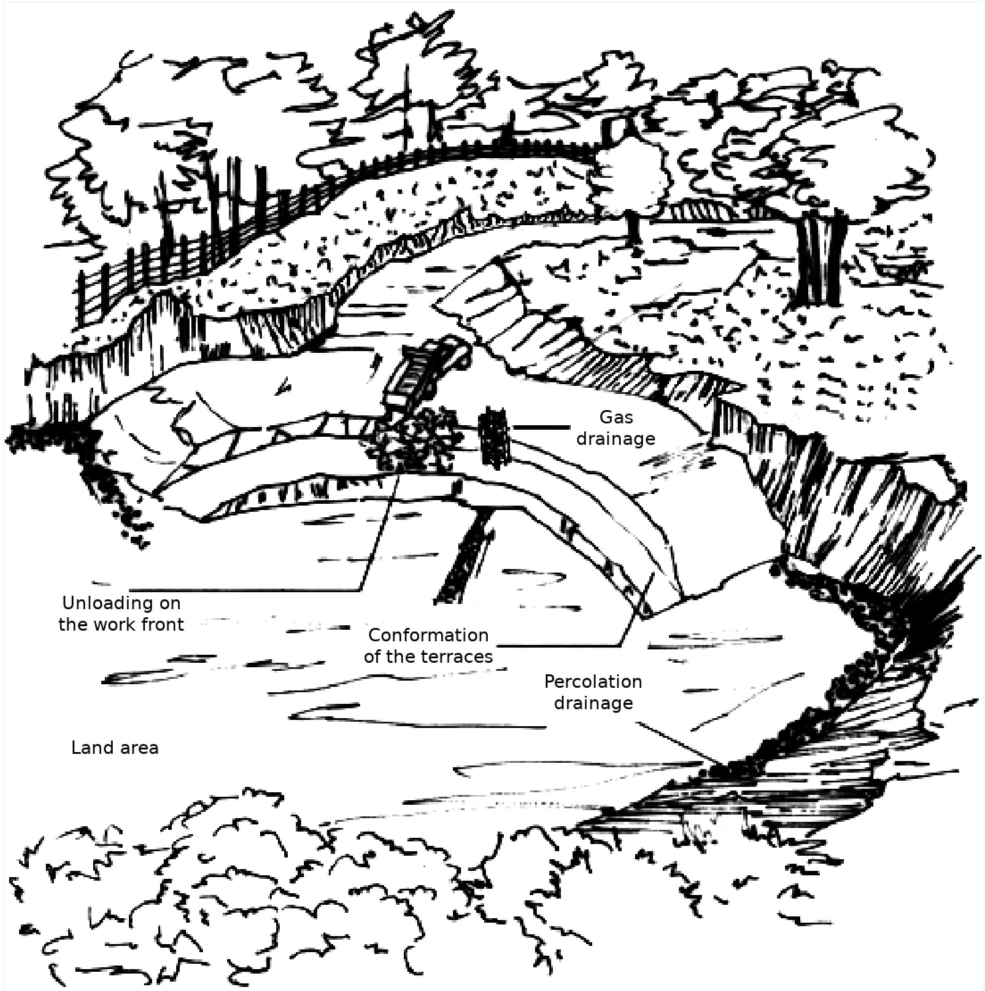

Figure 5. Area method for filling depressions.

Environmental control in the operation of landfills

An environmental monitoring program must be implemented in the operation of the landfills, covering them with ground and surface water, biogas and airborne particles. This must include measurement and control of the impacts generated at the final disposal site.

The frequency of monitoring should be related to the level of complexity of the landfill, depending on the population served by the system.

The parameters to be determined in the aquifer monitoring program are: pH, electrical conductivity, dissolved oxygen, heavy metals, COD, BOD5, organic matter, ammonia, nitrites and nitrates. For medium-high and high complexity levels, aquifers should be monitored with a half-yearly sampling frequency, and those of low and medium complexity with an annual sampling frequency.

1. **COD**. The Chemical Oxygen Demand (COD) determines the amount of oxygen required to oxidize organic matter in a water sample, under specific oxidizing agent, temperature and time conditions (Kolb, Bahadir, & Teichgraber, 2017).

2. **BOD5**. Biochemical oxygen demand - 5 days in water. It is a measure of the amount of oxygen used by microorganisms in the stabilization of biodegradable organic matter, under aerobic conditions, in a period of five days at 20^{o}C (Dasgupta & Yildiz, 2016).

The parameters that must be determined in the Biogas Monitoring Program are Biogas composition (CH_4, CO_2, O_2) that must be done bimonthly for the Medium-High and High complexity levels. The explosiveness must be daily for the High complexity level and monthly for the Medium-High complexity level.

The parameters to be determined in the Aero Transportable Particle Monitoring Program are Total Suspended Particles and Respirable Particles. The monitoring of these must be monthly for the Medium-High and High complexity levels and half-yearly for the Medium complexity level (Arias & Buitrago, 2012).

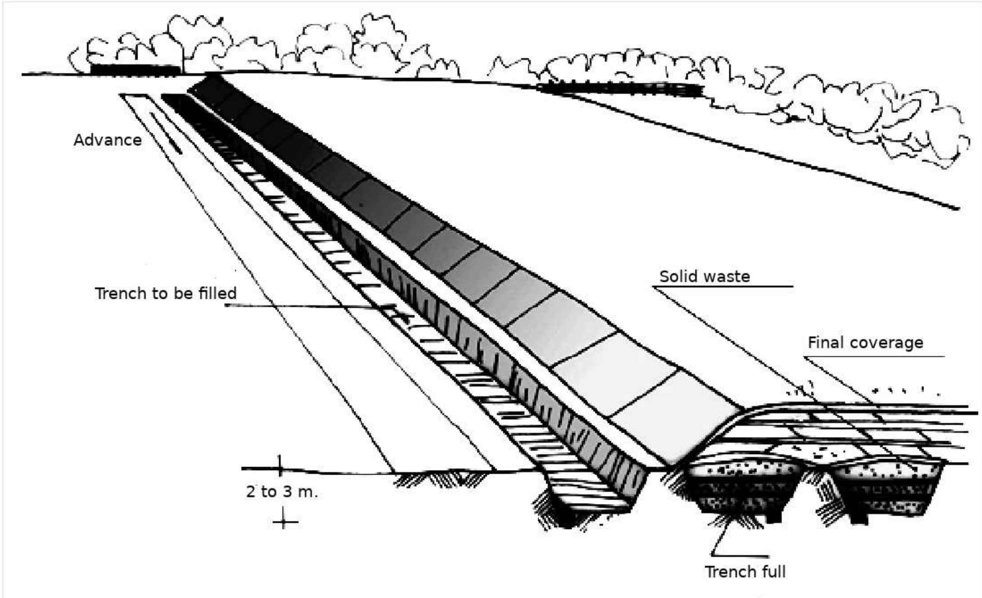

Figure 6. Combination of methods to build a landfill.

With these parameters, the aim is to have an adequate control of the operation of sanitary landfills, avoiding the emergence of environmental problems that trigger social and health problems.

Doña Juana landfill

The Doña Juana landfill is located in an urban and rural area of the Capital District of Bogotá, and in particular in the town of Ciudad Bolivar, south of the Sabana de Bogotá, in properties located on the left bank of the Tunjuelo River, along the highway to Villavicencio (Fig. 7) (Quintero, 2016).

Doña Juana has a total area of 456 hectares, of which only forty percent (40%) is used for solid waste disposal, divided into eight zones, where the conventional solid waste and hospital waste disposal stages have been implemented (L. Caicedo, 2016; Quintero, 2016).

The sanitary landfill currently has an average of 6,000 tons of waste per day (Murcia & Rodriguez, 2017) and an average of 180,000 tons per month; among these are household waste (65%), sweepings (6.4%), industrial waste (10.3%), rubble (10.8%), green waste (0.34%) and others (1.10%) (L. Caicedo, 2016).

The Mochuelo Alto was not always a designated area for what is now known as the Doña Juana dump, before, according to some inhabitants of this sector, it was a terrestrial part of the La Fiscala farm, where they grew onions, peas, barley and other crops to later go to trade in Bogotá, these crops were irrigated by several streams that passed through the area. Many of the inhabitants of here were no more than peasants, and Mochuelo only had approximately 30 houses that for the view of the district was like seeing an almost null population, this was an influential factor in the construction of the dump in the sector, besides having a quite open land and with abundance of clay which is a good cheap waterproofing.

The landfill was not originally planned to be built in that area, in fact, before that, three landfills were planned in Usaquén, Corabastos and Alicachín, which in the end were not carried out; and due to the high environmental pollution and accumulation of garbage in the city of Bogotá and surroundings (after the old dumps of Gibraltar and El Cortijo were closed), caused by the high production of waste from almost 3 million people, children and animals. And the need for a solution to this problem; the well-known Landfill (Botadero) Doña Juana was born on November 1, 1988 in the wide sector already mentioned Mochuelo in the town of Ciudad Bolivar, almost only 500 meters from Mochuelo Alto.

As a result, the landscape and life of the Mochuelo changed, and the area that was once one was divided into what we now know as the high and low Mochuelo, where the latter became increasingly populated due to the migration of recyclers and displaced persons, thus changing the landscape with the construction of tin and brick houses. By 1997 Doña Juana suffered a collapse of almost one million tonnes of waste, which was comparable to the amount of waste produced in half a year in the city, marking the beginning of a wave of events unfavourable to the population (Fig. 8). With the collapse of Zone II, which received waste from October 1995 to September 1997, the construction of the second phase of the Doña Juana landfill began, with Zone III and IV set up as an emergency zone for the collapsed waste (B. Caicedo, Giraldo, Yamin, & Soler, 2002).

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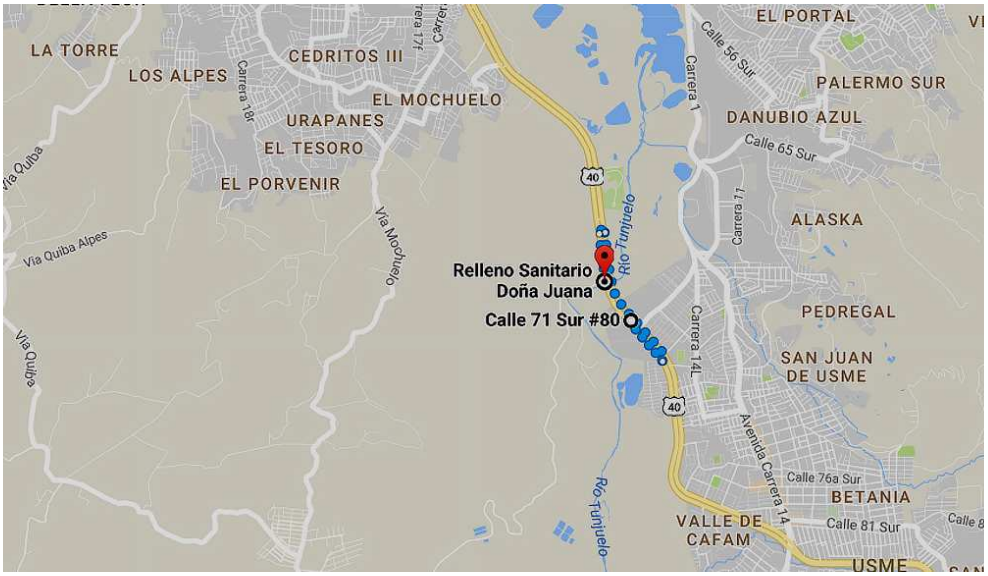

Figure 7. Location of Doña Juana Landfill.

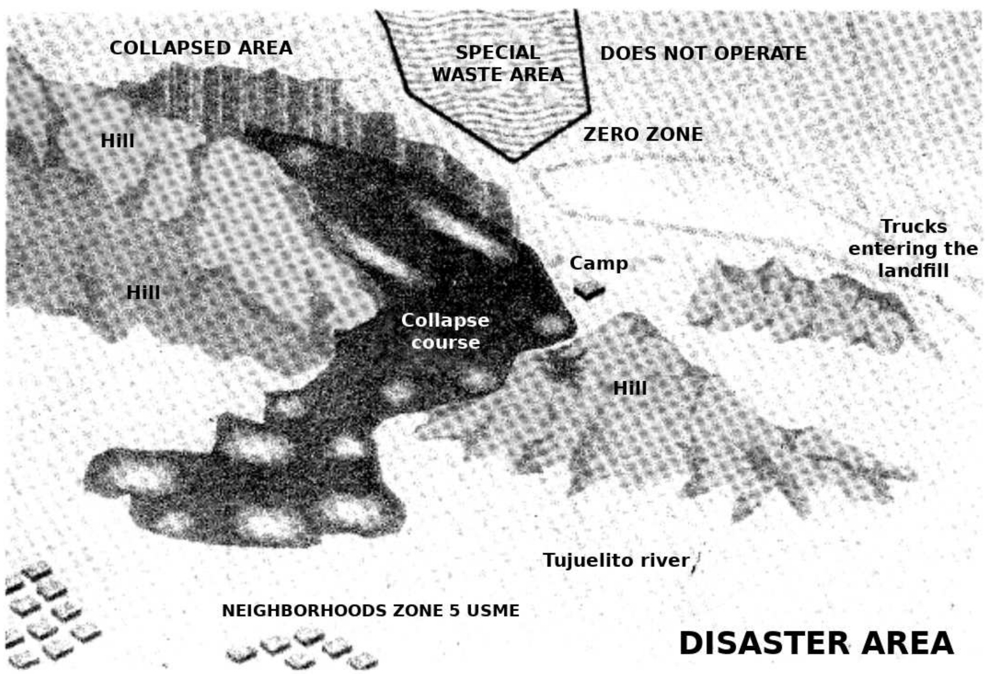

Figure 8. Doña Juana Landfill operation.

Conflicts generated by the Doña Juana landfill

The Doña Juana landfill has had several areas of operation since the beginning of its operations. Zone II received waste from October 1995 until 27 September 1997, when approximately one million tonnes of waste collapsed out of the three million tonnes that had been disposed of. This area had been estimated to have a useful life of approximately 4 to 5 years, but it was in operation for 1.5 years. Leachate management was carried out by recirculation within the waste mass, so the system depended on the proper functioning of the drainage system that maintained a balance between the amount of liquid entering and leaving. The system failed producing an increase in the pressure of liquids and gases in the pores of the waste mass, which caused changes in the characteristics of the material and, given the geometric configuration of design, the material became unstable and the cell collapsed, damming the Tunjuelito River (Fig. 9).

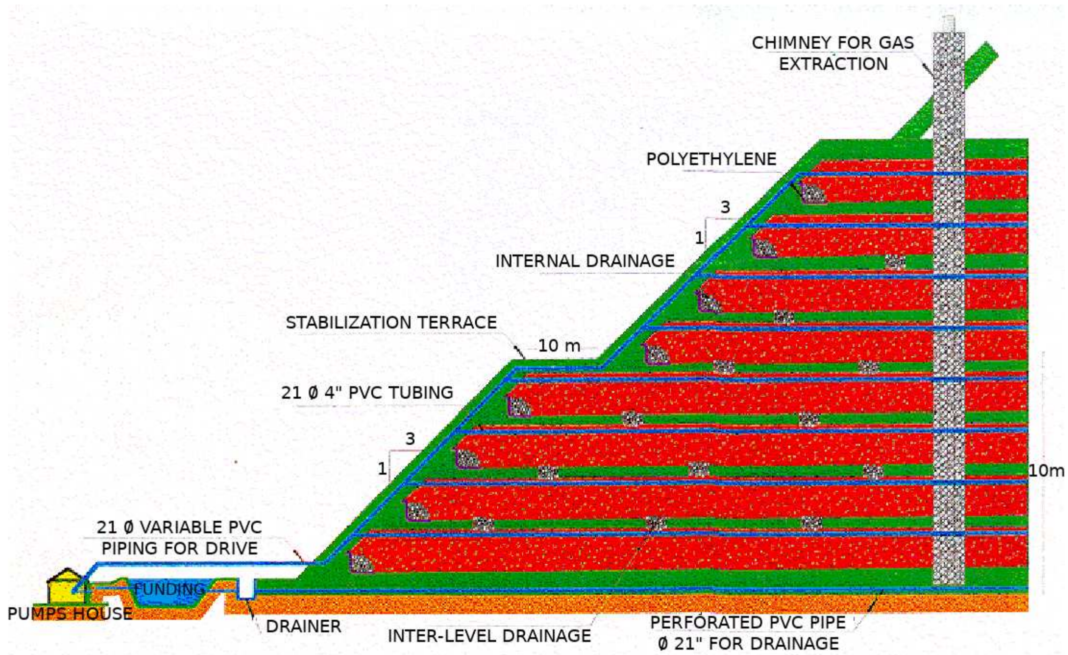

Figure 9. Landfill.

The emergency action plan consisted of: monitoring the stability of the refilled zone and the landslide zone; monitoring surface waters (leachates and the Tunjuelito River); monitoring gases that produce odors (H_2S and NH_3); monitoring methane gas; monitoring radioactive elements; attending to community consultations; and attending to public order. The firm SCS Engineers designed and put into operation a new zone, Zone IV. The design included leachate management through recirculation and gas management with PVC stacks at all levels of waste.

Currently the affected area was organized into three areas, as follows: Area 1, as of July 1998, restored, closed and re-vegetated. Area 2, arranged with part of the waste committed in the collapse, closed, re-vegetated and with a system of forced gas extraction. Area 3, disposed of with a percentage of waste committed in the collapse, closed and re-vegetated (B. Caicedo et al., 2002).

The materials that arrive at a sanitary landfill are of multiple natures and characteristics within which generally they are biodegradable materials, like all the organic compounds coming from animal or vegetal remainders, others coming from hospitals, factories, laboratories, electrical companies and chemical products, that must have a suitable handling by their dangerousness in the affectation of the environment and that attempts against the survival of many organisms and the human being by their high toxicity and contamination of the air and the water.

There are other materials coming from plastics that are not biodegradable and that remain without decomposition for a long time. In addition to these, there are many other materials and residues of other chemical substances used on crops such as herbicides, fungicides, fertilizers and in general that are used in agriculture.

This countless substances or materials interact with each other when mixed in large quantities to form a mixture of biodegradable crops and pollutants that are very harmful to ecosystems. It should be noted that all organic substances through time suffer a natural decomposition becoming especially substances such as hydrocyanic acid (HCN), hydrogen sulfide (H_2S), ammonia (NH_3), and gases such as methane (CH_4), ethane (C_2H_6) and propane (C_3H_8) which under normal conditions tend to be in a gaseous state that accumulates within the empty spaces of the decomposing substances, in which factors such as temperature, pressure, humidity and bacteria intervene, in addition to the presence of other substances.

Accumulated liquids of different types such as water, alcohol, oils, gasoline, paints are mixed in some way to form a large liquid mass that accumulates at the bottom of the deposited waste and accumulates over time increasing its volume if they do not have a good drainage process.

These factors accumulated in a place like Doña Juana's landfill generate great pressures on the bottom and the walls of the place where they are located and as the volume of the liquid and the quantity of the accumulated gas increases, the pressure increases in a considerably very high magnitude, these forces of great proportions unbalance the system and for some place that these pressures are not supported they become a time bomb, that at some moment for a telluric or vibratory movement they generate spaces that allow a great explosion throwing to great distances all the materials there accumulated.

Waste

Solid waste is all those materials or remains that have no economic value for the user, but do have a commercial value for recovery and incorporation into the life cycle of the material. Solid waste is a material or set of materials resulting from any process or operation that is intended to be disused, not to be used, recovered or recycled (Lee, Han, & Wang, 2017).

Chemical and physical characteristics

The characteristics of solid waste vary according to the dominant activity (industrial, commercial, tourism, etc.), the habits of the population such as rhythms, customs, food, habits, consumption patterns and climate mainly.

In order to determine the characteristics of solid waste in a given location, it is necessary to make periodic determinations (no more than 10 years on average) of the following aspects.

Physical characteristics.

1. **Gravimetric composition**. The percentage weight of each component in relation to the total weight of the waste handled, expressed as a percentage.

2. **Specific weight**. This is the ratio of the weight of the waste to the volume it occupies, expressed in kg/m^3. Its determination is fundamental for the dimensioning of equipment and installations (Arias & Buitrago, 2012).

3. **Compressibility**. Also known as degree of compaction, it indicates the reduction in volume that a certain mass of waste can undergo when it is subjected to a certain pressure, expressed as a percentage (Arias & Buitrago, 2012).

4. **Per Capita Production**. It relates the amount of waste generated daily by an inhabitant of a given region. It is expressed in kg/inhab-days (Arias & Buitrago, 2012).

Chemical characteristics.

1. **Calorific power**. Indicates the potential heat capacity that a material can give off when it is burned. This is an important parameter to determine the possible elimination method, basic parameter for an incineration treatment and to establish an energy balance in a pyrolysis process (Kcal/Kg) (Arias & Buitrago, 2012).

2. **Hydrogen potential (pH)**. Indicates the degree of acidity or alkalinity of the residues (Arias & Buitrago, 2012).

3. **Chemical composition**. It is important to know the percentages of ash, organic matter, carbon, nitrogen, humidity, potassium, carbon/nitrogen (C/N) ratio, calcium and phosphorus among others to define types of treatments applicable to the waste (Arias & Buitrago, 2012).

Waste classification

Separation at source is an activity that must be carried out by the generator of the waste in order to select it and store it in containers or recipients to facilitate its subsequent transport, use, treatment or disposal. This guarantees the quality of the waste that can be used and facilitates its classification (Figs. 10 and 11).

Figure 10. Classification of solid waste.

The waste is the result of domestic, commercial, industrial, institutional and service provision activities, among others (Fig. 12) (Amasuomo & Baird, 2016).

Hazardous waste. It is that which by its infectious, toxic, explosive, corrosive, flammable, volatile, combustible, radioactive or reactive characteristics can cause risk to human health or deteriorate the environmental quality to levels that cause risk to human health. Hazardous waste is also waste that, without being in its original form, is transformed by natural processes into hazardous waste. Likewise, containers, packages and packaging that have been in contact with them are considered hazardous waste (Kattel et al., 2016).

Solid waste or scrap. It is any object, material, substance or solid element resulting from the consumption or use of a good in domestic, industrial, commercial, institutional or service activities, which the generator abandons, rejects or delivers and which is susceptible to use or transformation into a new good, with economic value or final disposal. Solid waste is divided into usable and non-usable. Similarly, solid waste is considered to be waste from the sweeping of public areas (Kattel et al., 2016).

Usable solid waste. It is any material, object, substance or solid element that has no direct or indirect use value for whoever generates it, but that is susceptible to incorporation into a productive process (Kattel et al., 2016).

Unusable solid waste. It is any material or solid or semi-solid substance of organic or inorganic origin,

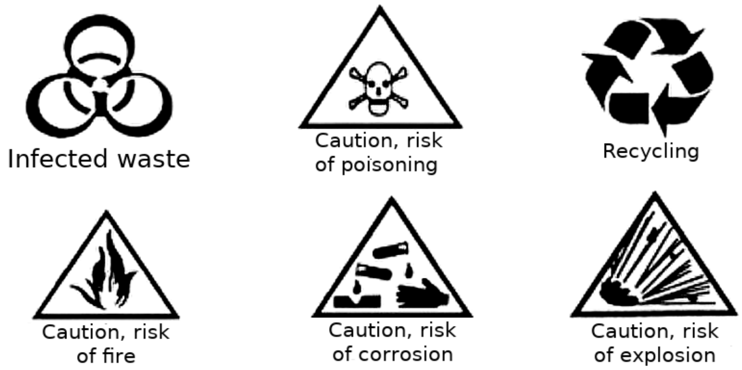

Figure 11. Waste classification.

Figure 12. Residues or solid wastes.

> putrescible or not, coming from domestic, industrial, commercial, institutional or service activities, which does not offer any possibility of use, reuse or reincorporation in a productive process. These are solid wastes that have no commercial value, require treatment and final disposal and therefore generate disposal costs (Kattel et al., 2016).

Leachate

Leachate is the liquid waste generated in a landfill (Fig. 13). It comes from two sources:

• Percolation water: water of external origin, generally from rain, percolates through the landfill, resulting in the output of water loaded with organic and inorganic pollutants.

• Generation water: the fermentation processes that occur inside the waste produce the generation of water that percolates in a similar way to the previous case.

Percolation is a natural phenomenon that scientists and water managers can calculate and use to ensure that surface and groundwater is free of contaminants and also to ensure that water intended for human consumption is safe (Rasool et al., 2016).

Organic and inorganic compounds are solubilised in these waters, which form the leachate from the solid waste disposal site. It can be estimated that 25% of the average precipitation is converted into leachate. Leachates have a strong pollutant load as a characteristic (Li et al., 2017).

Under normal conditions the leachates are located at the bottom of the landfill, from there they move through the layers by means of lateral movements depending on the characteristics of the surrounding material. In this process, many of the chemical and biological components that were originally part of the waste are removed by the liquids emanating through the landfill. Some studies have been carried out on the composition of the water that percolates through a landfill, and these show that this water serves as a vehicle for pathogenic germs, in addition to contaminating the groundwater by incorporating heavy metals, among other pollutants (Pan, Lei, Liu, Wei, & Liu, 2017).

The leaching rate of leachate from the bottom of the landfill can be estimated using Darcy's law, which is expressed as follows:

$$Q = -KA\frac{dh}{dl} \tag{1}$$

Where:

- Q = Leachate discharge per unit of time, m^3/year.
- K = Permeability coefficient, m^3/m^2.year.
- A = Profile area through which the leachate flows, m^2.
- dh/dl = Hydraulic gradient, m/m.
- h = Pressure drop, m.
- l = Length of flow path, m.

The negative sign in Darcy's law comes from the fact that the charge loss, *dh*, is always negative. Leachate control is carried out by placing drainage lines at the bottom of the landfills, having previously waterproofed the lower surface of the soil with material suitable for this purpose. The contribution to the total volume of leachate from water entering the landfill through the surface can be calculated using Darcy's equation (**?**).

The waste, especially the organic ones, when compacted by heavy machinery, releases water and organic liquids, contained in its interior, which drains preferably towards the

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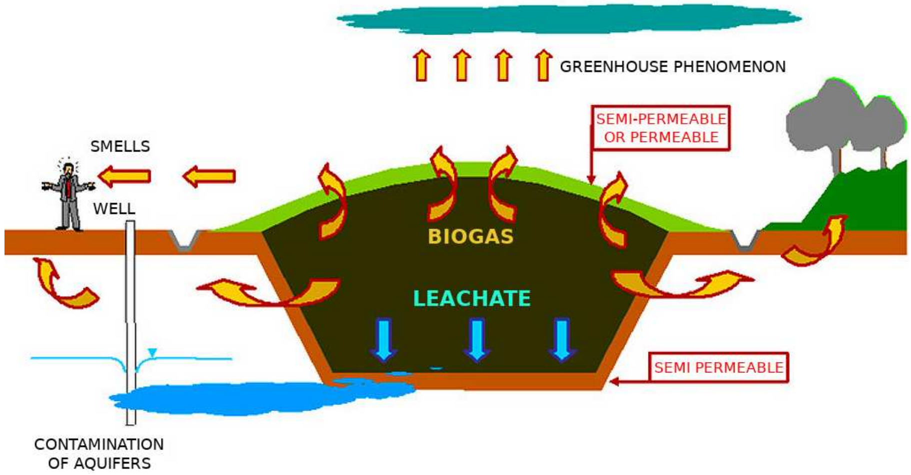

Figure 13. Leachate in a sanitary landfill.

base of the cell. The waste, which acts to some extent like a sponge, slowly recovers some of these liquids when the pressure of the machinery stops, but some of it remains at the base of the cell.

On the other hand, anaerobic decomposition quickly begins to act in a landfill, producing changes in organic matter, first from solids to liquid and then from liquid to gas, but it is the liquefaction phase that helps to increase the liquid content in the landfill, and at the same time its polluting potential.

At that point, the waste can be considered to be completely saturated and any water, either groundwater or surface water, that infiltrates the landfill will leach through the waste carrying with it suspended solids, and organic compounds in solution. This heterogeneous mixture, with a high potential for contamination, is what is called leachate or percolated liquid.

Leachate control is among the main requirements for the construction and operation of an organized landfill. Almost all contaminated sites and significant water contamination originate from uncontrolled leachate infiltration into the ground, and from there into the groundwater or a source (Alpaos & Moretto, 2016).

Although the composition of the leachates varies, in general, they are classified into three groups according to the age of the filler: fresh, intermediate and stabilized (Moody & Townsend, 2017).

The organic and inorganic contaminants in the leachate come from the solubilisation of the wide range of materials deposited in the landfill and from the products of the successive reactions of chemical, physical and biological processes that take place there. As a result these leachates have varying concentrations of toxic organic and inorganic and microbiological compounds (He et al., 2016).

But it is generally known that most contamination corresponds to organic matter, which is characterized by global parameters such as chemical oxygen demand (COD), which can vary from a few hundred to several tens of thousands of mg/L (Kaur, Mor, & Ravindra, 2016).

Fillers at an early stage of small methanogenesis emit more acid leachates containing high concentrations of fatty acids, the leachates produced in the older fillers have an active methanogenesis and therefore have a content of high molecular weight compounds (Moody & Townsend, 2017).

Methanogenesis

It's the production of methane by microorganisms. This is a very widespread and important type of microbial metabolism. There are several forms of methane production by microorganisms:

- The production of methane by reducing CO_2 is a type of anaerobic respiration. Methanogens do not use oxygen to breathe, as oxygen inhibits their growth. Therefore, generally this reaction is carried out from carbon dioxide (CO_2) and hydrogen (H_2), where CO_2 is an electron acceptor that is reduced thanks to the electrons supplied by H_2.
- The production of methane from organic molecules. Methanogenic bacteria can also produce methane from organic substrates such as acetic acid, methanol, methylamine, dimethyl sulfide and methane thiol. Using 14C, it has been shown that methane originates exclusively from methyl carbon in acetic acid.

$$CH_3COOH \longrightarrow CH_4 + CO_2 \qquad (2)$$

In this phase the bacteria convert the acetic acid into methane and CO_2. As the acids and hydrogen gas produced by the acid formers are converted to CH_4 and CO_2, the pH inside the landfill will rise to more neutral values, in the range of 6.8 to 8. The pH of the leachate will rise, and the concentrations of BOD5 and COD and the conductivity value of the leachate will be reduced. With higher pH values there are fewer inorganic constituents left in the solution and, as a result, the concentration of heavy metals present in the leachate will also be reduced.

Maturation and stabilization

This phase occurs after the inorganic biodegradable material CH_4 and CO_2 is converted. During this phase, the rate of generation of the landfill gas decreases significantly, because most of the nutrients have been separated with the leachate during the previous phases, and the substrates left in the landfill are slowly degraded. The main landfill gases during this phase are still CH_4 and CO_2. Depending on the sealing measures of the landfill, small amounts of nitrogen and oxygen may also be found in the landfill gas. During the maturation phase, the leachate will contain humic and fulvic acids, which are difficult to degrade biologically. Eventually, conditions may become aerobic again and this is when the landfill is stabilized (Arias & Buitrago, 2012).

Therefore, in the stabilized leachates, the fundamental components of the organic matter are the humic substances of high molecular weight; the rest of the components are compounds of low molecular weight, aromatic, aliphatic, phenolic, etc., considered toxic. The elimination of these organic compounds, which are generally very refractory to traditional treatment methods, is important because humic materials increase the presence of heavy metals such as cadmium, nickel and zinc in groundwater. Moreover, humic substances are the fundamental precursors of trihalomethanes which are proven carcinogenic compounds.

Trihalomethanes

Trihalomethanes are substances that are formed in the process of making water drinkable by reacting the organic matter contained in it with chlorine. The amount of trihalomethanes generated will depend on the dirt that persists in the water after the phase of elimination of the organic load that the water contains prior to purification.

Trihalomethanes are generated in the water purification process as a result of the chemical reaction that occurs when the natural organic matter present in the water comes into contact with the chlorine added as a disinfectant.

In this reaction three of the four hydrogen atoms of the methane molecules are replaced by halogen atoms, forming new compounds such as chloroform, dibromochloromethane, bromoform and bromodichloromethane, which are generically called trihalomethanes.

Chemical reactions

Two general types of chemical reactions take place within the mass of decomposing solid waste in a landfill.

- The first of these is the oxidation reactions due to the oxygen trapped in the disposed waste.
- The second type of acid-metal reaction, due to the presence of organic acids and CO_2.

These processes mobilize the metal ions and salts that are the potential contaminants. However, once the methane generation is established in the filler (Methanogenesis) less acid is generated and metals are generally retained.

Physical reactions

The effects of water when it comes into contact with the waste disposed of favour the dissolution of soluble materials, which become available for absorption and adsorption processes.

Usefulness

The term utilization refers to the process by which, through an integral management of solid waste, the recovered materials are reincorporated into the economic and productive cycle in an efficient manner, through reuse, recycling, incineration for energy generation purposes, composting or any other modality that entails health, environmental and/or economic benefits, according to Decree 1713 of 2002 of the Colombian Constitution.

A landfill is a biochemical reactor, with waste and water as the main inputs, and landfill gas and leachate as the main outputs. The material stored in the landfill includes: partially biodegraded organic material and other inorganic materials from the waste originally placed in the landfill.

Gas control systems are used to prevent undesirable movement into the atmosphere, or lateral or vertical movement through the surrounding soil. The gas recovered from the landfill can be used to produce energy, or it can be burned, under controlled conditions, to reduce the emission of harmful constituents into the atmosphere. The gases found in a landfill, according to various researchers in the field, are: carbon dioxide, carbon monoxide, hydrogen, hydrogen sulfide, methane, nitrogen and oxygen, as well as volatile fatty acids.

Biogas

Biogas is a gas composed of almost 60% methane (also known as natural gas) and 40% carbon dioxide, contains minimal amounts of other gases, including hydrogen sulfide (a compound whose formula is (H2S), is a colorless gas with a characteristic odor of rotten eggs.) that is part of this in a 1% and nitrogen that is perceived in about 2% (Urrego & Rodríguez, 2016).

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Table 1
Biogas composition.

Element	%
Methane (CH_4)	50-70
Carbon Dioxide (CO_2)	30-50
Nitrogen (N_2)	0.5-3
Sulfhydric Acid (H_2S)	0.1-1
Water Steam	Traces

Biogas is a little lighter than air, has an ignition temperature of 700^{o}C and its flame reaches a temperature of 870^{o}C, can be used like any other fuel, both for cooking food, replacing wood, kerosene, liquefied gas, etc., and for lighting, using lamps adapted to biogas. Biogas mixtures with air, in a 1:20 ratio, form a highly explosive detonating gas, which allows it to be used as a fuel in adapted internal combustion engines as well. It should now be clarified that this gas can only be used as a fuel when the methane present in it is greater than or equal to 50% concentration.

The longer the retention time, the higher the methane content, and with it the heating power. With short retention times the methane content can be reduced by up to 50%. With a methane content much lower than 50%, the biogas is no longer flammable. The first gas from a freshly loaded plant contains very little methane, so the gas produced in the first 3 to 5 days must be allowed to escape without use. The methane content depends on the fermentation temperature. At low fermentation temperatures a high percentage of methane gas is obtained, but the amounts of gas are lower.

This is naturally generated by rotting organic matter and is called natural gas or marsh gas. Artificially, biogas is produced by the decomposition of organic waste (animal manure, garden waste, food waste, among others).) through a process of anaerobic fermentation (absence of air), carried out by methane gene bacteria (living beings that produce methane), this process is carried out in a completely sealed plant called Biodigestor which is the tool that allows the production of biogas with the common principle of putting the organic matter, in anaerobic conditions, to start the process of gas production, which consists of three chambers in it, at first sight is a container of cylindrical or spherical shape, hermetically and impermeably sealed, which can be built with various materials such as brick, cement, metal or plastic.

This compound is quite advantageous as it reduces the amount of municipal solid waste, does not generate greenhouse gases and is renewable. It is something economical and very useful for schools, community kitchens, industrial and agricultural enterprises especially for areas where the natural gas network does not reach, it can be used for domestic use in cities, but it is necessary to have a constant amount of waste in order to generate gas.

From organic waste, electric energy can be generated, so it is an important resource that is often wasted. This leads to a great solution to supply electricity and gas services to small cities and remote villages; these are some solutions that biogas can generate in a community, it can be applied, but it is essential the collaboration of the community to make it work, because a family or small group of people is not enough to generate as much waste to feed the biodigester. Likewise, the biodigester does not have many disadvantages, but we can say that the burden of it requires a lot of time and patience since a selection and classification of the waste must be done previously; it can also present fluctuations in energy production due to the variable availability of natural resources, and finally, if it is due to its structuring, it can present problems of storage and distribution.

And how does it come about?

Biogas can usually be obtained from any organic material. Commonly used are excreta of any kind, cachet, distillery waste, organic components of municipal solid waste, organic waste from slaughterhouses, sludge from waste treatment plants, agricultural waste, organic waste from food production industries, etc. All organic materials that can be used as fermentation sludge are mostly composed of carbon (C) and nitrogen (N). The relationship between the two has a great influence on biogas production. With water, the flowability of the fermentation material increases, which is important for a more efficient fermentation process and therefore a higher biogas production. In a liquid fermentation sludge, methane bacteria reach the fresh fermentation material more easily, which speeds up the process. The fermentation process consists of two main phases: the acid phase and the methane phase. In the first one, amino acids, fatty acids and alcohols are formed from the proteins, fats and carbohydrates dissolved in the residual. In the second one, methane, carbon dioxide and ammonia, among others, are formed.

The facility for producing and capturing biogas is called a biogas plant. There are multiple designs and forms, depending on its size, raw material (waste) used, construction materials with which it is built, etc. Its variety is such that the existing models are adapted to practically all the needs and variants that are desired, in terms of volume, materials used and organic waste to be treated; Basically, it can be said that in all cases the process of biogas production is carried out in a container called a digester, as this is where the fermentation process takes place, similar to the digestion produced in our digestive system when we eat food, which is broken down by the action of enzymes, while the biogas is captured by means of a bell or vaulted or cylindrical surface (in most cases), from which the gas is extracted through a pipe or hose (Urrego, Rodríguez, & Sánchez, 2016).

Plants for the production of biogas can be classified into:

• **Discontinued or Bac**h. These are loaded once and completely emptied after a retention time. The continuous gas supply with these plants is achieved with gas tanks or with several digesters running at the same time.

• **Continuous**. These are loaded and unloaded periodically, usually daily, the fermentation material must be fluid and uniform. Continuous plants are suitable for rural households where the necessary maintenance is integrated into the daily routine and gas production is higher and more uniform. They have the advantage of being adapted to industrial use, e.g. in hatcheries where large amounts of manure must be treated and where both gas production and treatment of the pathogenesis of these wastes are not important. They are also suitable for automation.

The former are loaded and partially unloaded every day, periodically or permanently, while the latter are loaded at once and totally or partially unloaded after a certain time of using the introduced residual to ferment.

Among the simplest installations we can find those of fixed domes, Balloon type plant and floating bell (Fig. 14). Floating bell plants allow for constant gas pressure. The design and construction of the plant, as well as the materials to be used, must be carefully chosen according to the desired production, the characteristics of the soil, the type of load and the investment to be made. The climatic characteristics of the place must also be taken into account, as the digestion process itself is not exothermic, so heat must be provided to maintain its temperature. The temperature at which the digestion takes place varies the retention time of the sludge.

Sludge

It refers to mud that has a band consistency and is found in humid places and in the bed of lakes and rivers. Mud, on the other hand, is the combination of water and soil.

These biogas plants can be built for domestic or agricultural use, now, to ensure the successful operation of the digester (in a non-industrial size and for personal use) it is essential to perform a proper commissioning. To fill the plant, between 1 and 1.5 L of water per kilogram or liter of fresh excreta are mixed, always trying to keep the solids inside the digester in the range of 7 to 9%. Once this mixture is prepared, the digester starts to be filled, until it reaches the level of the floor of the compensation tank or pressure regulator.

It is very important that, during the filling process of the plant, from the referred level, the gas outlet valve is kept open, so that all the air contained in its interior escapes, as it fills up to its maximum water level, to avoid in this way the cracking of the dome by the action of shock loads (sudden filling). After this operation, the outlet valve is closed and we wait a few days, during which time biogas will be accumulated in the dome. If the filling took place with cattle excrements or inoculum (residual extracted from an anaerobic digestion process), for more than a week, the valve can be opened after 24 hours. Otherwise, it will be necessary to wait until the pressure inside the digester rises, which will be known by observing the exit of the liquid from the compensation tank until the bubbling begins in the area that communicates the digester with the compensation tank, which will indicate that the digester has reached its maximum working pressure and the start-up has been satisfactory.

In cases where there is easy access to sufficient quantities of water and the construction has not been done with the necessary rigour, it is advisable to carry out this start-up test with apparently clean water; and to do so, the same operation is carried out, but with the location of a pressure gauge, in the pipe at the gas outlet, to measure the pressure of the air accumulated in the dome, which will displace the water as the digester is filled, until the maximum pressure is reached. After reaching the maximum pressure, it is left full for 24 hours, and then the corresponding evaluations are made. If the loss of pressure during this time is negligible, then its start-up has been satisfactory, and it will be filled with excreta mixed with water or waste water, in the manner indicated above.

The gas accumulated in the dome above the water level at start-up should be disposed of by opening the valve placed, at the exit, in the inspection register, which will be used as a water trap, and immediately move about twenty meters away from the vicinity of the plant against the wind direction (smoking or lighting of any flame should be avoided), until the gas escapes completely (since methane is a highly toxic combustible gas and its inhalation can cause death). Afterwards, the plant will be turned over and when the pressure rises again it can start using the biogas in cooking.

In order to know the pressure that develops inside a biodigester, pressure gauges are used, which in a small biogas plant are less than 1.50 m from the water column (0.15 kg/cm^2) and can be made by the user himself with simple materials: a small diameter hose, preferably transparent, which supported on a vertical table allows the water inside to be observed (Fig. 15). The surface (meniscus) on one side is in contact with the biogas, and the pressure you want to know is exerted on it (on the meniscus of the outlet branch, the pressure is the atmospheric one). Initially, with the atmospheric pressure (Patm) on both branches, the two menisci occupy the position 0.0. As the pressure pA develops, it causes the meniscus to descend to the height h_1 and the height h_2 to rise. Thus, when measuring the difference between the two menisci, one has the manometric pressure:

$$pA = (h_1 + h_2) = Ht \tag{3}$$

At the first start-up, the pipe will be swept with the same gas. This initial gas should not be used because it is mixed

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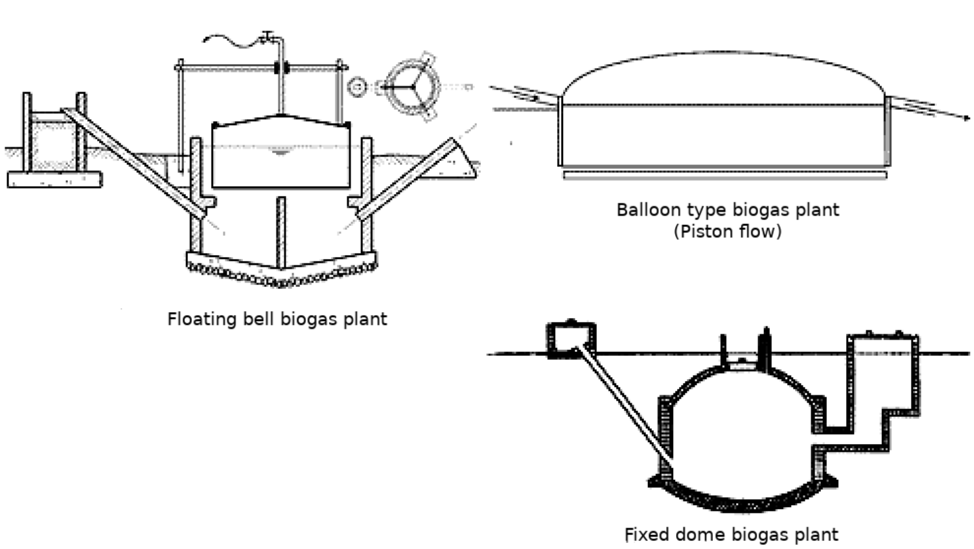

Figure 14. Biogas technology.

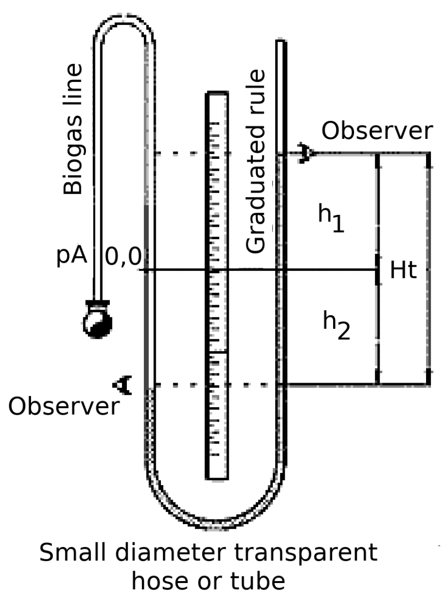

Figure 15. Manometric pressure measurement.

Figure 16. Biodigester structure.

with air and therefore can be explosive and dangerous (it may even be non-combustible due to the high CO_2 content), so it is recommended to let it escape into the atmosphere without being connected to the stove, in the same way as explained above. This biodigester can be as shown in Fig. 16.

Likewise, some precautions must be taken into account when setting up the biodigester, starting with the fact that the water used in the mixture must not be chlorinated. If it is supplied through an aqueduct, it is recommended that it is not directly from the network, since in the biogas there are colonies of microorganisms that can die or reduce their metabolic activity by the action of chlorine. In addition, this water cannot contain any disinfectant or toxic agent in concentrations that damage methano-genic microorganisms, such as acids, lubricating oil, detergents, antibiotics, etc.

Care must be taken that no soil or sand enters the digester, as they form sediments that are difficult to remove, as well as remains of fodder and straw, as they create surface crusts that reduce the level of effectiveness of the digester and make it difficult to operate and maintain.

The operation of a biogas plant

In one of these plants it is possible to see several processes of which we will speak in this section:

- Storage and conditioning of the substrates.
- Biogas production.
- Biogas conditioning.
- Energetic use.

Storage and conditioning of substrates

To begin with, we must know what substrates are. In biology, a substrate is the surface on which a plant or animal lives. The substrate can include biotic or abiotic materials. For example, algae that live embedded in a rock can be the substrate for another animal that lives on top of the algae, there are many types of substrates that are divided according to their origin, which leads to storage being different for each. These are divided into:

Storage of substrates of vegetal origin. These storage systems serve to balance variations between demand and production of biomass. The shape and size depends on the type of biomass and flow of use, these silos that are used for this type of plant are generally made of concrete, but can also be made of different plastics when the volume to be stored is not excessive and a large territory is available.

These substrates are harvested with specialized machinery for subsequent storage in the silos, must be chopped to a size between 6 mm and 10 mm so that they retain their properties for the production of biogas.

Storage of liquid substrates (slurry). The slurry is transported with the tanker to the plant, and unloaded into the tank which can be concrete or steel, and go to ground level, these must be closed tanks to avoid odors, as not to lose their properties.

Storage of slaughterhouse substrates. When the substrates are of this type it is normal that they are properly sanitized, in order to eliminate bacteria, parasites, and viruses. This is done by heating the substrates to a temperature of 70^{o}C for one hour. These are contained in steel tanks after sanitization.

Biogas production

Feeding system. As recommended above, it should be continuous, and the mixing should be very accurate so that the substrates are well homogenized. Generally we have a smaller silo, with a mobile floor, from which the solid substrates (silage, solid waste) are introduced to the feeder and other conduits for feeding the liquid substrate (slurry, glycerine, serum, etc).

The most modern feeding systems weigh each substrate separately so that the mixture always contains the exact percentage of each one, there are other types of installations that allow a greater homogenization of the mixture such as internal agitators in the feeder, placing a pump with blades to prevent large particles from being introduced into the digester, sieves to remove stones and other materials that could damage the installations, and so on (Martinez, Martinez, & Hernández, 2017).

Digesters. Biogas plants can be made up of one or more digesters, which can be: vertical, horizontal, dry or wet mixing, and continuous mixing. Its final design will depend on the type of substrate to be used.

Digesters are classified by mode of operation, filling and emptying. The general classification defines them as stationary regime, semi-continuous regime, horizontal, and continuous regime digesters. Depending on the humidity of the process, they are available as wet mix (up to 15% DM content) or dry mix with a higher DM content (up to 25%). One of the fundamental variations in terms of plant design consists of carrying out the digestion in one or two stages, based on the fact that the different groups of bacteria that carry out the process require different pH conditions and retention times. This involves the construction of one or two tanks, in the first one part of the anaerobic digestion is carried out (hydrolysis and acidogenesis) and in the second one acetogenesis and methanogenesis is carried out.

Digester tanks are built above or below ground. The floor and walls of the agro-industrial digesters are made of concrete. The roof, generally, is made of EPDM membrane. The digesters are usually fed by a submersible pump. The discharge of the digested mixture or its recirculation to stabilize the humidity levels of the process is done by means of an overflow. A pipe is installed on top of the digester that will connect it to the digestate storage tank and/or the recirculation tank (Fig. 17).

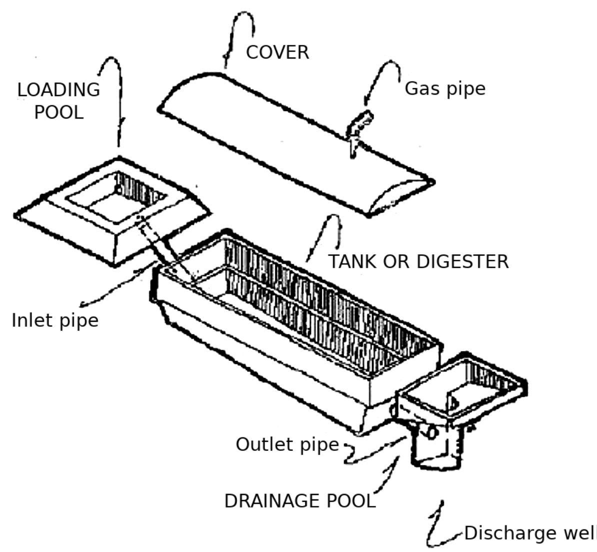

Figure 17. Biodigester: Components.

The cover of the digester as shown in Fig. 17 is where the biogas produced is stored, and can also be used as a gasometer.

Agitators. Thanks to these a better distribution of temperature, nutrients, also the elimination of biogas bubbles and a mixture of fresh substrate with all the bacteria that live in the digester: and all this due to the continuous agitation of the machine.

Heating system. The digesters will be equipped with a 4 cm thick polyurethane (or similar) insulation system to retain as much heat as possible. Likewise, a series of polyethylene pipes will be distributed inside the concrete wall to form the heating system.

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Biogas conditioning. Since the gas has a high moisture content and traces of other gases it must be treated and conditioned before handling. It must be conditioned in such a way that, the H_2SN (hydrogen sulphide) is reduced or eliminated, the percentage of humidity is lowered, there is a reduction of CO_2 (carbon dioxide), and finally the pressure of the biogas is corrected, calibrated and controlled.

When the biogas leaves the plants it is saturated with 100% humidity, and this problem increases when it is in summer due to the high temperatures, with this many particles that are not kept inert in the biogasification process travel through the water vapour, being harmful for the good use of the biogas. For this, a condensation unit is installed in the cogeneration unit, and in this way the biogas will be cooled to temperatures between $0^{o}C$ and $5^{o}C$ obtaining the condensation of the humidity in the biogas, after this, collection pipes will be made with a slope of 5% so that the condensate flows back to the digester.

The presence of Sulphuric Acid (H_2S) also known as sewer gas can be very harmful to health, since only about 30 ppm (parts per million) in the air to cause someone's death; it turns out to be a factor of difficulty when the biogas is to be used in engines, refrigerators, heaters and other metallic devices that can be affected by the corrosion produced by the acid in question. This can be removed or even controlled thanks to traps that use ferrous materials such as: steel, iron and castings, the gas is made to pass through a filter that contains iron hydroxide and thus the acid gas combines with the iron forming an iron sulfide (Fig. 18).

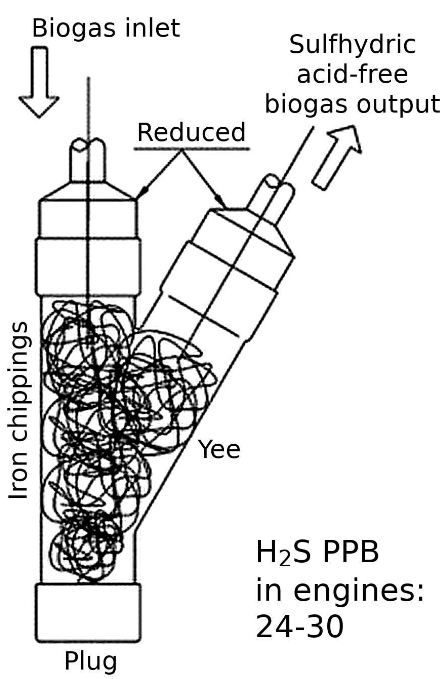

Figure 18. Biogas production and conditioning.

For the reduction of Carbon Dioxide (CO_2) can be made a purification with micro algae thus achieving an energy source of biomethane suitable for commercial use or domestic purposes, this is achieved by making a stream of biogas entering a hollow column and circulating in counterflow with micro algae in liquid medium that come from an open culture, the contact between these two produces the transfer of CO_2 from the gas to the liquid culture medium, this process takes place continuously 24 hours a day replicating natural light during half the process.

Energy use. Biogas has a high energy power of approximately 6 KW/m^3, this value depends on the content of methane gas in it; it can be used as a fuel for the generation of electrical energy and for the generation of heat.

The most common uses of biogas are:

- Combustion for heat production.
- Internal combustion engines with mechanical power utilization.
- Engines for electricity generation.
- Gas or steam turbines with use of electrical power.
- Motorized vehicles.
- Hook into the natural gas network.
- Production of chemicals.

Biogas as an energy source - Biogás Doña Juana S.A.S.. The biogas generated in the landfills is produced during the process of anaerobic degradation of the organic waste deposited there. This biogas, due to its methane component, is susceptible to being used as fuel for electric power generation engines and industrial processes involving high temperatures.

Since 2010, Biogás Doña Juana S.A.S. E.S.P. has been developing one of the most important environmental projects in Colombia and the world, as well as the only project in Colombia that currently uses biogas resulting from the decomposition of urban solid waste that reaches the Doña Juana Landfill for the generation of electricity and the reduction of greenhouse gas (GHG) emissions through the thermal destruction of methane (CH_4).

Approximately 6,700 tons of solid waste arrive at the Doña Juana Landfill every day and are disposed of in their entirety by the landfill operator (CGR) in a technical manner in waterproof cells with leachate drainage and biogas emission systems. Once the waste begins its anaerobic decomposition and biogas production begins, Biogás Doña Juana S.A.S. E.S.P. captures and conducts the biogas produced to the plant, where it burns methane and generates energy.

With the burning of methane, is reducing approximately 800,000 tons of carbon dioxide (CO_2) equivalent per year, this contribution to reducing emissions of greenhouse gases that makes Biogas Doña Juana annually, equivalent to:

- CO_2 capture from more than 160 million mature trees per year.

• To avoid the circulation during 1 year of approximately 400,000 compact vehicles in the city that travel 15 to 20 km per day.

Although it is true that with the treatment, thermal destruction and use of biogas, gas emissions are reduced, improving the air quality of the population located in the area of influence of the Doña Juana Landfill, in addition to reducing the presence of offensive odors; these aspects are the main effects of the construction of landfills in Colombia (Fig. 19).

At the Doña Juana landfill there is a project of electric power plants from biogas (Fig. 20). This project is structured in three plants, according to the availability of connection points granted by the Local Network Operator (CODENSA) and approved by UPME (Mining Energy Planning Unit):

- Central Doña Juana I:
- Phase I (1.7 MW) went into operation on 29 April 2016.
- Phase II (additional 3.3MW), will be operational January 2017-8.
- Central Doña Juana II:
- (9.8 MW) Will become operational in January 2018.
- Central Doña Juana III:
- (9.88 MW) Will be operational in the second half of 2018.

Conclusions

With the information exposed previously we can conclude that in the construction of a civil work as it is it a sanitary landfill it is of extreme importance that aspects like the planning, design, execution and operation are carried out correctly following certain guidelines to anticipate the emergence of problems in the future.

It is important the management given to the waste once they are deposited in the landfill, because if this management is not adequate can generate environmental problems, health, and even social, that is why seeking alternatives to find profits beyond those provided in its life is a vital issue. The generation of energy from biogas is a clear example of this, is an alternative that mitigates environmental damage and not only that, being a way to transform waste of which it is believed that its useful life just allows society to be aware of the importance of separating the waste that is generated, facilitating the management of these, thus giving opportunity to the emergence of sustainable projects that generate benefit to society and the environment. As it is a process that occurs through waste, it becomes a renewable resource since the source of generation is a constant since thousands of tons of waste are generated every day. This means that we do not depend solely on fossil fuels.

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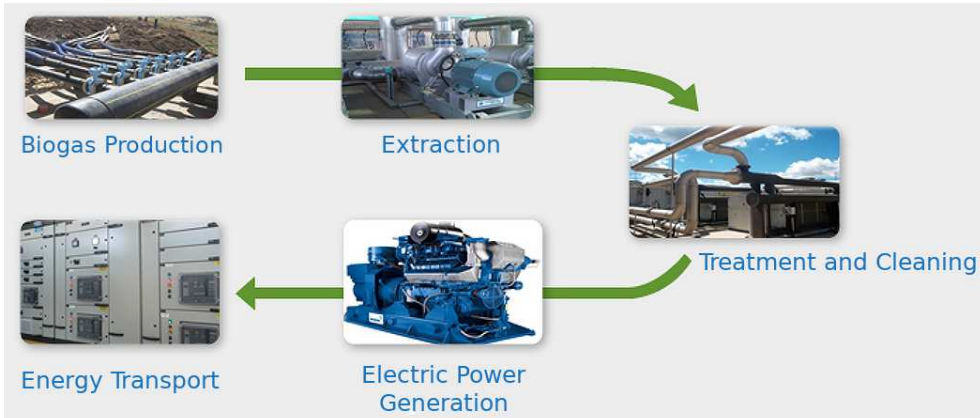

Figure 19. Cycle of energy production from landfill biogas.

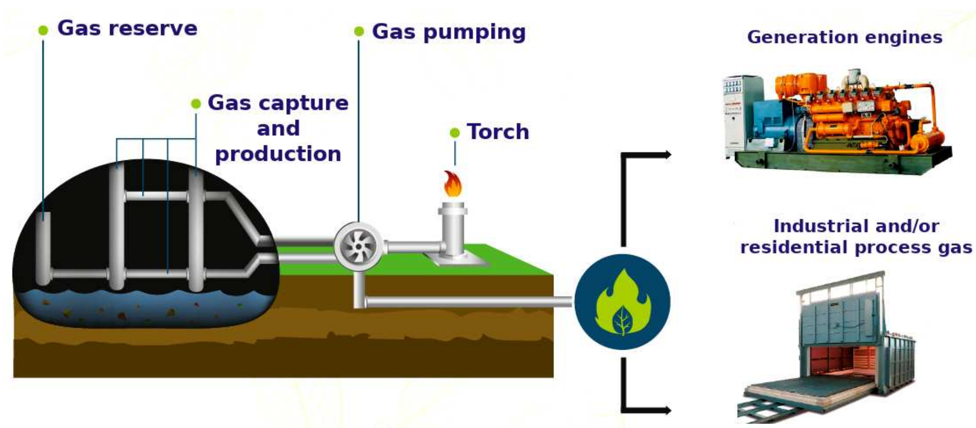

Figure 20. Transformación de energía eléctrica.

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