POLITECHNIKA GDAŃSKA
WYDZIAŁ CHEMICZNY

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Studia pierwszego stopnia

Forma studiów: stacjonarne

Kierunek studiów: GTM

Specjalność/profil: -

Bachelor thesis

Title: Sludge Treatment in Wastewater Treatment Plants.

Potwierdzenie przyjęcia pracy	
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Data oddania pracy do dziekanatu: 25/06/2018.

ABSTRACT

In wastewater treatment, a waste is created that must be treated correctly later to comply with the legislation. This residue is the mud. This can be different, since according to the wastewater treatment stage in which it comes, primary, secondary, activated and even tertiary sludge can be found. All of them have harmful substances that will have to be eliminated, as well as the most important thing, a large amount of water that makes transport very expensive. Therefore, in most stages the elimination of water is sought. In the last stages, depending on the use that we are going to give to the mud, it is already for agriculture, energy use or simply send it to the landfill to comply with the legislation and eliminate the pathogens or harmful elements that are demanded. The sludge is treated by a series of continuous operations, in which it is first prepared by pre-treatment until final dehydration by thermal drying or incineration. This last stage may not be necessary, it will depend on the use that we are going to give the sludge, since to take the landfill does not need a percentage of water as low as that presented by the mud after the incineration.

Keywords: Sludge; mud; dehydration; operation; treatment; temperature; solids; wastewater.

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1. INTRODUCTION

1.1 URBAN WASTE

One of the characteristics of current societies is the production of leftover materials that are useless and that are abandoned. When the populations were smaller, this waste was produced in quantities that the environment could absorb and eliminate. At present, the amount of waste produced is so large that they tend to be eliminated becoming a major environment problem.

In the article 3.b) of the Law 10/1998, of April 21, (published in State Official Newsletter BOE of Spain) urban waste is defined as: those generated in private homes, shops, offices and services, as well as all those that do not qualify as dangerous that by their natures or composition can be assimilated to the products in the previous places or activities.

This project is going to be focused on the liquid part of urban waste, which is what we call sewage water. It is essentially the water that is released from the community once it has been contaminated during the different uses for which it has been used. Then we can define wastewater as the combination of liquid waste which comes from residences, public institutions and industrial and commercial establishments, to which we can add underground, surface and rainwater.

If the accumulation and stagnation of wastewater it is allowed, the decomposition of the organic matter it contains can lead to the generation of large amounts of malodorous gases. In addition to this, we must add the frequent presence in the gross residual water of numerous pathogenic microorganisms and causing diseases that inhabit the human intestinal system that may be present in certain industrial waste. Another problem is that these waters, usually contains nutrients, which can stimulate the growth of aquatic plants and can also include toxic compounds. For all this in an industrialized society like ours, the immediate evacuation is needed without discomfort of wastewater from its generation sources, followed by its treatment and disposal.[1]

1.2 OBJECTIVE

To comply with the law to the provisions of Directive 91/271/ CEE on urban wastewater treatment, (transposed to Spanish legislation through Law 11/1995) Spanish municipalities must adopt measures necessary to ensure that these waters are treated correctly, in appropriate facilities, before they are discharged, with the ultimate aim of guaranteeing the protection of the environment.

In the treatment of wastewater, they are submitted to a number of processes, such as physicals, chemicals and biologicals that their aim is to reduce the concentration of pollutants and allow the discharge of purified effluents, minimizing risks to both environment and population, as it is said at

This process brings with it the generation of sewage sludge, which according to the community directive, adequate management and treatment in an appropriate way, that with increasing environmental limitations and methods of increasingly restrictive treatment by application legislation.[2]

Thus, it is needed to manage this sewage sludge correctly with the main objective of reduce its volume eliminating the maximum quantity of water that contains, since has many benefits as:

- Reduce the costs of transporting sludge to the final evacuation site.
- Facilitate mud handling and its direct application in agriculture.
- Improve the composting operation in case this is the destination of the sludge.
- Allow the entry of sludge in landfill controlled.
-Increase the calorific power of the sludge in case it goes to incinerate.
- Avoid odor generation and mud rot.

1.3 WASTE PRODUCTION

In the research from the National Study in relation to the purification were collected. Regarding the purification capacity, it is considered that in Spain it has a purification capacity of 8,130 hm^3/year, and a volume of treated residual water of 4,097 hm^3/year, which supposes a total of 102 hm^3 of residual water purified by inhabitant and year. In metropolitan areas this volume occupies 35% of treated water with 1452 hm^3/year, being 111m^3/hab·year. [3]

The use of this reused volume varies from agriculture, industry or the irrigation of gardens and leisure areas. This activity is regulated in Spain by the RD 1620/2007 that ensures the quality and safety of this practice.

In addition to the reuse of wastewater, sludge of the primary and secondary decanters is also produced in WWTPs. This muds also have an advantage for purposes, such as agriculture, gardening or incineration. Currently, 800,000 tons of dry matter sludge are produced in Spain.[3]

With all this, the supply and sanitation operators in Spain contribute significantly to the use of the resources extracted from urban and industrial wastewater. This avant-garde has been developing for years and aligns these services with the new economic strategy promoted by the European Union on Circular Economy.

1.4 COMPOSITION OF WASTEWATER

This chapter it will be focusing in the parameters of wastewater, basically it will be physical parameters, chemical parameters and biological parameters.

1.4.1 PHYSICAL PARAMETERS

1.4.1.1. SOLIDS

It is defined as total solid the matter obtained as waste after subjecting the water to an evaporation process of between 103 and 105 °C in accordance with “A Spanish Rule” UNE (77030:2015). Solid matter lost during evaporation due to its high vapor it is not defined as solid.

In addition to the content of total solids, it is advisable to know that one part of these solids is sedimentable. The sedimentable part of total solids are determined by decanting from a one-liter sample volume left standing in a conical vessel (Imhoff cone) for one hour, expressing the sediment volume at the bottom of the cone in ml/L. This volume gives an idea of the amount of sludge that will be produced in the primary settling.

On the other hand, we can define the other kind of solids as filterable or non-filterable, (solids in suspension) by passing a known volume of liquid through a filter. The filterable fraction of the solids corresponds to colloidal and dissolved solids. The colloidal fraction is composed of particles sized between 0.001 and 1 µm. Dissolved solids are composed of organic and inorganic molecules and ions in solution in water. It is not possible to eliminate the colloidal fraction by sedimentation. Normally, biological oxidation or coagulation complemented by sedimentation is needed to eliminate the colloidal fraction.

Each of the categories of solids discussed can be divided according to their volatility at 550± 50 °C.[4] At this temperature, the organic fraction will rust and disappear as gas, leaving the inorganic fraction in the form of ash. Hence, the terms “volatile solids” and “fixed solids” are used to refer, respectively, to the organic and inorganic (or mineral) components of suspended solids. The analysis of volatile solids is usually used to determine the biological stability of wastewater sludge.

1.4.1.2. TEMPERATURE

It is a very important parameter as its effect on chemical reactions and reaction rates, also it is interesting due to the fact it may contain aquatic life, and the suitability of the water for beneficial uses.

The increase in the rate of biochemical reactions that accompanies an increase in temperature, combined with the decrease in the quantity of oxygen present in surface water, can often cause serious depletions in dissolved oxygen concentration in the summer months.

Moreover, an increase in temperature modifies the solubility of the substances, increasing that of the dissolved solids and decreasing that of the gases. The biological activity approximately doubles every ten degrees (law of Q10), although exceeded a certain characteristic value of each living species, has lethal effects for organisms. An abnormal increase (due to non-climatic causes) of the water temperature, usually originates in the discharge of water used in industrial processes of heat exchange. The temperature is determined by thermometry carried out "in situ".

Finally, it is known that the optimum temperature for the development of bacterial activity is between 25 and 35 °C. The processes of aerobic digestion and nitrification stop when 50 °C is reached. At temperatures of around 15 °C, the methane-producing bacteria cease their activity, while the autotrophic nitrifying bacteria stop acting when the temperature reaches values close to 5 °C.[4] If temperatures of the order of 2 °C are reached, even the chemoheterotrophic bacteria acting on the carbonaceous matter cease to act.

1.4.1.3. COLOR AND ODOR

They are what are called organoleptic properties or determinable by the senses. They are not usually a precise measure of the level of contamination.

Taking into consideration information presented in ISO 7887:2011, there is no direct relationship between color and degree of contamination, as being a parameter strongly influenced by interferences with other colored substances, its absolute evaluation is difficult.[5] The most used method involves the determination of color by visual comparison with standard solutions of hexachloroplatinate and can be applied to raw and potable waters.

In recent times, wastewater often has a grayish color. However, by increasing the transport time in the sewerage networks and by developing conditions closer to the anaerobic ones, the color of the residual water changes gradually from gray to dark gray, to finally acquire black color. At this point, wastewater is usually classified as septic.

Odor is also important parameter and its determination is increasingly important to the extent that the public has become more interested in the operation of the wastewater treatment facilities. The odor of a fresh wastewater is generally harmless, but a large number of malodorous compounds are released when biological degradation of the matter occurs under anaerobic conditions of the wastewater. The main undesirable odor compound is hydrogen sulfide.

1.4.1.4. DENSITY

It is an important physical characteristic of wastewater since the potential formation of density currents in sedimentation sludge and other treatment facilities depends on it. The density of domestic wastewater that does not contain large amounts of industrial waste is practically the same as that of water at the same temperature. The density will depend on the temperature and varies depending on the total concentration of solids in the wastewater.

1.4.1.5. TURBIDITY

Turbidity, as a measure of the dispersion properties of water light, is another parameter used to indicate the quality of natural waters and treated wastewater in relation to colloidal suspension material.

Practically, it constitutes an optical measurement of the material suspended in the water. Raw wastewater, in general, is cloudy, due to 0.1 % solid organic or inorganic material, suspended in the water. In treated wastewater it can be an important factor of quality control.

1.4.2. CHEMICAL PARAMETERS.

The chemical characteristics of wastewater are organic matter, inorganic matter and the gases present in these waters. To be measured, it has to be done separately due to its importance in the management of water quality and in the design of water treatment facilities.

1.4.2.1. ORGANIC MATTER

The most important objective of urban wastewater treatment is the elimination of organic matter. When the wastewater is discharged directly into the environment without purifying the organic matter it contains, it is responsible for the degradation seen in the receiving water currents. Since most of the organic matter that contains urban wastewater is biodegradable, microorganisms use it as food, for which they need to consume oxygen. This gas is moderately soluble in water, and when it is consumed quickly in this degradation of organic matter, its concentration decreases until reaching levels of anaerobiosis, that is, absence of dissolved oxygen.[4]

Therefore, the most important characteristic of urban wastewater is its content in organic matter. This material may have a vegetable or animal origin and is normally added to water as waste products of human activity.

Within the organic matter can distinguish between different types of compounds, more or less complex, and whose biological degradation requires a more or less long time. However, from the point of view of the purification it is usually avoided the detailed study of the components of the organic matter, and it is used instead of this one measures that give an idea about the necessary oxygen for its stabilization. The most widespread measures of organic matter are the biochemical demand for oxygen and the chemical demand for oxygen defined as follow:

- Oxygen biochemical demand at five days (BOD5): this measure represents the amount of oxygen necessary to biologically stabilize the organic matter contained in a water sample, incubated for five days at 20 °C. This measure is intended to reproduce the consumption of oxygen in a natural environment, such as a river, caused by the discharge of wastewater. The temperature of the test is 20 ° C, and its duration corresponds to a stabilization of 60-70 % of organic matter.[2]

- Chemical demand for oxygen: with this measure the oxygen necessary to chemically oxidize the organic matter contained in the water is estimated. Since by chemical means the oxidation of organic matter is more complete, the COD value is higher than that of BOD5. It is possible to establish relationships between BOD5 and COD for different types of wastewater, so that sometimes one measure is replaced by the other. For untreated urban wastewater, the approximate ratio between BOD5 and COD is as follows (Equation 1):

$$\frac{BOD5}{COD} = 0.5 \qquad \text{(Equation 1)}$$

In the test, a strongly oxidizing chemical agent is used in an acid medium for the determination of the oxygen equivalent of the organic material that can be oxidized.

The Table 1 shows the results that can be considered typical for the content in organic matter of urban wastewater. Depending on the pollutant load, one can speak of very strong, strong, medium or weak concentration. The pollutant load depends mainly on the amount of water used by the population. In general, the greater the water consumption per inhabitant, the lower the residual water load.

Table 1. Typical content of organic matter in wastewater

	WEAK	MEDIUM	STRONG	VERY STRONG
BOD5	<200	350	500	>750
COD	<400	700	1000	>1500

1.4.2.2. INORGANIC MATTER

In addition to organic matter, urban wastewater contains inorganic species that also have a great impact on their treatment by biological methods. Many of the measures of these species are often handled in the treatment plants because they give a good idea about the progress of the process, or because it is convenient to eliminate them during the treatment to avoid contamination problems in the receiving watercourses.

1.4.2.3. PH

The measurement of the pH by itself does not indicate if the water has impurities, since a residual water can be very charged and have a neutral pH. However, pH is very important to determine thebiological treatability of water [4], since microorganisms have a very small tolerance for pH changes.

Moreover, the range of concentrations suitable for the proliferation and development of most biological life is quite narrow and critical (5,5-9,5), therefore, as urban wastewater has a pH value around 7.5-8.0 being an optimum range for the development of biological processes.

1.4.2.4. NUTRIENTS

It is what is known as the food of microorganisms. Although the nutrients are a great number of species, it is usually spoken of nutrients, mainly to refer to the different forms of nitrogen and phosphorus, which are the ones that are needed in greater quantities. In the case of urban wastewater analysis, they contain a high content of both.[4] What is advantageous is a biological treatment without the need to adjust the feed composition at the entrance to the treatment plant, but as a consequence the disadvantage is acquired when leaving the plant, as the nutrients stimulate the growth of microorganisms in the courses of water receivers.

1.4.2.5. NITROGEN

Nitrogen can be found in various forms, either in organic form (proteins) or inorganic; it can be said that in nitrogen it is found in the same way, that is 50 % organically and another 50 % inorganically.

The inorganic part of the nitrogen that can be found in the wastewater of the city is: ammonia, nitrites and nitrates, which originally were only found ammonia. In the aerobic environment and thanks to the action of bacteria, ammonia is oxidized to nitrate and nitrite forms which in turn serve for the proliferation of algae or matter in the waters.[4] The subsequent decomposition of these algae favors the formation of ammonia, forming a cycle. Therefore, it is necessary to adopt measures, for a reduction of nitrogen in wastewater.

1.4.2.6. PHOSPHOR

It is also found in wastewater in organic and inorganic form. Among the inorganic forms, as polyphosphate and organic phosphate and the most important is soluble phosphorus (orthophosphates),[4] which is directly usable by microorganisms. As with nitrogen, the different forms of phosphorus are interconvertible.

Orthophosphates include molecules with two or more phosphorus atoms, oxygen atoms and, in certain cases, hydrogen atoms combined in complex molecules. The hydrolysis of polyphosphates, a process in which they recover their forms as orthophosphates, takes place in aqueous solutions. However, this hydrolysis is usually a rather slow process.

1.4.2.7. SULFUR

The sulfate ion is found, naturally, in most water supply and wastewater. For the synthesis of proteins, it is necessary to have sulfur, an element that will later be released in the degradation process. Sulfates are chemically reduced to sulfides and hydrogen sulfides under bacterial action under anaerobic conditions. Sulfates are reduced to sulfides in sludge digesters and can alter the normal development of biological treatment processes if the sulfide concentration exceeds 200 mg/L. Fortunately, these concentrations are rarely achieved.

1.4.2.8. METALS

As important constituents of many waters, quantities are also found, at the trace level, of many metals. Among them we can highlight nickel, manganese, lead, chromium, cadmium, zinc, copper, iron and mercury. Many of these metals are listed as priority pollutants. Some of them are essential for the normal development of biological life, and the absence of sufficient quantities of them could limit the growth of algae, for example.[4]

Due to its toxicity, the presence of any of them in excessive amounts will interfere with a large number of water uses. That is why, often, it is convenient to measure and control the concentrations of these substances.

1.4.3. BIOLOGICAL PARAMETERS

1.4.3.1. BACTERIAS, VIRUS, PROTOZOOS

Bacteria is a unicellular microorganism without a differentiated nucleus, some of whose species decompose organic matter, while others produce diseases.

Virus is very simple organism structure, composed of proteins and nucleic acids, and capable of reproducing only in the bosom of specific living cells, using its metabolism.

Protozoos (said of an organism) is constituted by a single cell or by a colony of cells equal to each other, and that is almost always microscopic.

These pathogens which are present in the wastewater may be of fecal origin or involved in the biodegradation process. In the raw wastewater species belonging to groups such as Escherichia, Salmonella, Enterovirus, Adenovirus, Entamoeba, Giardia predominate, which can affect humans contracting meningitis and hepatitis for example.

The analysis of the wastewater composition is carried out to make it easier to plan the treatment in the plant and to anticipate possible problems derived from this water to be treated. However, if it is known that the composition of a specific wastewater is of urban origin, no such exhaustive analysis is made and only the most important parameters are treated. The most important information that needs to be known about this type of water is about suspended matter, organic matter, bacteriological contamination, dissolved oxygen and pH.

2. SLUDGE

When carrying out the treatment of waste water to eliminate its contaminants, in almost all processes, and together with the treated water, residual materials are produced that must be managed properly, called sludge.

Proper management and treatment of them are as important as the purification process itself.

The sludge produced in the water line is, in origin, a liquid material with a concentration of solids higher than the starting waste water, and in them the contaminating species of the same are concentrated, together with part of the possible reagents used and the biomass that could have been generated. It could be said that it is, therefore, waste water more polluted than the starting.[6]

The two main sources of sludge production are primary and secondary treatment. The settled solids removed from the bottom of the primary and secondary decanters are, in reality, an aqueous mixture of characteristic color and odor called fresh mud, and it has the following characteristics:

- They have a large amount of water (95-99 %), so they occupy a large volume and are difficult to handle.

- They have a large amount of organic matter, so they easily decompose (putrefaction), producing bad odors.

- They have a large number of pathogenic organisms, causing diseases.

Depending on the kind of treatments wastewater has received we can received different kind of sludge, with different concentrations of solids. They are describe as follows:

Crude sludge meaning that it has not been treated or stabilized, which can be extracted from wastewater treatment plants. It has to produce the acidification of digestion and produces odor.

Primary sludge is produced during the primary treatment processes of wastewater. This happens after screens and de-sand and sew on undissolved products from wastewater. The mud at the bottom of the primary sedimentation tank is also called primary sludge. The composition of the mud depends on the characteristics of the water collection area. The primary mud usually contains a large amount of organic material, vegetables, fruits, paper, etc. The consistency is characterized by being a dense fluid with a percentage in water that varies between 93 % and 97 %.[6]

Active sludge: Disposal of dissolved organic matter and nutrients from wastewater takes place during the biological treatment of water. It is usually characterized by the interaction of different types of bacteria and microorganisms, which require oxygen to live, grow and multiply and consume organic matter. The resulting mud called active mud. Normally this sludge is in the form of floccules containing live and dead biomass as well as adsorbed and stored organic and mineral parts.

The sedimentation behavior of the flocs of the active sludge is of great importance for the operation of the biological treatment plant. The flocs must be removed, to separate the biomass from the clean water, and the required volume of active sludge can be pumped back into the aeration tank.

Secondary sludge; in order to achieve a constant mud life, the excess biomass must be removed from the biological treatment plant. Secondary mud contains non-hydrolysable particles and biomass as a result of cellular metabolism.Tertiary sludge is produced through subsequent treatment processes, ex. addition of flocculating agents.

Thus, before the treatment itself, the sludge has to be prepared for it, therefore it is treated in the most efficient way, as well as taking care of the best way the machinery used in the treatment.

3. SLUDGE PRETREATMENT

The main objective of pre-treatment is to ensure that the sludge feed to the treatment facilities is constant and homogeneous. Therefore, to assure this to happen it is necessary to dilacerate, to remove sand, to mix and to store the mud. The mixing and storage can be carried out in a single unit designed to fulfill both functions, or separately in other elements of the plant.

3.1. DILACERATION

Dilaceration of the sludge is a process in which the large solids contained in the sludge are cut or shredded into smaller particles to avoid clogging and the formation of skeins in the rotating equipment. Historically, dilators have always required a lot of maintenance, but modern designs of low speed dilators have proven to be more reliable and offer greater durability.[7]

These designs include improvements to the seal and bearings, hardened steel blades, overload sensors, and mechanisms that intervene in the direction of rotation of the blades to eliminate obstructions or, in the event that it is not possible to eliminate the obstructions, the disconnection of the unit.

3.2. SAND REMOVING

The objective of sand removing operation is to eliminate all particles with a particle size greater than 200 microns, in order to prevent sediment from forming in the channels and pipes, to protect the pumps and other equipment against abrasion, and to avoid overloading in the phases of next treatment.

In some treatment plants, where grit chambers are not available before the primary decanters, or in which the de-sanding facilities are not suitable for the handling of peak flow rates and peak sand loads, it may be necessary to dewater mud before proceeding with your treatment. In cases where the primary sludge is to be thickening, it is good practice to take into account the possibility of de-sanding it.[7] The most effective method of removing sand from the sludge involves the application of centrifugal forces to a moving body of water to separate the sand from the organic sludge. This separation is achieved by the use of cyclone sand trap.

3.3. MIXING

Mud is generated in the primary, secondary and advanced treatment processes. The primary sludge is formed by settleable solids existing in the raw residual water, the secondary consists of biological solids and additional amounts of settleable solids and the one that is generated in the advanced treatment processes can be formed by biological solids and solids of chemical origin. The sludge is mixed to ensure that the feed to the subsequent processing and treatment operations is a uniform material. The uniformity of the mixture acquires greater importance in the case of systems of short time of detention, as it can be the case of the dehydration of the sludge, the thermal treatment, or the incineration. The feeding of a well-mixed mud with uniform characteristics favors, to a great extent, the performance and performance of the plants.[7]

The mixing of the primary and secondary sludge and sludge generated in the advanced treatment processes can be carried out in different ways as follows:

- In primary decantation tanks: the secondary or tertiary sludge can be recirculated to the primary decanters for sedimentation and mixing with the primary sludge;

- In pipes: to ensure proper mixing, this procedure requires careful control of the sludge generation points and feed rates. If this control is not exercised, wide variations in mud consistency are expected;

- In sludge treatment facilities that provide long retention times: the aerobic and anaerobic digesters (full mix type) can achieve a uniform mixture of the fed sludge;

- In an independent mixing tank: this practice provides the best method of controlling the quality of mixed sludge.

In treatment plants with a capacity of less than 3800 m^3/day, mixing is usually carried out in primary decanters. In large-scale installations, optimum efficiency is achieved by thickening the sludge in separate units before mixing. To ensure proper mixing, the mixing tanks are usually equipped with mechanical mixers and deflectors.

3.4. STORAGE

A sludge storage tank can be used for several purposes. The most frequent application is the mixing and homogenization of primary, secondary or highly concentrated digested sludge. The solution used to stir the sludge, or to mix it with chemical thickening products, depends on the design and volume of the sludge storage tank.

On the other hand, sludge storage must be carried out to eliminate fluctuations in sludge production and allow accumulation of sludge during periods in which subsequent treatment facilities are out of service (for example, night shifts, week, and unscheduled equipment stop periods). The storage of the sludge is particularly important in the case of processes of stabilization with lime, thermal treatment, mechanical dehydration, drying and thermal reduction, for which it is important to ensure that the feeding is carried out at constant flow.[7]

4. CONCENTRATION OF SLUDGE

As was mentioned, the fluids that are removed from the water line give rise to the sludge line of the WWTP. This line is formed by stages of treatment between which the thickeners are. The purpose of the thickeners is to separate the two phases (solid and water) effectively, increasing the concentrations of solids, so that the volumes are smaller, and the handling and final disposal is easier.

The reduction of volume is beneficial for the following processes, such as digestion, dehydration, drying and combustion, since it reduces the volumes and equipment needed, the quantity of reagents for its conditioning, as well as the amount of heat required by the digesters, or the amount of fuel to be used in any other process; reduces the equipment needed for dehydration and improves its effectiveness.

In large projects, in which the sludge must be transported important distances such as the treatment in an independent plant, the reduction of the volume of the sludge can represent the reduction of the dimensions of the conductions and of the costs of pumping. In small projects, the need to make a minimum practical size of the pipe compatible with a minimum speed, may require the pumping of significant volumes of wastewater in addition to the sludge, which decreases the value of the volume reduction achieved. The reduction of volume is very desirable in the cases in which liquid sludge is transported by means of tankers for its direct application to the ground as a soil conditioner.

The most common processes of concentration of sludge are the next ones:

- Gravity;
- Dissolved air flotation;

- Centrifugal basket;
- Solid shirt centrifuga;
- Gravity band filter;
- Rotatory drum thicker.

Then, it is showed a table when we can see the results and the used of each method.

Information on the methods of sludge concentration together with results of application of these techniques is presented in Table 2.[8]

Table 2. Information on different methods for concentration and the results of its application.

METHOD	TYPES OF SLUDGE	FREQUENCY OF USE AND SUCCESS
GRAVITY	Primary + crude	often used; excellent results
GRAVITY	Primary + crude + active	Often used, especially in small plants; satisfactory results with variable mud concentrations between 4 and 6 %. In large plants the advantatges are minimal.
GRAVITY	Active	hardly ever used; poor exit around concentration of 2-3 %
DISSOLVED AIR FLOTATION	Primary + crude + active	limited used, similar resuts of gravity thickeners
DISSOLVED AIR FLOTATION	Active	Common used; Good results (3.5-5 %)
CENTRIFUGAL BASKET	Active	Limited used; excellents results (8-10%)
SOLID SHIRT CENTRIFUGA	Active	use is increasing; good results (4-6%)
GRAVVITY BAND FILTER	Active	use is increasing; good results (3-6%)
ROTATORY DRUM THICKER	Active	Limited use; excellents results (5-9%)

4.1. GRAVITY THICKENER

A gravity thickener is similar to a circular clarifier. The mud enters the center of the thickener and the solids decant into a tent in the bottom. The conventional sludge collection mechanisms consist of devices equipped with deep scrapers or vertical pegs that slowly remove the sludge, promoting the opening of channels to provide water outlet and favoring densification.

These scrapers have in their great majority vertical peaks in the upper part, to favor the process. The scraping mechanism produces adequate agitation and the peaks eliminate gas bubbles and keep the sludge in the center, from where it is pumped to another process. The elimination of bubbles and the agitation of the layer produce the thickening.[9]

Finally, the fed sludge settles and compacts, and the thickened sludge is removed from the bottom of the tank, while the diluted sludge is conducted to a central feed chamber.

4.2. FLOATER

The flotation in sludge is used, and has historically been used, for the elimination of floatable materials, that is, solid and/or liquid materials of lower density than water. [10]This process consists in the creation of air microbubbles in the mud, which are attached to the particles to be eliminated forming aggregates capable of floating. In recent years with the improvement of this treatment has led to the process of flotation by dissolved air that is also capable of eliminating, by flotation, solids with a higher density than water.

The application in which thickened by flotation is more effective, is with the secondary sludge, active and from processes of treatment of biological culture in suspension, since the flocs have a low specific weight and weak characteristics of compaction, besides has been used for the treatment of other sludges such as primary sludge, humus from trickling filters, aerobic digestion sludge, and sludge containing metal salts originated in chemical treatments.

4.3. CENTRIFUGA

Centrifuges are used both to thicken sludge and to dehydrate them. Its application is usually limited to the thickened biological sludge, ergo the active sludge. Thickening by centrifugation involves sedimentation of the sludge particles under the influence of centrifugal forces. The two main types of centrifuges currently used for thickened sludge are the solid-sleeve centrifuge and the basket centrifuge.

The solid sleeve centrifuge consists of a solid shirt arranged horizontally, with a frustum-shaped end. The sludge is fed to the unit continuously, and the solids are concentrated in the periphery. A helical screw, which rotates at a slightly different speed, displaces the accumulated sludge towards the truncated cone end, where an additional solids concentration is produced prior to the discharge of the sludge.[11]

The operation of the basket centrifuge is discontinuous. The liquid sludge is introduced into a basket that rotates around a vertical axis. The solids accumulate in the walls of the basket, resulting in the classification of the centering. When the solid retention capacity of the centrifuge is reached (usually between 60 and 85 % of the maximum depth of the basket), the speed of rotation is reduced, and a scraper is introduced to facilitate the extraction of accumulated sludge. [8]This type of centrifuge is especially indicated for its application with soft sludge or for fine solids that are difficult to filter, or in cases in which the nature of the solids is very variable.

4.4. GRAVITY BAND FILTER

The origin of gravity band filter systems are coming from the dehydration band filters, thus it is new method. The equipment developed for thickened consists of a band that moves on rollers driven by a variable speed motor and most of the thickened occurs in the area of the filter dedicated to drainage by gravity.

The sludge is conditioned with polymers and is conducted to a distribution-feeding chamber located at the end of the unit. This chamber is used to distribute the sludge evenly over the entire width of the mobile belt, while the water runs through it and the sludge is conducted to the discharge end. [8]During the course on the band, a series of blades cut and form furrows in the mud, allowing the water released from the mud to pass through the band. Once the thickened sludge is eliminated, the band goes through a washing cycle. This type of thickeners has been used for the treatment of raw and digested sludge and requires the addition of polymers.

4.5. ROTATORY DRUM THICKER

Sludge thickened is also carried out by coated rotary drums. A rotary drum thickening equipment consists of an activated sludge conditioning system and rotating cylindrical sieves. The sludge is mixed with the polymer in the mixing and conditioning drum, and then the conditioned sludge passes to a series of rotating screens that separate the flocculated solids in the water. The thickened sludge exits at one end of the drums, while the separated water is filtered through the sieves.

In the application to activated sludge thickeners of the order of 3 and 4 % have been achieved, with the addition of polymers. The advantages of this type of thickeners are the low maintenance required, the low energy consumption, and the small space required.

5. STABILIZATION

The objectives of the stabilization of sludge are as follows: reducing the presence of pathogens; eliminate unpleasant odors; and, reduce or eliminate its putrefaction potential. This process can be managed in different ways, it can be biological stabilization in which we use digestion, it might be chemical adding $Ca(OH)_2$ or CaO and also it can be thermal by incineration.

The success in achieving these objectives is related to the effects of the stabilization process or operation on the organic or volatile fraction of the sludge. The survival of pathogenic organisms, the proliferation of odors and putrefaction, occur when microorganisms are allowed to develop on the organic fraction of the sludge.

5.1. THERMAL TREATMENT

The heat treatment is a continuous process in which the sludge is heated in a pressure tank at a temperature of up to 260 °C and pressures of up to 2760 kN/m^2,[12] for a short period of time (approximately 30 min). The heat treatment serves, basically, as a process of stabilization and conditioning, although, in most cases, it is considered as a conditioning process.

The thermal conditioning of the sludge allows solids to be suitable for dehydration without the use of thermal reagents. When the sludge is subjected to high temperatures and pressures, the thermal activity releases the water bound to the solids, causing their coagulation, and in this method solubilizes in the order of 20 % to 30 % of the BOD of the sludge. The juices that are extracted from dehydrated cooked sludge contain a high BOD (2000 - 5000 ppm) (2-5 kg/m^3 in International System).

On the other hand, thermal treatments are quite controversial because they involve high investments, considerable maintenance costs, since complex and personnel-intensive installations are necessary, and there is a need to carry out a treatment against odors. [13] It is usually an interesting treatment when the plant is large and when there is already an anaerobic digestion of the mud. The gas produced by digestion can be used to cover part of the heat demand necessary for thermal conditioning.

5.2. LIME ADDITION TREATMENT

In the stabilization process with lime, sufficient lime is added to the sludge to raise its pH above 12, for a minimum of 2 hours. This high pH value creates an environment that does not favor the survival of microorganisms. As a consequence of this, as long as this pH is maintained, the sludge will not rot, will not create odors and will not cause risks to public health. This system is usually used:

- Small water treatment plants with sludge incorporation to natural lands or stored before transport;
- Water treatment plants with the need for additional stabilization;
- Complementary stabilization system during periods when other systems are out of service.[12]

For stabilization, both hydrated lime, $Ca(OH)_2$, and quicklime, CaO can be used. In some cases, lime has been replaced by fly ash, dust from cement kilns and calcium carbide. Thus, the amount of lime necessary to stabilize the sludge is determined by the time of the sludge, its chemical composition and the concentration of solids. In broad terms, the range goes from 6 to 51 %. Taking into account that primary sludge are the ones that require the least amount of lime and the activated sludge uses the greatest amount.

It is usually incorporated before the sludge is dried, although it can also be used after using smaller amounts of lime. The dosage of lime depends on:
- Type of mud;
- Chemical composition of the sludge (including organic matter);
- Mud concentration.

5.3. BIOLOGICAL STABILIZATION

5.3.1 ANAEROBIC DIGESTION

Anaerobic digestion of sludge is among the oldest forms of biological treatment of wastewater, and its origin can be dated around 1850, when the first tank designed for the separation and retention of solids was developed. Due to the great interest in saving and recovering energy, and in the desire to obtain products that allow beneficial uses of wastewater sludge, anaerobic digestion is still the most widely used stabilization process.

It consists of the decomposition of biodegradable material in the absence of oxygen to produce two main products: biogas (composed mainly of methane) and stabilized sludge. This technology uses closed digesters where the parameters are controlled to favor the anaerobic fermentation process, a well-known process since it also occurs naturally and spontaneously in various areas, such as in marshes, in underground deposits or even in the stomach of the animals.[14]

Being a biological process, it is necessary to ensure a constant diet that does not alter the metabolism of the microorganisms involved, and that therefore can not affect the performance of the plant, it is also a very complex process due to the number of biochemical reactions that take place, as per the amount of group of bacteria involved in them. In fact, many of these reactions occur simultaneously.

In anaerobic digestion, the degradation process of organic matter is divided in four stages as follows:

-Hydrolysis stage which isconsists of a transformation controlled by extracellular enzymes in which the complex and undissolved organic molecules are broken into compounds capable of being used as a source of matter and energy for the cells of the microorganisms.[15]

-Acidogenic stage which is the second stage, controlled by bacteria, consists of the transformation of the compounds formed in the first stage into other compounds of intermediate molecular weight; such as carbon dioxide, hydrogen, aliphatic acids and alcohols, methylamine, ammonia and hydrogen sulfide.[14]

-Acetogenic stage, in which, acids and alcohols that come from the acid genesis are transformed by the action of bacteria in acetic acid, hydrogen and carbon dioxide.

-Methanogenic stage which is the only strictly anaerobic and in it the methanogenic bacteria produce CH_4 from CO_2 + H_2 or acetate. Both the kinetics of the process and the rate of formation of new bacteria is low. The working pH is close to 7.[15]

The main route of methane production is that corresponding to the transformation of acetic acid, with around 70 % of the methane produced. This is a slow process and constitutes the limiting stage of the anaerobic degradation process, but methane is not the only gas produced in the degradation of organic matter under anaerobic conditions, it is a gas mixture known as biogas. It is composed of 60 % methane, approximately 38 % carbon dioxide and traces of other gases such as hydrological, nitrogen, hydrogen sulfide, and less than 0.1 % of oxygen.[14]

5.3.1.1 Influential factors

Then, it is going to be analysed some factors that can alter the anaerobic process, and are determinants for the succes or the failure of the operation. They are the next ones:

- pH: which must be kept close to neutrality, being able to have fluctuations between 6.5 and 7.5. Its value in the digester not only determines the biogas production but also its composition.[16]

- Redox potential with recommended values lower than -350 mV;

- Nutrients with values that ensure the growth of microorganisms. One of the inherent advantages of the anaerobic digestion process is its low need for nutrients as a consequence of its small growth rate. Carbon and nitrogen are the main sources of food for methane-forming bacteria. Therefore, the Carbon/Nitrogen (C/N) ratio is of great importance for the fermentative process, recommending a 20-30 ratio as the optimum;

- Toxics and inhibitors: the inhibiting substances are compounds that are either present in the residue before digestion or are formed during the anaerobic fermentation process. These substances reduce the performance of digestion and may even cause complete destabilization of the process;

-Temperature: As the temperature increases, the growth rate of the microorganisms increases and the digestion process is accelerated, leading to higher biogas production.

There are two main ranges, the mesophilic range (between 25 and 45 °C) and the thermophilic range (between 45 and 65 °C).[14] The mesophilic range is the most used even though the thermophilic is being used more and more to obtain a greater speed of the process and a better elimination of pathogenic organisms. However, the thermophilic range is usually more unstable to any change in operating conditions and also presents greater problems of inhibition of the process due to sensitivity to some compounds, such as ammonia.[16]

- Agitation: Depending on the type of reactor, the level of energy necessary to favor the transfer of substrate to each bacterial population must be transferred to the system, and a balance between good homogenization and the correct formation of bacterial aggregates is necessary;

- Hydraulic Retention Time which is defined as the quotient between the volume of the digester and the feed flow, that is, the average time of residence of the influent in the reactor;
- Organic Volumetric Load (VOC) which is defined as the amount of organic matter introduced daily into the digester, usually expressed in volatile solids, per unit volume and time.

The capital advantage of this digestion is that Biogas is the main product obtained in the process, which has a high calorific value, it can be used in the own installation for generation of electricity and heat, with the consequent economic benefit. Moreover, it is a biofuel, therefore, it helps to meet the Kyoto protocol objectives, it can give the possibility of receiving grants in innovation and demonstration in specific applications, and you can even receive incentives for investment in facilities of biomethanization.[16]

On the other hand, we can say that it is difficult to maintain the stability of the process, due to its sensitivity to toxic inhibitors, requires a high initial investment in civil works and implementation of equipment and the set-up of the system requires long periods.

5.3.2. AEROBIC DIGESTION

The main objective of the aerobic stabilization of sludge is to obtain a stable product in which the organic matter is completely degraded. It is usually used for excess activated sludge, mixtures of excess activated sludge or sludge from beds percolators with primary sludge, excess sludge from prolonged aeration systems or sludge from activated sludge treatment plants that do not have primary settling. In addition, it is mainly used in plants below 20,000 m^3/day.[17]

Aerobic digestion is similar to the process of activated sludge. As the supply of available substrate (food) is depleted, microorganisms begin to consume their own protoplasm to obtain the energy needed for cell maintenance reactions.

In the cases in which activated sludge or previous sludge from percolating beds is mixed with primary sludge for aerobic digestion, both the direct oxidation of the organic matter contained in the primary sludge and the endogenous oxidation of the cellular tissue will occur.[18]

Currently, two variants of the aerobic digestion process are used: the conventional system and the pure oxygen system, although thermophilic aerobic digestion has also been used. In conventional aerobic digestion, the sludge is aerated for a long period of time in an open, unheated pond, using conventional diffusers or surface aerators. The process can be carried out continuously or discontinuously.

In plants of small size, the discontinuous system is used, in which the sludge is aerated and mixed thoroughly for a long period of time, allowing it to settle in the interior of the same pond. In continuous systems, the decanting and concentration of the sludge is carried out in an independent pond. Digestion with pure oxygen is a modification of the aerobic digestion process in which the air is replaced by pure oxygen. The resulting mud is similar to the mud obtained in conventional aerobic digestion processes.[17]

Thermophilic aerobic digestion represents an additional refinement of the aerobic digestion process. This process can achieve high yields of elimination of the biodegradable fraction (greater than 80 %) in short detention times (3 to 4 days) through the action of thermophilic bacteria at temperatures between 25 and 50 º C above room temperature.

Contrary to what is going to happen with the anaerobic stabilization, this process will not need heating of the sludge, although it is necessary to provide oxygen during the stabilization, which implies an exploitation cost. Other advantages of this process compared to anaerobic is that the final product has less odor, the supernatant has a lower BOD and the exploitation is very simple. A problem with this process is its sensitivity to low temperatures.[17]

5.3.2.1. Influential factors

As It has been said before, below are defined some parameters that are protagonists of the process. They are the next ones:

-Quantity and characteristics of the sludge: Mixed sludge needs more oxygen since the biological sludge is already partly stabilized and the primary sludge requires passing through the growth and endogenous respiration phases. The concentration of a mixed sludge is greater than the concentration of a secondary sludge, so the agitation powers will be greater. The volatile content must be known since it is the matter to be stabilized.[19]

-Retention time: The hydraulic retention time must be greater than 15 days.

-Workload: The workload or mass load is defined as the amount of volatile matter that enters the reactor daily per cubic meter of volume. For a given workload, performance increases with increasing retention time.

-Temperature: It is a fundamental parameter in any biological process, since below 10 ºC the yields worsen. In the winter months, when temperatures approach zero degrees, yields may drop to 1 % with 15 days of stay, therefore, in case of wanting to obtain normal yields, TRH should be doubled.

-Oxygen and mixing requirements is determined based on the biodegradable volatile solids eliminated in the endogenous respiration. The oxidation of one kg of organic matter requires 1.42 kg to oxidize the carbonaceous matter and 0.56 kg to oxidize the nitrogenous matter. That is, total oxidation requires 2 kg of O_2 per kg of biodegradable material, which is a fraction of the volatile that reaches the reactor.

-Aeration modes: The aeration systems can be by diffusion, by surface aerators and can also use submerged aerators. Its capacity is determined by the mixing needs, which are superior to oxygenation.[19]

5.4. COMPOSTING

One of the treatments that has always been applied to stabilize organic matter is composting. It is a simple, versatile foundation system and can be applied to different types of materials; it is considered economic and ecological, in addition the increasingly restrictive regulations of atmospheric pollution and sludge evacuation, together with the foreseeable shortage of available landfills, have accelerated the development of composting as a viable option for mud management.[20]

When it is required to apply composting, it is necessary to prepare the conditions so that, thanks to a complex microbial activity, the waste becomes a stable product. If it is properly compacted it is a humus type material, hygienic and free of unpleasant characteristics. Approximately 20 or 30 % of the volatile solids are converted into carbon dioxide and water. As the organic matter contained in the sludge decomposes, the compost is heated to temperatures in the pasteurization range (50 to 70 °C), [21] which allows the destruction of enteric pathogenic organisms. A well-composted sludge can be used as soil conditioner for agricultural and horticultural uses, or be sent to landfill, always complying with the limitations applicable to the constituents of the sludge.

Although composting can be carried out under both aerobic and anaerobic conditions, aerobic composting is used in almost all applications of sludge from urban wastewater. Composting under aerobic conditions accelerates the decomposition of matter and leads to a greater increase in temperature, sufficient for the destruction of pathogens, and also minimizes the production of unpleasant odors.[20]

Although most organic materials can be composted, the process is often not applied properly, or it is not done on suitable materials for the product that is intended to be obtained. On other occasions, when a composting test or a treatment carried out for a certain period of time works, it is decided to vary the working scale (work with much larger quantities) without taking precautions or changing the controls, causing a decrease in the quality of the product.

Composting takes place in two phases: decomposition and maturation. Then, they will explain and differentiate in detail.

The decomposition phase depends entirely on the type of material to be treated and on the characteristics of the system to be applied. It can be divided into three stages: an initial mesophilic phase, thermophilic stage, and finally a cooling stage.[20]

-Mesophilic phase: Various families of microorganisms initiate the decomposition of easily degradable compounds, causing an increase in the temperature and in which the pH drops due to the formation of organic acids.

-Thermophilic stage in which the thermophilic microorganisms are appearing and in which the temperature exceeds 40 ^{o}C. If it reaches 60 ^{o}C the fungi are inactivated and the decomposition is carried out by actinomycetes and spore-forming bacteria. Easily degradable substances, such as sugars, fat, starch and proteins, are quickly consumed and most human and plant pathogens are destroyed; the pH becomes alkalinized when proteins are released ammonia; in turn cellulose and lignins are partially altered.

-Cooling stage is characterized by a decrease in temperature, decrease in the rate of degradation and recolonization of the substrate by mesophilic microorganisms.

These three stages last from a few weeks to several months depending on the material to be composted and the working conditions. The decomposition phase is the most demanding of the process and if it is not done under good conditions, the continuation of the process is on risk, as the appearance of leachate problems and bad odors, as well as influencing the quality of the final product.[20]

In the maturation stage, pH remains slightly alkaline. In this phase the mesophilic microorganisms, as well as different types of micro fauna, colonize the mature medium compost. It generates intense competition for food, formation of antibiotics and the appearance of antagonisms; obtaining at the end a product, more or less stable, according to the duration of the last phase, that it might be between some weeks until months.

There are different ways to do the composting procces, they are: aerated static stack, flipped piles and closed composting systems.

5.4.1 AERATED STATIC STACK

The static aerated stack system consists of a network of air conduction pipes on which a mixture of dehydrated sludge and a support material is distributed. In a typical system of static piles, the support material is usually made up of wood chips that are mixed with the dehydrated sludge by means of a paddle or rotating drum mixer or by mobile equipment such as a digging shovel. The material is composted for a period of 21 to 28 days and matured for an additional period of 30 days or more. The height of the batteries usually ranges between 2 and 2.5 meters. Often, to isolate the pile, a layer of compost is placed on top of it.[21]

For the supply of air, it is common to use corrugated plastic pipes and, to improve the control of the aeration system, it is recommended that each of the batteries has an individual blower system. The screening of matured compost is usually carried out to reduce the amount of final product that needs to be evacuated and to recover the support material. To improve the control of the process and the emission of odors, many of the most modern installations cover all or the most important elements of the system.

One thing that is difficult to control, due to the lack of movement of this system is a lack of homogenization of the mass, with the consequent formation of temperature gradients and preferential routes for air circulation, producing in addition the gradual compaction of the material during the decomposition of the same with the consequent loss of porosity.[19]

5.4.2. FLIPPED PILES

In the system of flipped batteries, the operations of mixing and screening are similar to those used in static aerated batteries, but being more shorter and thicker, as their height is from 1 to 2 meters, with a width at the base of 2 to 4.5 meters. The piles are mixed and flipped periodically during the composting time and even in some applications, additional mechanical aeration is incorporated. Under normal operating conditions, the batteries are turned a minimum of 5 times while the temperature is maintained at or above 55 °C. This operation is often accompanied by the release of unpleasant odors. The composting period ranges between 21 and 28 days.[21]

The main inconvenient of this system is that do not allow effective temperature control and are considered less effective than static stack in the destruction of pathogens due to the re-circulation during turning by those microorganisms located in areas not subjected to high temperatures.

As it was explained, there are a few inconvenients in both systems and that is why in current times there are systems that combine turning and forced ventilation.

5.4.3. COMPOSTING CLOSED SYSTEMS

Composting in closed systems is carried out inside closed tanks or reactors. Mechanical systems are designed to minimize odor production and process duration by controlling environmental conditions such as air flow, temperature and oxygen concentration. The use of closed composting systems has increased rapidly in recent years being the main reasons like, control over the process and odors, low labor costs, and lower field needs.

They present as a major drawback the high costs of investment, maintenance and energy, and involve the use of a reactor or digester, where the first phase of the process is performed to subsequently let the material mature on the outside of the reactor.[21]

5.4.3.1. Influential factors

There are some parametes, that have to be controlled in order to succed in the operation. Below are the most important parameters:

Type of sludge: Both raw and digested sludge can be satisfactorily composted. Crude sludge has a greater potential for generating odors and has a higher oxygen demand, but it has a greater energy and degrades at a faster rate.[22]

Carbon/Nitrogen relation: The C/N ratio must be within the range between 25:1 and 35:1 by weight, in addition, the carbon present must be analyzed to ensure that it is easily biodegradable.

Volatile Solids: The volatile solids content of the mixture to be composted must be higher than 50 %.

Air requirements: To obtain optimal results, it must be ensured that air with at least 50 % of the remaining oxygen reaches the entire mass of material to be composted.

Humidity: The moisture content of the mixture to be composted should not be higher than 60 %, in the case of static batteries and tumbled batteries, and it should not be higher than 65 % in the case of closed reactors.

pH: Must be between neutrality, around 6 and 9.

Temperature: The optimum temperature for biological stabilization is between 45 and 55 °C. To obtain optimal results, the temperature should be maintained between 50 and 55 °C during the first days and between 55 and 60 °C during the rest of the composting period. If temperatures are allowed to exceed 60 °C for important periods of time, the biological activity is reduced.[22]

Heavy metals and organic compounds: Trace the heavy metals and trace organic compounds present in the sludge and in the final composting product to ensure that the limitations applicable to the uses of the final product are not exceeded.

6. CONDITIONING

In order to eliminate the free water present in a sludge by mechanical means it is necessary to break the colloidal stability and increase the size of the flocs. Basically, there are two ways of conditioning in the treatment of sludge, you can talk about chemical conditioning or physical conditioning.

6.1. CHEMICAL CONDITIONING

The use of chemical products for conditioning the sludge for dehydration is an economic practice due to the increase in production and the greater flexibility that is obtained. The chemical conditioning allows to reduce the humidity of the sludge, from 65-85 % to 90-99 %, depending on the nature of the solids to be treated. This chemical product may have an organic or inorganic naturalness, for an inorganic reactive we use $FeCr_3$ or lime, whereas the organic reactive are polyelectrolytes, the last ones do not cause a significant increase in dry solids, while iron and lime salts can cause increases of 20-30 %. Conditioning is done to facilitate the next operations, in this concrete case before mechanical dehydration.[23]

The main objective of this operation is to create bigger solids, to facilitate the liberation of the water, this process is call coagulation. It is a process of chemical destabilization of the colloidal particles that are produced by neutralizing the forces that keep them separated, by means of the addition of the chemical coagulants and the application of the mixing energy, it can be said that is the most effective treatment, but it is also the one that represents a high expense when it is not well done. It is also the universal method because it eliminates a large amount of substances of various natures and weight of matter that are eliminated at the lowest cost, compared to other methods.

The dosage and application of the reagents is easier if done in liquid form. In the case that the supply of chemical products is powder, it will be necessary to have dilution tanks. In most plants, these tanks must have sufficient capacity to store, at least, the amount of liquid necessary for the corresponding dosage for a whole day, and two units must be available. In large-scale plants, tanks are usually available with sufficient capacity for the power supply corresponding to a work shift. Tanks must be made of or coated with a corrosion resistant material. For the tanks and pipes through which acid solutions must circulate, the most indicated materials are polyvinyl chloride (PVC), polyethylene and rubber. The dosing pumps must be resistant to corrosion.

6.2. THERMAL TREATMENT

It follows the same procedure than thermal treatment in stabilization which was explained previously. The sludge is heated under pressure for short periods of time and is used to coagulate solids, break the gel structure and destroy the affinity of water to the solids contained in the mud. It has some good advantages such as solid content in dehydrated sludge its higher than in chemical treatment (30-40 %), it allows to stabilize the mud and destroy most of the pathogenic organisms, it is relatively insensitive to variations in the composition of the sludge and the sludge has a calorific value of between 28 and 30 kJ/g of volatile solids.[23]

On the other hand, it needs a high investment cost due to the mechanical complexity of the process and the use of materials resistant to corrosion, it is necessary to be monitoring continuously with specialized operators and a thorough exhaustive preventive maintenance program, generates by-products with a high content of organic matter, ammoniac nitrogen and very odorous gases that require confinement, treatment or destruction.

7. DEHYDRATION

Dehydration is a unitary physical (mechanical) operation used to reduce the moisture content of the sludge, it is one of the last sludge treatment processes and it is used to eliminate the capillary water contained in the sludge, which is around 25 % of the total. This technique can be carried out by filtration or centrifugation, depending on the sludge dehydrating.

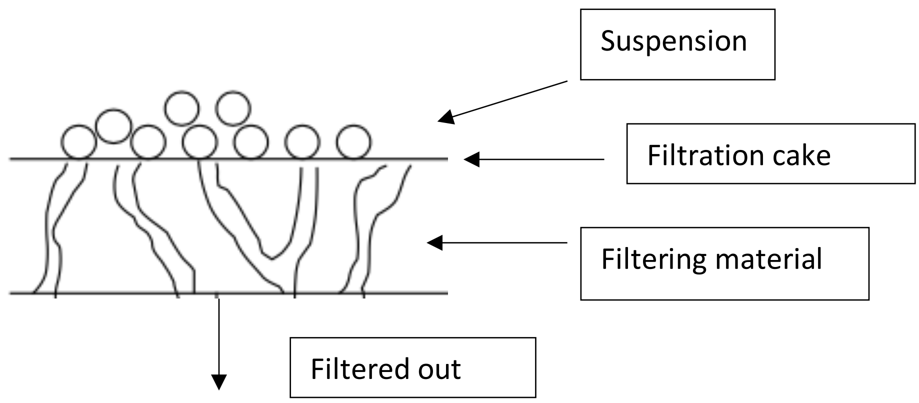
7.1. MECHANICAL DEHYDRATION

One way of dehydration of suldge is mechanical dehydration, in wchich we have can differ between filtration and centrifugation. Then, they are going to be defined both and their variants.

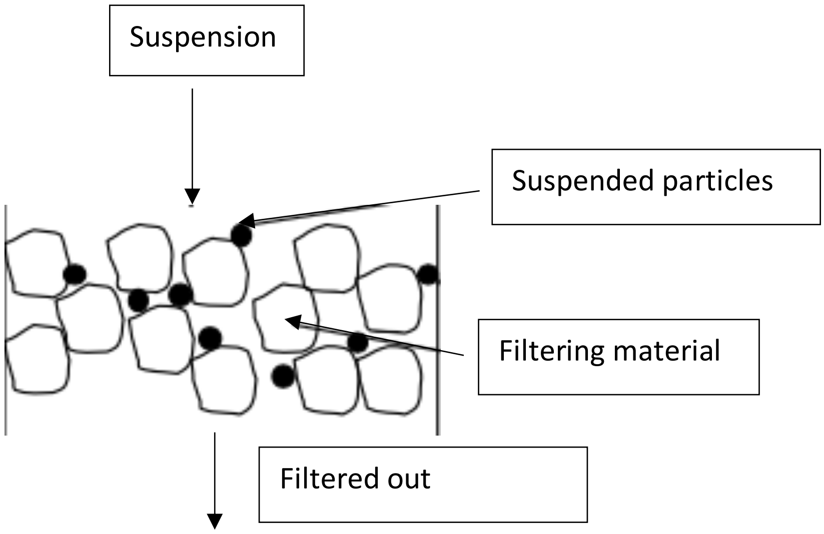
7.1.1. FILTRATION

Filtration is a technique by which suspended particles are separated from water. It consists of passing the liquid through a porous medium (filter), providing sufficient pressure to the water. These particles can be retained either on the surface of the filter (surface filtration) or in the voids left by the material that constitutes the filtering medium (volumetric filtration).

Schematic representations of surface filtration and volumetric filtration Are presented on Scheme 1 and Scheme 2, respectivelly.



Scheme1. Schematic representation of surface filtration.



Scheme 2. Schematic representation of volumetric filtration

The filtration process will be successful, the pressure parameters need to be adequate, the smallest possible cake size and an increase in the granulometry of the grain. This increase in particle size is achieved by the addition of polyelectrolytes to form flocs.

7.1.1.1. VACCUM FILTRATION

In vacuum filtration, the driving force acting on the liquid phase causing the movement through a porous medium, is the atmospheric pressure, due to the application of vacuum on the lower surface of the filter medium. The vacuum filter consists of a horizontal cylindrical drum that rotates, partially submerged, in a sludge tank. [24]A chemical conditioning of the sludge is performed before the filtration is carried out to increase the solids content, reduce the filtrate solids and improve the dehydration characteristics, it is conditioned with ferric chloride, polymers or lime, as already explained in the conditioning section.

The results obtained with this type of system vary depending on the characteristics of the sludge to be filtered. But in this type of system it is advisable to treat a sludge in which its solid content is about 6-8 % and the cake obtained usually has 20 % solid matter.

7.1.1.2. FILTER PRESS PLATES

A filter press comprises a set of juxtaposed vertical hollow plates pressed firmly against each other by means of a hydraulic jack at one end of the plate assembly. A filter cloth fits or hangs over each of the plates. The plates are held together with sufficient force to adhere hermetically and can, thus, resist the pressure applied during the filtration process. For the plates to be held together, hydraulic presses or mechanically driven screws are used. It is a batch or batch filtering cycle, since you have to close the filter, fill it, carry out the filtering and once done, reopen the filter and wash it.[23][24]

During operation, the chemically conditioned sludge is pumped into the space between the plates, and a variable pressure between 690 and 1550 kN/m^2 is applied, which is maintained for 1-3 hours, forcing the liquid to pass through the filter cloth. and the exit holes of the plates. Next, the plates are separated, and the mud cake is removed. The filtered liquid is usually recycled to the plant head. The thickness of the mud cake varies between 25 and 38 mm, and the moisture content between 35-50 %.

7.1.1.3. BAND FILTER

It consists of a system that in addition to having mechanical dehydration, also employs the use of previously explained mechanism such as chemical conditioning and drainage by gravity.

First, the conditioned sludge is introduced into a drainage area by gravity, in which as much water as possible is eliminated by the effect of gravity. Once this has happened, the sludge to be filtered is deposited on the surface of the band and the pressure is lowered to be compressed between two opposite porous fabrics. In some units, this low-pressure application zone is followed by another high-pressure zone, in which the sludge is subjected to tangential stresses as the bands pass through a series of rollers, thus favoring the release of additional quantities of water contained in the mud. As a consequence, as the band progresses, the sludge always falls on a clean filter, while the liquid permeates through the filter, leaving the solid sludge retained in the filter cloth. The quality of the cake is about 20-25 % of solid matter.[23]

7.1.2. CENTRIFUGATION

The centrifugation process is widely used in the industry because is a continuous separation process that uses the action of centrifugal force to accelerate the settlement of the particles in a solid-liquid mixture. During the centrifugation the formation of two different phases appears: sediment and liquid.

7.1.2.1. HORIZONTAL AXIS CENTRIFUGA

Centrifuges of this type consist of a horizontal rotary drum that rotates at a high speed. Inside the drum there is a helical extraction screw located coaxially so that it fits perfectly inside the drum, there being a minimum separation between the drum and the internal screw.

It has a simple operation, since, due to the effect of the centrifugal force, the heavy particles decant and settle against the inner wall of the tank. The conveyor screw scrapes the particles and sends them continuously to the conical part, which rotates slightly faster than the container thanks to a reducer, therefore, the sediments compacted in the cone are evacuated at one end and collected in a discharge hopper. At the same time, due to the continuous feeding, the liquid is evacuated to the effluent collection area by means of adjustable collectors.[23][15]

7.2 ADVANTATGES AND DISADVANTAGES

After define every operation of mechanical dehydration, we will see in the table 3. The advantages and drawbacks of all operations.

Table3. Advantages and disadvantages of different types of mechanical dehydration.

	ADVANTAGE	DISADVANTAGES
VACCUM FILTRATION	-Occupy little space. -It is not necessary to have qualified personnel.	-High energy consumption. -High doses of reagents to condition the sludge. - High maintenance costs.
FILTER PRESS PLATES	-High concentration of solids in the cake. -Obtaining a very clarified mud liquor. - High catches of solids.	-Big cost of labor. -High doses of reagents to condition the sludge. -Limited life of the fabrics.
BAND FILTER	-Low energy consumption. -Easy to use and good visual control of the dehydration process. - Low operating costs and reasonable investment costs. -The process is continuous as is the washing of the band filter. -Production of sludge easy to detach. -Flocculant saving.	-High consumption of washing water. -Recreate a sludge trap in the feed pipe. -The useful life of the medium is short compared to the other devices that use fabric means.
HORIZONTAL AXIS CENTRIFUGA	-Continuous feeding and extraction operation. -The separation is produced by sedimentation, there are no filters so there are no problems of seals. -High separation of liquid and sediment is obtained. -Odors are reduced. -Effective separation in the case of sludge fed with low concentration of solid matter. - Mud is not visualized during dehydration.	- Periodic calibrations. -Sensitivity to variations in mud concentration. -Elevated energy consumption. -Need for sound insulation.

8. THERMAL TREATMENT

Thermal drying is a process that is based on the application of thermal energy to evaporate water from the sludge that is not separable by mechanical means, bringing the sludge to a temperature near 350 ^{o}C. The dryness of the mud usually reaches 90 %,[26] but a large amount of heat is needed to evaporate the water, so this system is feasible if it is easy to obtain cheap heat or the final dry product is going to be sold. Its main objectives are improving reuse, recycling or recovery of sludge.

First of all, it need to be conditioned thermally, as explained in Section 5.3, since the heating of a sludge at a sufficient temperature produces an irreversible transformation of its physical structure facilitating its dehydration due to the coagulation of solids, the breakage of the colloidal structure and the destruction of the affinity for water of the solids contained in the sludge.

As we are working with high temperatures, we have to tke into account some aspects that can occur during mud heating and can be dangerous. The first is that the sludge can go through a plastic phase, in which there is a great increase in its viscosity, low heat transfer and there is a risk of clogging. To avoid this phase that occurs when the dryness of the sludge is 50 % in the dryer, most systems resort to recirculation. In these systems the 90 % dry sludge is mixed with wet sludge before entering the dryer, obtaining a mud with a solids content of 65 %.[26]

The second risk, more dangerous for workers, is the risk of explosion. It need to be taken into account that at the exit of the dryer, the gas is full of dust (dry mud), water vapor and volatile organic compounds (VOC`s). The problem arises because of the oxygen that is the precise comburent to detonate and / or combust the dust contained in the gas.

As precaution the first thing we have to do is to reduce the oxygen content, that is, to work in a humid atmosphere, this can be done, or by adding nitrogen to the gases of the closed circuit or CO_2, the latter is much more affordable and cheaper. For this purpose, the boiler gases that have an amount of O_2 close to the stoichiometric. The O_2 limit that guarantees operational safety is difficult, if not impossible, to establish. It is a factor that depends on the quantity and quality of the VOC`s, the quantity, quality and state of the powder, the temperature, but it is advisable not to exceed 8 % in volume of oxygen. The second, is to reduce the quantity of dust we have at the exit, this it has to be done by filtrating the air. The content of dust has to be less tan 30 g/m^3.

In this process depending on the temperature range, in which we work, it will be discussed between incineration, convection and contact drying.

In high temperature (incineration), in special ovens, a self-combustion of the mud is carried out at temperatures of the order of 700 ºC.[26] In reality they can not be considered as thermal dryers since they combine drying with combustion.

In medium temperature (normally convection and drying) the mud is subjected to temperatures of 120 to 150 ºC.[26]

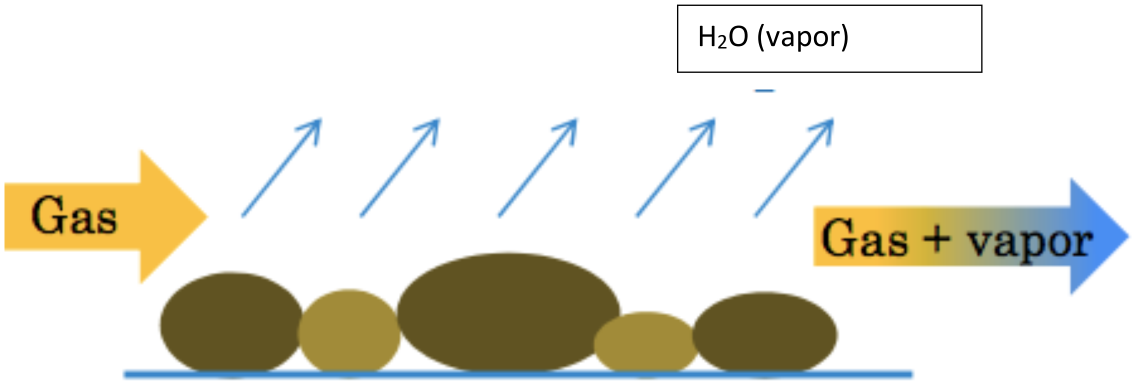
In low temperature, the previously formed sludge is subjected to temperature limits of 70 ºC in a continuous drying tunnel, where the necessary heat is supplied with systems that work at low temperatures. a sludge with final humidity of less than 15 % is obtained and the residue of the process is condensed water. This technique fits within the techniques of energy saving, since the largest stop of energy of the process is achieved by recovering the residual heat of the evaporated water itself.

8.1. CONVECTION DRYING

In convection systems, the heat needed to dry the sludge is transferred by means of a powerful heating fluid stream, usually preheated air in a burner or exhaust gases from a cogeneration engine. In these dryers, the sludge is heated by direct contact with the fluid, receiving the name of direct dryers. The fluid current acts in two ways, on the one hand it provides the necessary heat, and on the other it drives the particles, that is, it is both a heating fluid and a conveyor.

These systems suppose elevated speeds of transport, therefore, there are many shocks inside the dryer and, obviously, large amount of oxygen. Because of all this, these systems are the most likely to have fires and/or explosions.

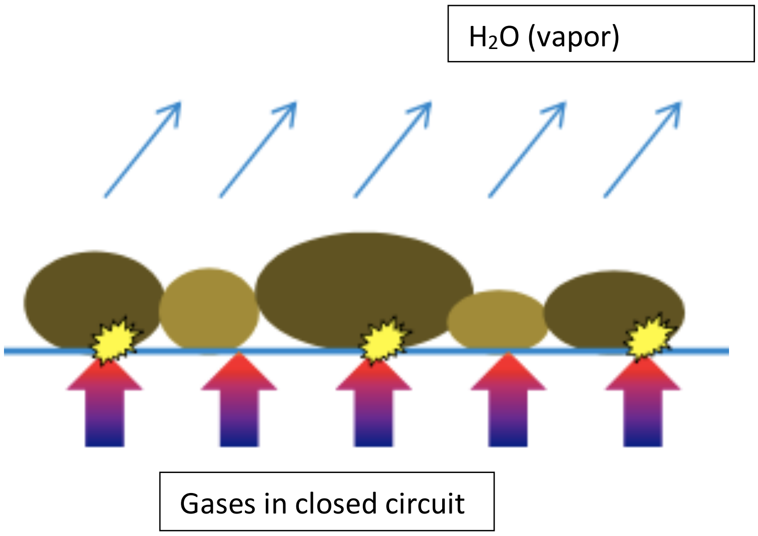
The main advantage of convection dryers is their relative low investment cost. The main drawback is related to the transfer of large amounts of air, resulting in a high loss of energy, in addition to requiring adequate air delivery systems and control of pollution. Then, in Scheme 3. there is a shcematic representation of how this system works.



Scheme 3. Schematic representation of convection dryer

8.2. CONTACT DRYING

In drier ducts there is no physical contact between the heating fluid (steam or thermal oil) and the sludge, hence it is also called indirect drying. the heat is transferred through a metal surface. This system has two main advantages. Firstly, to introduce in the dryer a limited amount of air, the emission of polluted air and odors is considerably smaller than in direct dryers. On the other hand, the risk of fire and explosion is considerably reduced since the amount of oxygen (air) in the dryer is much lower. The problem is usually the higher temperature of the metal sheet, which can lead to over-heating of the sludge and poor heat transmission in the sludge layer, since it may not heat evenly, for this the sludge must be removed the hot surface. We can see the functioning of this system in Scheme 4 below.



Scheme 4. Schematic representation of contact drying

In this system a dryness in the mud of 60-70 % is reached, while in the convection system it can reach up to 90 %.

8.3. INCINERATION

As mentioned before, incineration is a process where temperatures reach 650-700 ºC, this is a very exothermic process of complete oxidation of the constituents of the waste, converting most of the solid product into gases (CO_2 , SO_2) and water vapor, also generating a limited amount of unburned that depend on the amount of inert introduced in the process. The parameters to control in combustion are: the amount of air and resources to be used and the speed of advance of the waste.[27]

It is not usually necessary to stabilize the sludge before incineration. In fact, this practice can be counterproductive since stabilization, especially aerobic and anaerobic digestion, reduces the volatile content of the sludge and therefore increases the needs for auxiliary fuel. The use of thermal treatment before incineration constitutes an exception to this circumstance. The thermally treated sludge has very good characteristics for dehydration, making the sludge self-combustible. The sludge can be subjected to thermal reduction by itself or in combination with urban solid waste.

This process is usually carried out more frequently in large plants, where the final disposal options are limited, since it entails a large investment.

The main advantages of incineration are as follows:

-Maximum volume reduction thus reducing evacuation needs;

-Destruction of pathogens and toxic compounds;

-Possible energy recovery.

While the main drawbacks are:

-High investment and exploitation costs;

- Highly skilled workers required;

-The possible negative environmental effect of the waste produced (air and ash emissions);

-The disposal of waste, which can be classified as hazardous waste, can be complicated and expensive.

9. SLUDGE APLICATIONS

After the treatment of sludge, and having removed almost all the water inside the sludge it has to be used so that everything does not go to landfills. The use of treated sludge has both economic and environment benefits.

9.1. AGRICULTURE

The composition of sludge, although variable, makes them a source of organic matter and fertilizer elements for their use in agricultural activity, which is the most appropriate way to eliminate them, by allowing them to be incorporated into the natural cycles of the matter and energy. This produces a double benefit, environmental and agricultural, consequence, on the one hand, of its elimination without significant alteration of the ecological balance, and on the other, of the effect that derives from its application in our soils, which observe an accelerated and worrying decrease of its content in organic matter with the myriad of problems that this fact entails.

Both in the rest of Europe and in Spain, this sludge has been and are being used for that purpose, although with a geographical character and especially limited, following the rules in the Spanish legislation (BOE) R.D. 1310/1990 and Order AAA/1072/2013, on the use of sewage sludge in the agricultural sector, which limits the amount of pollutants that the sludge used can have so as not to harm the vegetative cycle of the plants, nor for people. The limit values of the heavy metals, and of the analyzes required for the soils and sludge are in annexes IA, IB, IC, IIA, IIB of the R.D. 1310/1990 published in BOE.

9.2. ENERGETIC VALORIZATION

The basis of energy recovery is based on the partial or total substitution of fossil fuels for waste, from which energy is obtained. This is supported by the waste law 22/2011, which aims to "give priority to prevention, preparation for reuse, recycling and other types of recovery of waste (including energy recovery) on disposal".

The best-known method of energy recovery of sludge is probably that of biogas, already mentioned in Section 5.3.1 above, which is a gas composed of methane and carbon dioxide for the most part and which is obtained in sewage treatment plants. they perform anaerobic digestion, that is, decompose organic matter in the absence of oxygen.

This biogas is used mostly for the production of electric power and heat by internal combustion engines, but there are other methods of using biogas as its integration into the natural gas network when the quality of the biogas is adequate, a process that It has already been carried out on an industrial scale in countries such as Germany or Denmark.

Other methods under study for the use of biogas are its use as fuel in vehicles, its use as auxiliary fuel in solar thermal power plants or its application in fuel cells.

In another sector where it is beginning to be used is in the cement industry, which is betting on the diversification of its energy sources, since the characteristics of the production process allow to energetically value the waste and even use it as raw material (recycle) to obtain cement clinker. But to carry this out you have to have a series of guarantees:

- Alternative fuels come from authorized managers;

- The thermochemical conditions of the furnace (alkaline environment, high temperature) guarantee the destruction of possible hazardous waste;
- During valuation, both the parameters that ensure adequate combustion and the emissions of the process are controlled;

This is leading to a series of benefits such as the reduction of greenhouse gas emissions, the CO_2 that is emitted is not accounted for in the emission rights assigned by Kyoto, raw materials are saved, natural resources are conserved, waste is generated and avoids the deposit of waste in the landfill.

10.CONCLUSION

Sludge treatment has never been considered as important as wastewater treatment, but as years have passed and waste has been increasing, it has become a problem in sewage treatment plants.

Nowadays from the European Union great emphasis is being placed on its proper treatment with the main objective of caring for the environment. By means of four keys: to minimize the waste created, to reuse them and to valorize the organic matter, to value them energetically or to eliminate them in a safe and controlled way. Therefore, the solution lies in the correct management of the sludge in the treatment plants.

To seek the greatest economic and environmental benefit, the sludge in the treatment plants receive a treatment of thickened and mechanical dehydration since in this way the solids content in the sludge can even increase up to 25 %, even with this percentage can already be used directly on cropland.

On the other hand, if we want to use the sludge energetically, we must continue with the process and take sludge from the treatment plant to combustion or incineration furnaces, it can be carried out together with other waste such as urban solids. But the released energy has to evaporate all the water contained in the sludge, therefore, it is necessary not to skip any operation in the treatment of sludge, since the greatest energy saving is achieved by dehydrating the sludge to the maximum before entering the kiln.

Finally, the thermal drying also favors the recovery of the waste, since it can reach a very high level of mud dryness (95 %). Thanks to the stabilization, after a complete drying, the sludge can be stored for long periods and can be transported long distances. On the other hand, dry solids can be valued as fertilizers or as biofuels.

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