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Use of whey through anaerobic codigestion for biomethane production

Utilización del lactosuero mediante codigestión anaerobia para la producción de biometano

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RESUMEN

El lactosuero generado por la producción de queso es el principal subproducto generado por la industria láctea, que causa un impacto considerable en el medio ambiente si no se trata adecuadamente. Este potencial contaminante se debe principalmente a su alto contenido en materia orgánica. En los últimos años se han llevado a cabo numerosos estudios con el objetivo de utilizar el lactosuero de forma más eficiente, empleando métodos tecnológicos innovadores para el tratamiento de las aguas residuales como el método de digestión anaerobia, y así poder obtener productos derivados como el biogás o los biocombustibles, que generan un menor impacto ambiental y desarrollan actividades económicas. El objetivo de este estudio es recopilar estudios sobre el uso del lactosuero para la obtención de biogás mediante la técnica de digestión anaerobia. La revisión permitió conocer la amplia aplicación del método de digestión anaerobia para la producción de biogás a partir de lactosuero y otros sustratos agroalimentarios, demostrando la alta eficiencia del método en asociación con medios biológicos en condiciones semicontinuas y discontinuas. Asimismo, se pudo conocer que el método de co-digestión anaerobia es una alternativa prometedora para pequeñas y medianas industrias que podrían sustituir combustibles fósiles por biogás y que a su vez contribuyen a la conservación del medio ambiente evitando la contaminación y los problemas ambientales por efecto de la mala gestión de los sueros.

Palabras clave: *Biogás; digestión anaerobia; codigestión; lactosuero.*

ABSTRACT

The whey generated by cheese production is the main by-product generated by the dairy industry, which causes considerable impact on the environment if it is not treated properly. This potential contaminant is mainly due to its high content of organic matter. In recent years, numerous studies have been carried out with the objective of using whey more efficiently, using innovative technological methods for the treatment of wastewater such as the anaerobic digestion method, and thereby being able to obtain derived products such as biogas or biofuels, which generate less environmental impact and develop economic activities. The objective of this study is to collect studies on the use of whey to obtain biogas through the anaerobic digestion technique. The review allowed us to know the wide application of the anaerobic digestion method for the production of biogas from whey and other agri-food substrates, demonstrating the high efficiency of the method in association with biological media in semi-continuous and discontinuous conditions. Likewise, it was also possible to know that the anaerobic co-digestion method is a promising alternative for small and medium-sized industries that could replace fossil fuels with biogas and that in turn contribute to environmental conservation by avoiding pollution and environmental problems due to the effect of the poor serum management.

Keywords: *Biogas; Anaerobic digestion; Co-digestion; whey.*

INTRODUCTION

The whey is a transparent yellowish to greenish liquid extracted during cheese production (Guo y Wang, 2019). This whey as a byproduct arises from the processing of cheese and casein; this residue presents significant concentrations of lactose and other components (Deshmukh et al., 2024). Certainly this biowaste is used as livestock feed, as agricultural fertilizer or also derived for human consumption (Dopazo et al., 2023). Without adequate treatment, whey represents an important source of environmental contamination due to the large amounts of organic matter (Koutinas et al., 2009), which should go through methods used in wastewater treatment to obtain better performance and greater efficiency (Verma y Subudhi, 2021). Many industrialized countries are regulated by strict legislation regarding the treatment of their effluents, technological wastewater treatments contribute to the correct whey disposal procedure within environmental specifications, to reduce this difficulty, an innovative alternative is to subject the whey to processes by which other products can be obtained (Panesar et al., 2007). The growing interest in the appropriate treatment of industrial liquid waste proposes more efficient and innovative methods that reduce the load of contaminants, promote environmental protection and public health (Odiete, 2024). These searches propose innovation and optimization of parameters, development of new reactor systems and the use of strains of microorganisms for the production of biogas and biofuels (Cremonez et al., 2021). The use of biomass for the production of biofuel or biogas presents an alternative for the generation of bioenergy that can satisfy the growing energy demand of people around the world and at the same time reduce greenhouse gas emissions (Manikandan et al., 2023). There are varieties of thermal and non-thermal technologies for the use of waste. These technologies are applied depending on waste flows, volumes and environmental factors, as well as regulatory limitations, cost, acceptability, operability, and the availability of land, among these technologies the anaerobic digestion method stands out, which produces biogas through the degradation of biodegradable organic matter (Kumar et al., 2023). The codigestion is an anaerobic digestion process that consists of a combined method for the treatment of solid waste, standing out for its hygienic safety and a higher rate of digestion performance. This technique provides benefits such as the dilution of potentially toxic compounds, better nutrient balance, synergistic effect of microorganisms, greater load of biodegradable organic matter and better biogas performance (Ağdağ y Sponza, 2007). For the use of waste, anaerobic co-digestion technology is presented as an excellent alternative to significantly improve methane yield and adequate dehydration of the digestate (Wang et al., 2022). As part of the process of using the anaerobic digestion method, anaerobic reactors are designed and developed for the correct co-digestion of waste. These reactors can improve mass transfer and microbial cooperation between acidogenic and methanogenic units and can co-digest efficiently and stable solid waste (Xing et al., 2014). The objective of this review is to collect updated information on the use of whey to obtain biogas through anaerobic co-digestion, as an alternative to reduce its environmental impact.

Waste characteristics

The whey is a liquid residue generated after the separation of the curd and resulting from the coagulation of milk proteins by acid or proteolytic enzymes. The production of whey comes mainly from cheese manufacturing (Panesar et al., 2007). Whey is classified into sweet whey and sour whey. Sweet whey has a high lactose and protein content, high pH, low fat and acidity, however, acid whey has a higher lactic acid content and lower pH. Whey is also rich in minerals, such as calcium, phosphorus, magnesium, sodium and potassium and in lower concentrations, zinc, iron, copper and manganese (Mazorra y Moreno, 2019).

Table 1

Composition of sweet and acid whey

Components	Sweet whey (g/l)	Acid whey (g/l)
Total solids	63–70	63–70
Lactose	46–52	44–46
Protein	6–10	6–8
Calcium	0.4–0.6	1.2–1.6
Phosphate	1–3	2–4.5
Lactate	2	6.4
Chloride	1.1	1.1

Source: (Panesar et al., 2007).

Table 2

Chemical characterization of whey

Parameters	Whey
pH	4.6 ± 0.1
COD (g/L)	47.1 ± 2.1
Total Kjeldahl nitrogen (g/L)	0.15 ± 0.02
Total solids (g/L)	55.3 ± 0.5
Volatile solids (g/L)	45.8 ± 0.7
Sulfate (mg/L)	100 ± 5
NO_3 (mg/L)	149 ± 3
PO_4 (mg/L)	665 ± 8
K (g/L)	1.95 ± 0.06
Lactic acid (g/L)	7.5 ± 0.4
Acetic acid (g/L)	0.72 ± 0.08

Source: (Hashemi et al., 2022)

Technology description

Anaerobic digestion

Anaerobic digestion is considered a biotechnology that follows greenhouse gas reduction policies and circular economy development objectives. However, the activity and quality of the inoculum are critical factors to ensure the successful startup and stable operation of an anaerobic digestion reactor (Meng et al., 2023).

Anaerobic digestion is the degradation of organic matter in the absence of oxygen, producing biogas whose main components are methane and carbon dioxide. The formation of methane does not take place in environments where electron acceptors such as oxygen, sulfates or nitrates are present. , anaerobic digestion is an effective means of treating liquid and solid waste, effluent treatment by anaerobic digestion has numerous advantages compared to aerobic technology (Arhoun, 2017).

The anaerobic digestion process uses organic matter and converts it by bacterial action into a gas mixture. This reaction occurs in the absence of oxygen and other inorganic electron acceptors, conditions in which the organic matter is used to generate a gas mixture. composed mainly of methane and carbon dioxide (Neumann y Jeison, 2015).

Figure 1

Anaerobic digestion process diagram model (Neumann & Jeison, 2015)

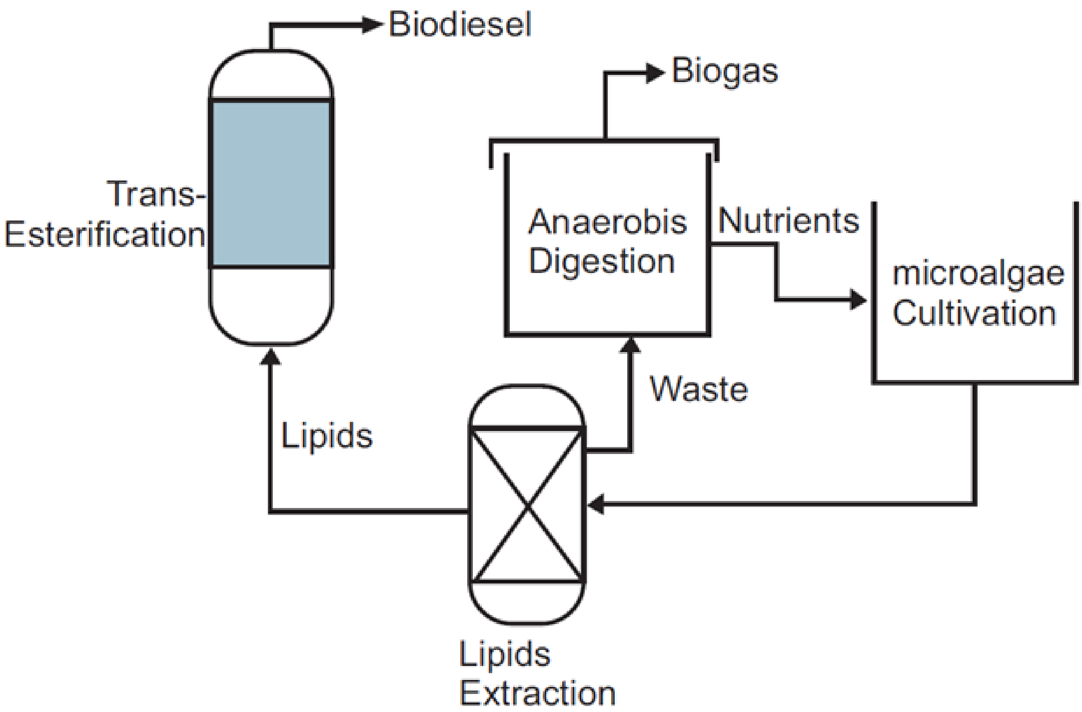


Table 3

Advantages and disadvantages of anaerobic treatment

Advantages	Disadvantages
High efficiency in the removal of organic load.	Low in the elimination of nutrients and pathogens, the elimination of certain nutrients is not complete or they are partially eliminated.
Simplicity in the construction and operation of the reactors.	Due to the slow growth rate of methanogenic microorganisms, the initiation period compared to aerobic processes is long, when inoculum is not available.
Anaerobic treatment can be very flexible and easy to apply on a small and large scale.	Possible bad odors, hydrogen sulfide is produced during anaerobic cycles, especially when there are sulfate concentrations.
Low space requirements.	Need for post-treatment, effluent post-treatment is generally required to meet organic matter discharge standards.
Low energy consumption, the energy consumption of the reactor is almost zero.	
Low chemical and nutrient requirements, adequate and stable pH can be maintained without the addition of chemical agents and macro- and micronutrients remain stable in the waste, while toxic compounds are absent.	

Source: (Parra Huertas, 2015).

Technology methods and techniques

Anaerobic digestion involves complex and sequential metabolic processes that react in the absence of molecular oxygen and depend on the activity of at least three different groups of microorganisms to promote the stable and self-regulated fermentation of organic matter, obtaining mainly methane and CO_2. These processes include acidogenic bacteria, acetogenic bacteria and methanogenic archaea, the reduction of oxidized sulfur compounds to dissolved sulfur in the effluent and to hydrogen sulfide in the biogas occurs thanks to the activity of sulfate-reducing bacteria (Moraes et al., 2015).

Figure 2

Scheme of anaerobic digestion of complex organic matter (Moraes et al., 2015)

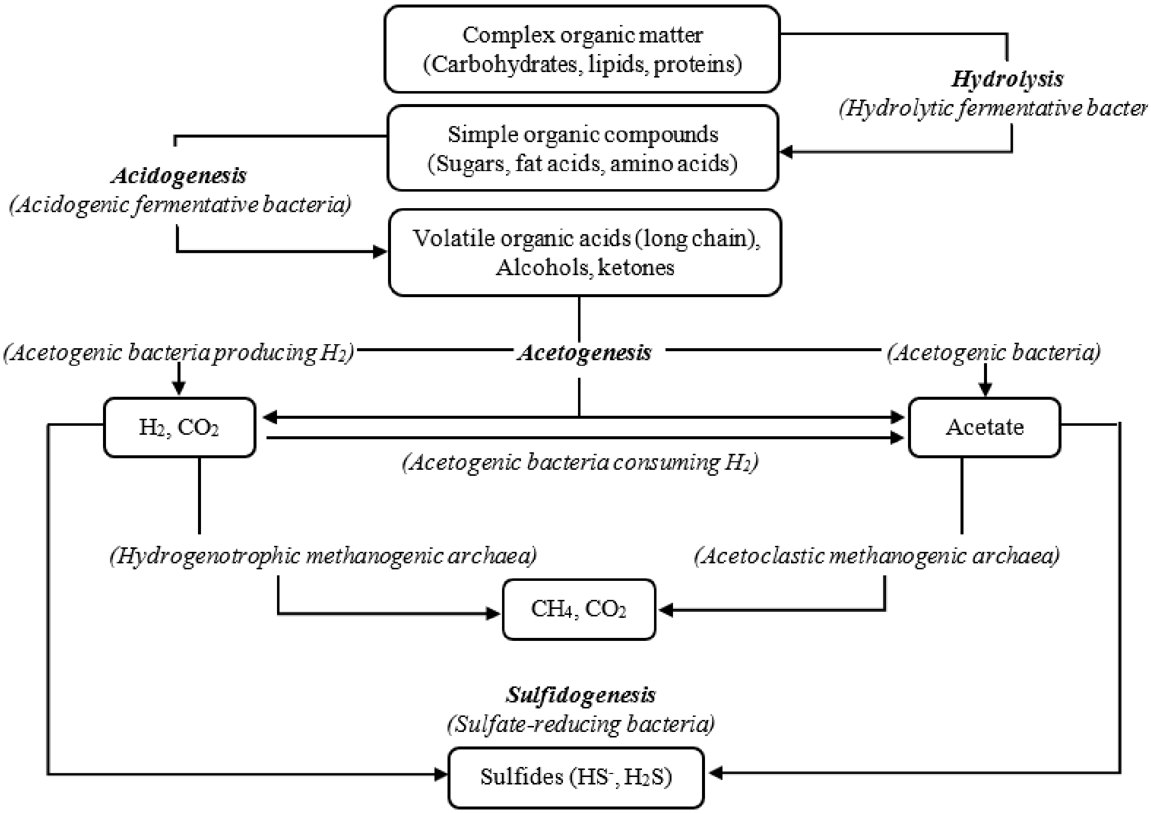
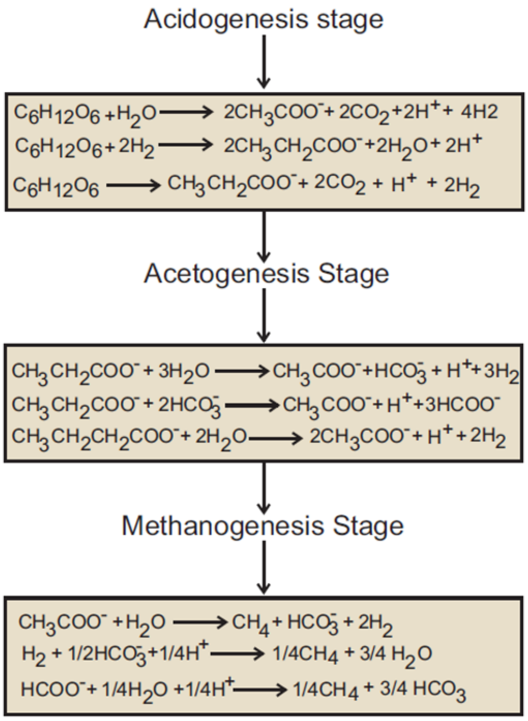


Figure 3

Reactions in anaerobic degradation



Source: (Moraes et al., 2015)

Anaerobic codigestion

The joint digestion of two or more substrates of different origin and composition is confirmed as a form of optimization of this process, since it increases the production of biogas. The mixture of different substrates, or codigestion, compensates for the deficiencies of each one separately. In addition to this advantage, co-digestion allows us to share treatment facilities for various waste and compensate for temporal variations in the production of each substrate. Codigestion can be carried out between different types of substrates, although usually in rural areas it is between slurry, with a low methane production rate, but with high water and nutrient content, and with high buffer capacity, and other easily degradable substrates such as waste from agroindustrial, urban organic waste, animal waste or energy crops. In codigestion, the proportion between the substrates used is variable and affects the final production of biogas and its methane content. In the case of the fermentation of livestock waste and energy crops, the proportion is usually 60% livestock waste and 40% plant waste or energy crops, which may vary slightly, and obtaining a methane content of between 51 and 55% (Palau, 2016).

The figures 4 and 5 shows the models for the comprehensive use of whey in a co-digestion process in the presence of another substrate, which allows the obtaining of Bio methane and other effluents produced during anaerobic digestion to be used in 2 phases, for its application as a fuel medium and in irrigation activities.

Figure 4

Model one, for comprehensive use of whey in an anaerobic co-digestion process (Hashemi et al., 2022).

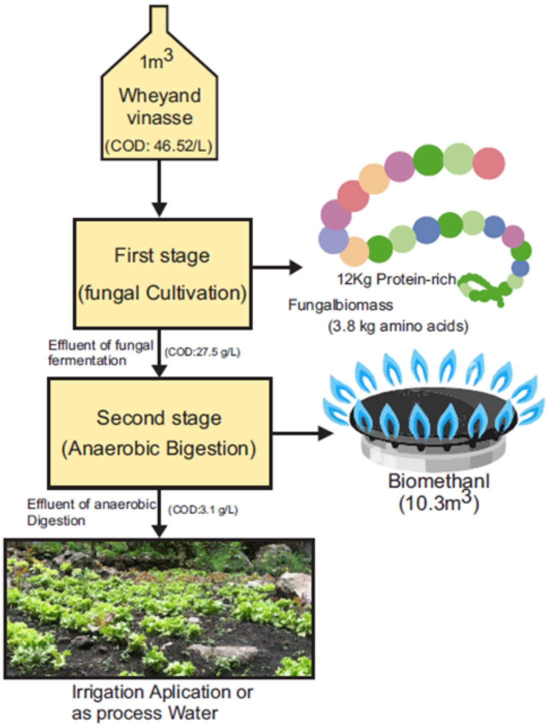
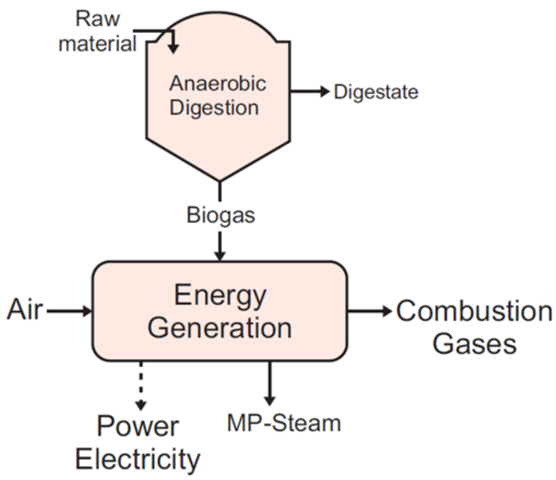


Figure 5

Model two, for comprehensive use of whey in an anaerobic co-digestion process (Martínez-Ruano et al., 2019).



Recent related research

Below are the main and most recent studies referring to the use of whey in the production of biogas, with technologies and procedures used for the treatment of wastewater.

Table 4

Recent related research

Nº	Title	Journal	Main research focus	Reference
1	A comprehensive evaluation of cheese whey to produce biogas in the Canary Islands	Biomass and Bioenergy	Dairy industry, Methane Biochemical methane potential, Anaerobic digestion Bioenergy	(Ramos-Suárez et al., 2024)
2	Cheese whey and dairy manure anaerobic co-digestion at psychrophilic conditions: Technical and environmental evaluation	Environmental Research	Anaerobic digestion, Biogas. Circular economy, Greenhouse gases emissions, Life cycle analysis, Dairy sector	(Casallas-Ojeda et al., 2024)
3	The role of hydrochar on the production of biogas and volatile fatty acids during anaerobic digestion of cheese whey wastewater	Sustainable Chemistry and Pharmacy	Circular economy, Biogas, Hydrothermal carbonization, Anaerobic digestion, Volatile fatty acids	(Liakos et al., 2023)

4	Enhancing biogas production from cheese whey using Zero-Valent Iron: A comparative analysis of batch and semi-continuous operation modes	Journal of Environmental Chemical Engineering	Alkalinity, Biogas upgrading, Methanothrix, Microbial pathways, Hydrogenotrophic methanogens	(Charalambous et al., 2023) and its anaerobic treatment presents several challenges. Among these is the production of high levels of volatile fatty acids (VFAs
5	Integration of anaerobic digestion and chain elongation technologies for biogas and carboxylic acids production from cheese whey	Journal of Cleaner Production	Biofuel, Biohydrogen (H_2), Fatty acids, Chain elongation Fermentation, Clostridium kluyveri, Cheese whey	(Reddy et al., 2022)
6	Feasibility assessment of biogas production from the anaerobic co-digestion of cheese whey, grease interceptor waste and pulped food waste for WRRF	Energy	Anaerobic digestion, Co-digestion, Energy, Food waste, Volatile-fatty acid, Waste activated sludge	(Bolen et al., 2022)
7	Anaerobic co-digestion of cheese whey and septage: Effect of substrate and inoculum on biogas production	Journal of Environmental Management	Whey wastewater, Septage, Anaerobic digestion, Methane yield, Inoculum, Modelling	(Bella & Venkateswara Rao, 2022)
8	Anaerobic co-digestion of agro-industrial waste with cheese whey: Impact of centrifuge comminution on biogas release and digestate agrochemical properties	Biomass and Bioenergy	Organo-mineral fertilizers, Biogas, Particle size, Sewage sludge, Vegetal waste, Anaerobic digestion	(Ivanchenko et al., 2021)
9	Valorization of vinasse and whey to protein and biogas through an environmental fungi-based biorefinery	Journal of Environmental Management	Wastewater treatment, Fungal biorefinery, Anaerobic digestion, Neurospora intermedia, Amino acids	(Hashemi et al., 2022)
10	In situ biogas upgrading and enhancement of anaerobic digestion of cheese whey by addition of scrap or powder zero-valent iron (ZVI)	Journal of Environmental Management	Acidification, Anaerobic digestion, In-situ biogas upgrading, Cheese whey, Powder zero valent iron, Scrap zero valent iron	(Charalambous & Vyrides, 2021)

11	Effect of co-digestion of milk-whey and potato stem on heat and power generation using biogas as an energy vector: Techno-economic assessment	Applied Energy	Co-digestion, Potato stem, Milk whey, Heat and electricity, Economic assessment, Biofertilizer	(Martínez-Ruano et al., 2019)
12	Improving biogas production from anaerobic co-digestion of sewage sludge with a thermal dried mixture of food waste, cheese whey and olive mill wastewater	Waste Management	Anaerobic co-digestion, Food waste, Cheese whey, Olive mill wastewater, Pre-treatment	(Maragkaki et al., 2018)
13	Biogas Production from Poultry Manure and Cheese Whey Wastewater under Mesophilic Conditions in Batch Reactor	Energy Procedia	Anaerobic co-digestion, cheese wastewater, poultry manure	(Carlini et al., 2015)
14	Biogas production by anaerobic co-digestion of cattle slurry and cheese whey	Bioresource Technology	Anaerobic digestion, Methane yield, COD reduction, Digestate yield test, Energy production	(Comino et al., 2012)
15	Biogas production from co-digestion of a mixture of cheese whey and dairy manure	Biomass and Bioenergy	Cheese whey, Co-digestion, Dairy manure, Biogas, Acidifying	(Kavacik & Topaloglu, 2010)

CONCLUSIONS

The efficient management of these raw materials allows us to significantly reduce the environmental impact; contributes to the economic development of society through the construction of plants specialized in the treatment of this liquid waste (biorefineries, industries to produce bioplastics, biofuels, animal food), and promotes scientific research, that is, its use develops the economy circular.

The dairy industry, more specifically the cheese industry, generates waste whose management and final disposal have been widely debated. A promising alternative is to provide adequate treatment using technologies for the use of biomass through anaerobic digestion.

Whey, as an agri-food by-product, can be transformed into new products to generate economic credits, but mainly to avoid environmental impact.

Anaerobic Digestion is a reliable way to process agri-food, industrial and municipal waste; the whey, not having adequate treatment, is causing damage to our land and water reserves. The use of this method could ensure that this cheese effluent can be treated and processed to obtain various benefits, which will not only help the well-being of the planet, but we can also obtain additional monetary income.

Anaerobic codigestion is an option for the use of whey, since through this process it is feasible to obtain alternative energy through the production of fuel biogas. It is recommended to use co-digestion with manure and other agricultural waste.

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