Desalination and Water Treatment
www.deswater.com

doi: 10.1080/19443994.2015.1033652

57 (2016) 2702–2711
February

Taylor & Francis
Taylor & Francis Group

An optimized water reuse and waste valorization method for a sustainable development of poultry slaughtering plants

Carlos Morales-Polo*, María del Mar Cledera-Castro

Escuela Técnica Superior de Ingeniería (ICAI), Universidad Pontificia Comillas, Madrid, Spain, Tel. +34 915422800; emails: cmorales@upcomillas.es (C. Morales-Polo), mcledera@upcomillas.es (M.d.M. Cledera-Castro)

Received 15 October 2014; Accepted 12 March 2015

ABSTRACT

The primary aim of this study is to find a solution to four of the major environmental and energy problems that currently exist in the poultry industry: (a) high water consumption, (b) emissions from excessively contaminated wastewater, (c) intensive consumption of electric and thermal energy, and (d) production of non-recoverable by-products and organic waste. It was decided that a wastewater treatment plant (WWTP) would be designed, which would, in addition to treating the water, create an effluent that meets the water quality standards, so that the water can be reused in plant processes. As part of this, a closed water circuit was created to reduce water consumption and the emission of wastewater. In order to address the issue of high-energy consumption and waste production, the construction of a biomethane production plant was proposed. Given that most of the waste is organic, the waste had to undergo anaerobic digestion processing. This resulted in biogas production, as well as subsequent use of the said biogas primarily as a thermal energy source, which was used to reduce external consumption. Both the WWTP and the biomass power plant required an anaerobic digester. The final aim of this study was to propose the implementation of a hybrid co-digestion system for wastewater and organic waste that would allow water to be treated and, at the same time, produce biogas, which could subsequently be used as an energy source.

Keywords: Poultry industry; Wastewater; Anaerobic co-digestion; Waste; Biogas

1. Introduction

The four main environmental and energy problems in the poultry industry are: (a) high water consumption, (b) emissions from excessively contaminated wastewater, (c) intensive consumption of electric and thermic energy, and (d) production of non-recoverable by-products and organic waste.

Water is the most useful, and necessary, resource in the agrifood industry, especially in the poultry industry, where a significant flow is used in almost all the plant processes, such as: the scalding and pluck stages and the washing process. Given its importance, water consumption is exceptionally high, thus making the agrifood industry one of the largest water consuming industries.

---

*Corresponding author.

Presented at the International Congress on Water, Waste and Energy Management
16–18 July 2014, Porto, Portugal

As water is a limited resource, and the need for it increases every day, strong environmental regulations have grown around this issue. It is for this reason that so much attention is given to reducing drinkable water consumption and wastewater production and emission.

Over the course of the study, the four aforementioned environmental aspects were improved through two key actions:

- The reduction of water consumption, as a result of intensive water treatment that allows for the complete reuse of all processed water;
- The energy use of all waste generated both by the slaughtering plant's own process (feathers, grease, blood, etc.), and any other non-reusable waste, which may create biomass and could be considered valuable for energy purposes, such as the sludges from the wastewater treatment plant (WWTP).

In order to be compliant with European law, in particular *Directive No. 91/271/CEE* [1], all industries that generate large quantities of excessively contaminated wastewater must own a WWTP, in order to release all residual effluents. Bearing this legal requirement in mind, a wastewater treatment process was developed that would be capable of regenerating water and which would meet the water quality standards. Through this process, the purified effluent could be used in all processes of production that require a higher quality (cleaning water, scalding, plucking, etc.) and so would reduce the external water consumption as much as possible.

Water reuse is an issue that has always been studied [2], given its usefulness and necessity [3], both for society and in industry. Water reuse creates a new resource and a new water acquisition point from a waste product that was no longer intended for use. As a result, water reuse increases both the water's quality [4] and its available quantity. The most important advantage is that it can ensure a continuous water supply.

Nowadays, many of the objectives relating to water reuse have been achieved [5,7] and both current and potential uses of regenerated water are clear evidence to support this, for example: garden and agriculture irrigation [3], urban uses, such as street cleaning, car washing, firefighting and industrial, for example, its use in refrigeration plants [8] and as processed water, or even for recreational uses for ornamental lakes [7]. Other uses, which may be considered as potential uses, include the complete reuse of the water as drinking water. There have been instances, in California [6], where total drinkable quality has been achieved through purification processes, based on reverse osmosis.

Whilst it is true that there is currently a series of technical improvements, known as best available techniques (BAT), that recommend the energetic re-evaluation of all generated waste, ways of putting these improvements into practice have previously been looked into [7,9], but have never been successfully implemented. Taking this into consideration, the simplest way to re-evaluate waste in the existing facilities, with the aim of reducing the external energy dependence as much as possible, was studied.

Initially, two separate, and totally different, solutions were looked into. The first involved using a WWTP that met water quality standards, in order to ensure an equant drinkable quality and the water's complete reuse. The other solution focused on a small biomass power plant that would be capable of converting the waste into energy.

The water effluents were contaminated with a high organic load. As a result, it was necessary to incorporate anaerobic biological processes into the WWTP. Such processes have a key feature which is biogas production, which can then be subsequently used, if burnt, as a source of thermal and electrical energy (Fig. 1).

On the other hand, the waste that was generated (blood, skin, grease, feathers, etc.) was organic in nature and possessed a high level of humidity [10]. As such, it was unsuitable for use as direct combustion in biomass. Consequently, in order for it to be converted into energy, prior treatment would be needed. The simplest way to assess the wet residual biomass was to subject it to a process of anaerobic digestion (AD) (Fig. 2). This would result in biogas production and its subsequent use as fuel.

AD is a technology that has been known, and used, for over a century, in particular with regard to stabilizing the sludge produced in WWTPs [11]. Recently, some other uses for this technology have also been studied, such as its use in the conversion of biosolids (slaughterhouse waste [10], fruit and vegetable waste [12,13], manure [14] and food waste, and other organic wastes [11] such as algal sludge and waste paper [15]) into energy. Using AD is attractive from both an economical and environmental point of view, as it reduces organic waste disposal, as well as soil contamination and, in addition, makes renewable new energy available as a biogas, which has a null final CO_2 balance.

As both solutions would require the use of anaerobic digesters, a hybrid co-digestion system that could be used for both wastewater and organic waste (Fig. 3)

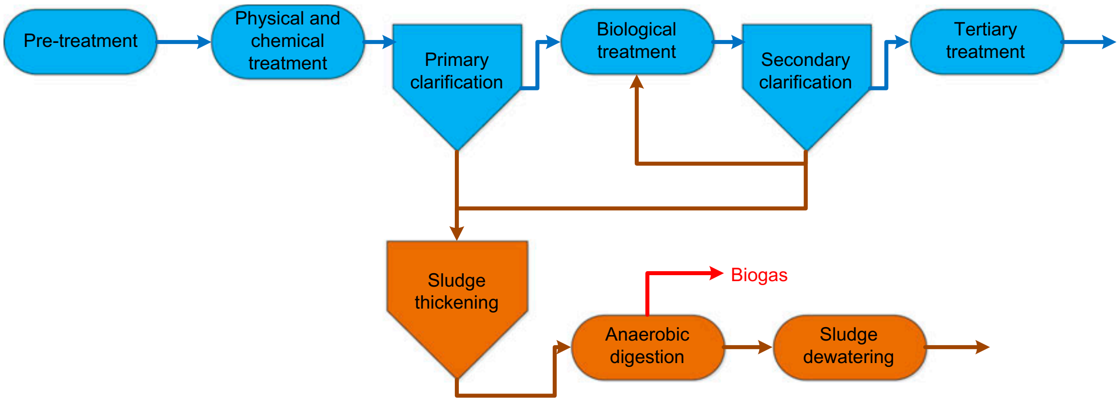

Fig. 1. General scheme of a simple WWTP.

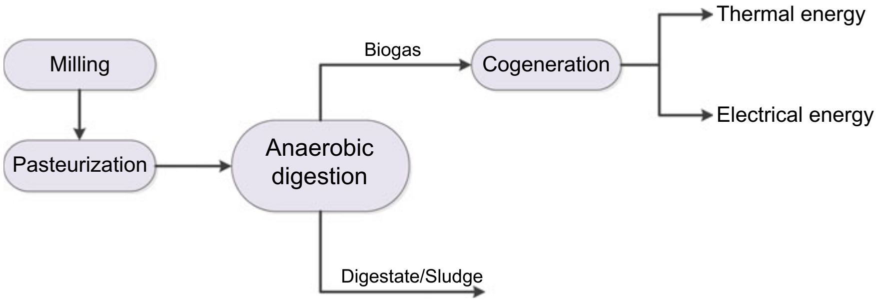

Fig. 2. General scheme of a biomethanation plant.

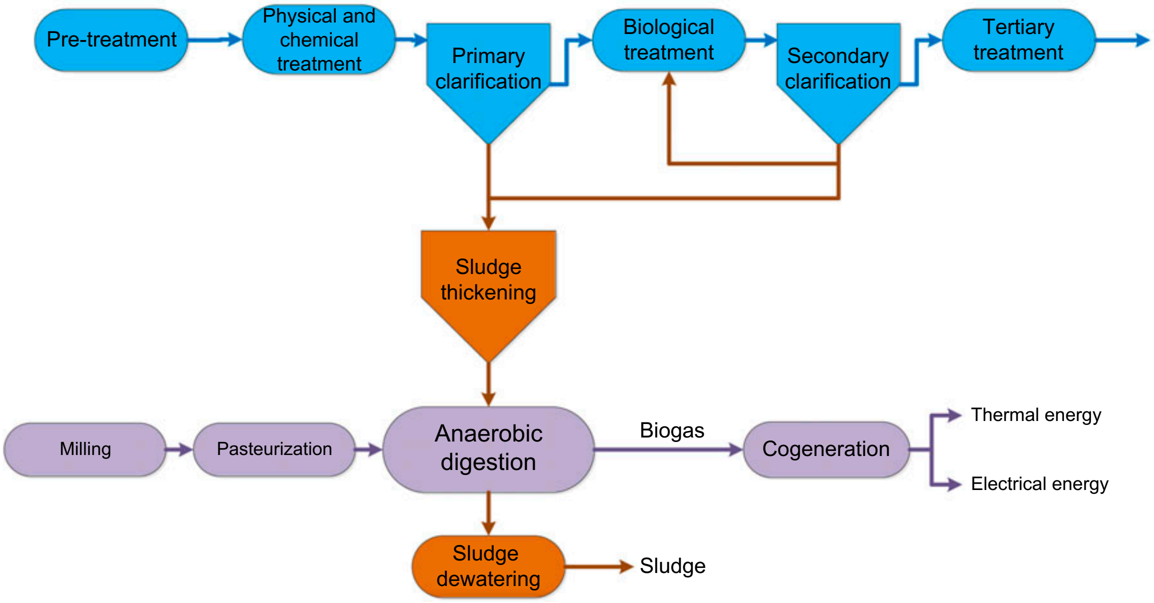

Fig. 3. Scheme of the hybrid co-digestion system of wastewater and waste.

was cogitated. This hybrid co-digestion system would allow water to be treated and would, at the same time, produce biogas from non-recoverable organic waste.

This solution, combining sludge from the WWTP with other organic waste products, creates a synergy in the anaerobic processes [10–15], as the nutrient balance between both substrates, such as in the C/N ratio [9–11], is adjusted. So, in comparison with mono-digestions, the biogas production is increased with co-digestion processes [16,17]. This ratio is exceptionally low in poultry waste, due to the waste's high nitrogen content. This synergy results in a higher biogas production if compared with the individual substrates. Also, this hybrid system involves some technical arrangements that create advantages in both aspects (water purification and anaerobic co-digestions) due to a necessary and novel current distribution.

2. Methodology

The challenge in this study was to design a purification system that would ensure that the legally required quality standards were met, so that the water could be reused in most plant processes. The fact that the system would have to contain as few stages as possible with regard to a quick and intensive water treatment, was a serious consideration. Furthermore, the system would need to be easy to implement in processing plants that have an existing WWTP.

The digestion plant was designed based on the layout of a basic biomass power plant that is capable of cogeneration. The rationale for this was that this design would make use of the previously produced biogas in thermal and electric generation, subject to the demand for such.

All calculations used were based on the experiments carried out in pilot plants or in real industrial plants in Rheda's (Germany) [9,10] and Schewechat's (Austria) [9,18] and recognize the numerous works carried out by prestigious and experienced authors in this field. Also, data from experiments have been used, from example studies treating poultry waste in upflow anaerobic sludge blanket reactors [19], and other configurations [20,21].

In order to calculate the biomethane potential, or the biogas production rate, experiments known as biochemical methane potential tests need to be carried out. These experiments are an easy, and affordable, way of analyzing how much biogas could be produced using each residue and involved creating a scenario similar to that of the AD process with real digesters.

All the experiments are based on the one conducted by Owens and Chynoweth [22], but modified to adapt them to the new technologies and purposes. At present, normalized experiments exist thanks to the European [23] and American [24] normalization associations, and are the best way to conduct the test, as they ensure the same conditions for every experiment.

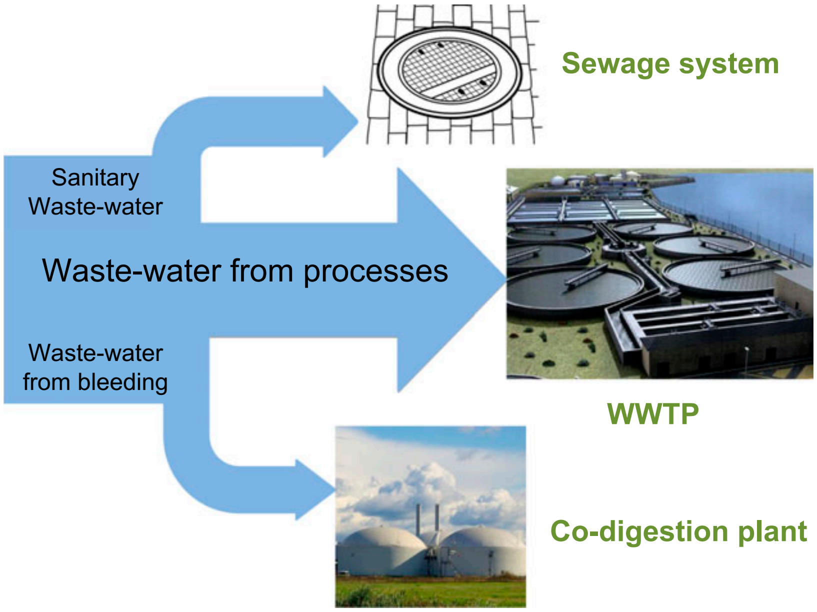

Fig. 4. Distribution of residual currents.

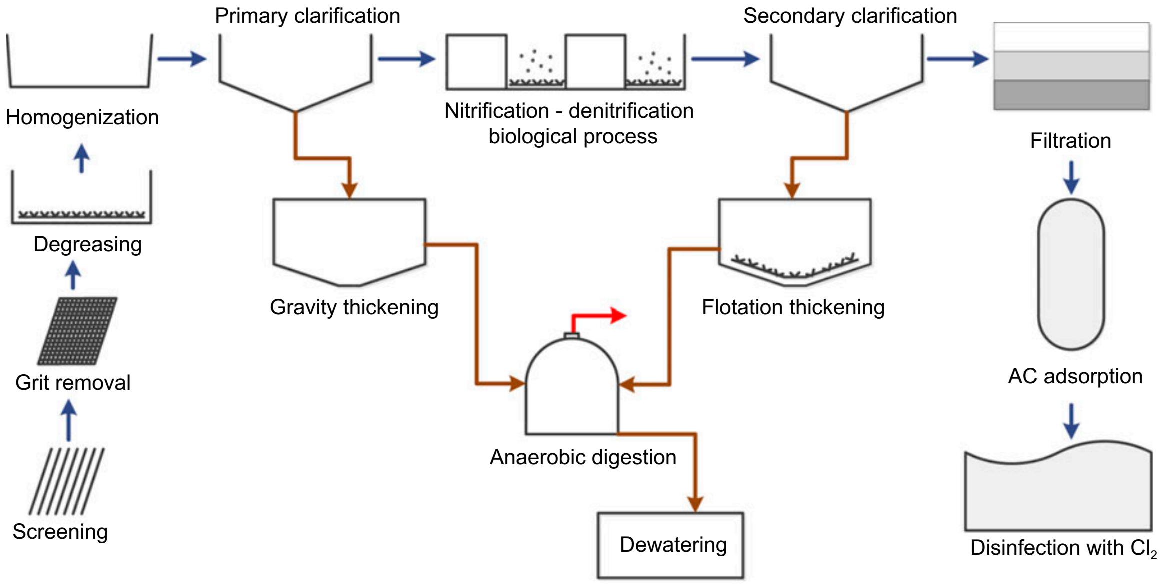

Fig. 5. Design of the planned WWTP.

Table 1
Comparison between the effluent contamination, discharge limits and drinkable quality standards

	Maximum	Minimum	Medium	Limit for discharge	Drinkable quality
COD (mg/l) (Chemical Oxygen Demand)	1,815.7	1,255	1,509.54	125 mg/l	5 mg/l
BOD (mg/l) (Biological Oxygen Demand)	1,357.74	993.45	1,161.40	25 mg/l	<1 mg/l
TSS (mg/l) (Total Suspended Solids)	653.33	443.67	538.39	35 mg/l	1 NTU
VSS (mg/l) (Volatile Suspended Solids)	604.67	382.33	480.82		
O&G (mg/l) (Oils and Greases)	302.3	87.9	163.01		
TKN (mg/l) (Total Kjeldahl Nitrogen)	123.2	102.71	112.49	10–15 mg/l	10–15 mg/l
P (mg/l) (Phosphorus)	17.22	6.48	10.56	2 mg/l	2 mg/l
pH	6.48	6.3	6.39		6.5–9.5

The general procedure would consist of mixing the substrate (organic waste to be digested) with the anaerobic biomass and a nutrient mix in a bottle, in order to create optimal conditions for the digestion process to occur. The bottle is hermetically closed so that the biogas can accumulate inside the chamber. The production of biogas can then be measured by transforming the pressure of the gas inside the chamber into its corresponding volume (considering it an Ideal Gas [23]).

Finally, the composition of the biogas would be measured through gas chromatography [23,24] and it is through this method that the percentage of each component would be obtained. Generally, a good biogas comprises mostly methane (CH_4), carbon dioxide (CO_2) and other gases, such as oxygen (O_2), nitrogen (N_2) and hydrogen sulphide (H_2S) [9,25–28] in much smaller proportions. It is important for the latter of these gases, hydrogen sulphide (H_2S), to be the lowest, as it causes equipment to corrode.

3. Results and discussion

3.1. Designing a WWTP capable of regenerating water for complete reuse

The WWTP's design was based on an aggressive tertiary system in which new stages were added in order to improve the effluents quality. These new stages would allow for easy implementation inside an existing water purification plant, as it would only require the incorporation of new processing stages into the existing ones, without the need to modify any existing equipment.

In order to accomplish the aforementioned aim, it was important that the contamination of the wastewater should be as constant as possible.

In a common processing plant, two different residual currents can be distinguished. On the one hand, the wastewater current from the slaughtering process and, on the other, sanitary wastewater, i.e. toilets. As mentioned above, the purification process must be as fast as possible, and the water supply quality must be optimal. It is for this reason that the depuration process would be extremely efficient. It was decided that only the water from the slaughtering process would be purified, as the contamination here would be constant and known (i.e. always contaminated with blood, feathers, greases, skins, etc.) as it can be appreciated by its BOD coefficient of variance, ($CV_{BOD} = 0,\ 8$). It was also decided that the sanitary wastewater would be sent to the sewage system ($CV_{BOD} = 2,\ 1$), as this would have a more variable level of contamination (i.e. it is dependent on human beings).

The biggest advantage to the hybrid system was that it requires humidity to be added to the biodigestion plant waste. As a result of this, it was decided that the wastewater current from the bleeding stage, which contains high quantities of organic matter (BOD_5 ~60% of total), would be sent to the biomass plant (Fig. 4). From this transfer, the most heavily contaminated current would be eliminated from the purification process, thus making it more efficient and, in addition, biogas production would be increased due to high loads of organic matter being sent to the methanation plant.

The WWTP was designed based on a basic purification plant [6,18,28–31] that allows wastewater to be channelled outside. The design incorporates new stages so that the discarded effluent would have a quality that could be equated with drinking water and could be reused in different plant operations. The stages that were amalgamated into the design are shown in Fig. 5.

In using this purification system, the discharge contamination parameters would ensure an equant drinkable quality of the effluent, as shown in Table 1, given that the quality would be higher than the discharge limits required by law [1], as well as those stipulated by the corresponding drinkable quality standards.

Taking into consideration that this WWTP would have numerous purification stages and that water would need to be readily available, as a final adjustment, it was decided to make the process more dynamic by treating each current separately, using the most indispensable components.

Table 2
Different residual currents and contamination levels. Source: Adapted from [2]

	Flow		COD		BOD_5		SS		O&G		TKN		P	
	(m3/h)	% of total	(mg/l)	% of total	(mg/l)	% of total	(mg/l)	% of total	(mg/l)	% of total	(mg/l)	% of total	(mg/l)	% of total
Slaughtering bleed	2.98	5	924.61	61.25	711.37	61.25	69.02	12.82	5	3.07	79.51	70.67	7.47	70.70
Scalding	5.96	10	129.67	8.59	99.77	8.59	147.72	27.44	92	56.44	18.56	16.50	1.74	16.51
Plucking	5.96	10	18.32	1.21	14.10	1.21	26.38	4.90	27	16.56	2.49	2.22	0.23	2.22
Gutted	4.77	8	366.46	24.28	281.95	24.28	268.18	49.81	12	7.36	9.63	8.56	0.90	8.56
Washing	14.89	25	56.38	3.73	43.38	3.73	16.71	3.10	22.1	13.56	1.77	1.58	0.17	1.58
Cutting	7.15	12	14.09	0.93	10.84	0.93	10.38	1.93	5	3.07	0.53	0.47	0.05	0.47
Cleaning	17.87	30	73.03	4.84	16.12	1.39	112.32	20.86	5	3.07	32.56	28.94	6.33	59.90

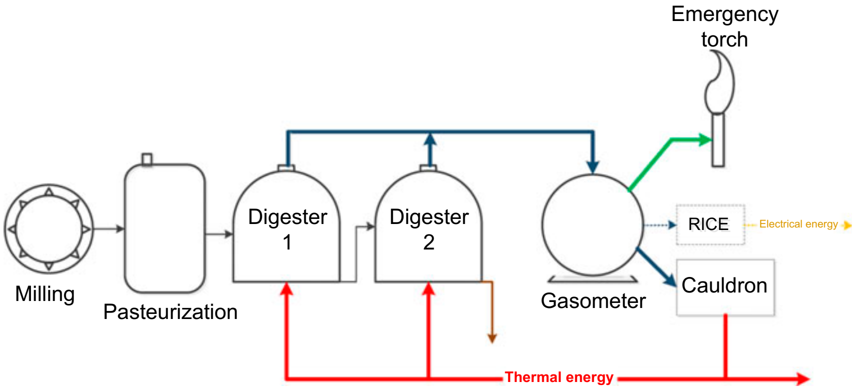

Fig. 6. Design of the biomethanation plant.

Each residual current contamination was studied separately, as shown in Table 2.

Having examined the data provided in the table, it was deduced that all currents must go through biological treatment, due to the high level of organic matter and nutrients: nitrogen and phosphorus. Furthermore, all currents had to endure tertiary treatment, which is the form of treatment used to give the equivalent drinkable quality to the water, as per the aim of this project. Preliminary treatment is the only treatment that can be divided, and so it was separated into two wastewater flows with different levels of contamination. To select these two currents, the suspended solids (SS), oils and grease (O&G) levels had to be analyzed. As can be seen in Table 2, there are some currents with a low level of O&G (less than 3%). One current involved the WW flowing from the bleeding, cutting and cleaning processes that had a very low level of O&G, so the degreasing stage could be removed from the process, resulting in the remaining grease being eliminated in the biological process. The other current had to undergo all the purification stages in order to reach the equivalent drinkable quality. Thus, some elements had been eliminated and the elements size and energy needs of the remaining stages had been reduced by up to 50% (Table 3).

3.2. Design of the waste digestion plant

The design of the digestion plant was based on a simple layout of a basic biomass power plant. It comprised a series of pre-treatment stages that were used to make waste more suitable for processing, milling to reduce the substrate size, which favoured the reactions and then pasteurized the milled substrate to sanitize the product and make the process safer. After that, the substrate (waste) is subjected to digestion and the produced biogas was stored in a gasometer (Fig. 6).

It was necessary to select continuous stirred-tank reactors without recirculation [25]. This type of reactor was chosen, instead of a common reactor (see Fig. 7), primarily because it was able to admit a high load of incoming solids, due to the mixing and stirring equipment included in the reactor. A continuous tank without mixing equipment would be unable to intake solids because, due to its weight, the solids would sink to the bottom of the tank and would not be digested. Furthermore, these kinds of reactors include a temperature and pressure controlling device and, due to the mixing equipment, the digestion process took place in the reactor as a whole, resulting in the digestion process becoming more stable and uniform.

The digesters were installed forming a two-stage system (Fig. 8). In the first digester, the hydrolysis reactions improved whilst in the second, the organic matter and acids that arose from the first were digested. Consequently, the digestion's kinetics were

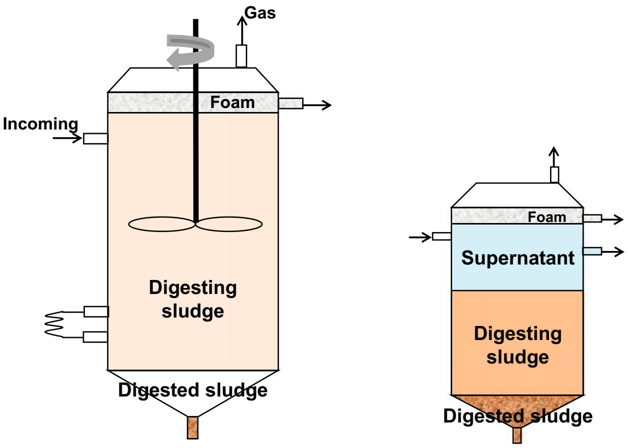

Fig. 7. Continuous stirred-tank reactor (left) and batch reactor (right).

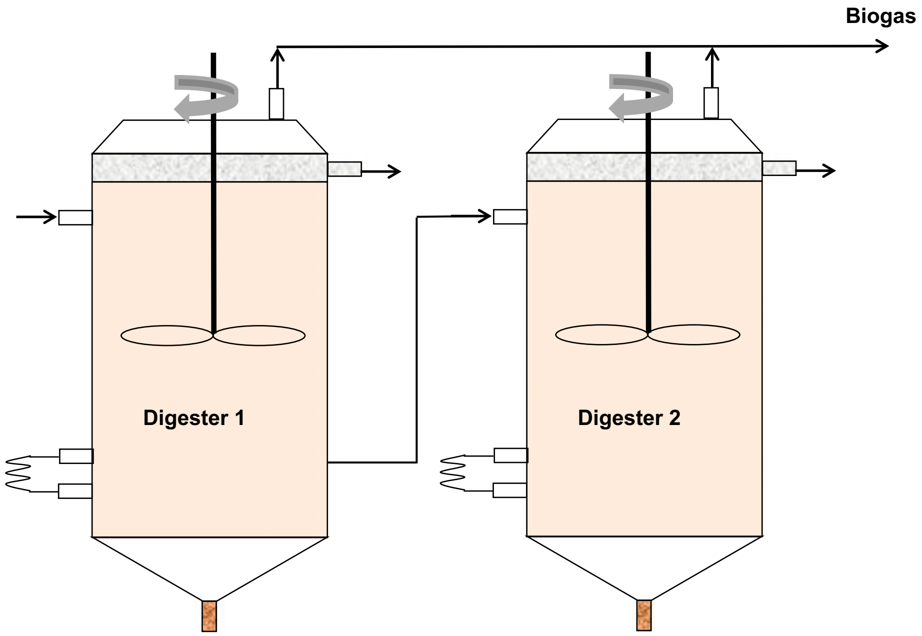

Fig. 8. Two-stage system of digesters.

Table 3
Percentage of reduction obtained with the current division

Percentage of reduction		
Screening	–	
Grit removal	26.64%	
Degreasing	Volume	65.83%
	Air needs	58.33%

Table 4
Methanation potential of by-products. Source: Adapted from [1,2]

	m^3 gas/ton
Poultry waste	100–200
Viscera and entrails	55–65
Blood	65–75
Meat waste	300–350
Grease	300–400

Table 5
Available biogas and power produced by methanation

Biogas from waste methanation	5,001.875 m^3/d
Biogas from WWTP	3,150 m^3/d
Available biogas	8,151.875 m^3/d
Available power	1,773.78 kW

taken advantage of, in order to maximize biogas production.

As previously stated, there is currently no record of a technological advancement of this nature being used in Spain. As such, there is a lack of empirical data. However, in Rheda's (Germany) and Schewechat's (Austria) (mentioned in the introduction) WWTPs, co-digestion experiments have been conducted. These experiments have resulted in a respective increase of 100 and 160% in biogas production.

On the basis of this empirical data, and the production rate of a plant, the available biogas from the waste was calculated. In addition to the biogas generated after the sludge digestion process, the available power obtained would be very profitable, as can be seen in Tables 4 and 5.

This biogas, formed by the digestion of this specific waste, comprises approximately 60% methane and 40% carbon dioxide. This waste also consists of other gases, such as hydrogen (H_2), nitrogen (N_2), oxygen (O_2) and hydrogen sulphide (H_2S).

The biogas would be able to be used as fuel to generate either thermal or electrical energy or a combination of both through cogeneration [25,26]. Firstly, it was decided that it would cover the thermal requirements of the WWTP and some other plant operations, such as the scalding stage, by using boilers and heaters. Secondly, the remaining biogas, if any, would be used to cover the electrical requirements as

Table 6
Economic ratios for different biogas plants

	Electric. *E*	Thermal *E*.	Cogeneration
NPV (M€) (Net Present Value)	0.410	0.740	0.194
IRR (%) (Internal Rate of Return)	9.2	14.3	6

much as possible, though the use of an internal combustion engine (RICE) as a generator.

This decision was made based on viability surveys [32] (Table 6) that have demonstrated that it is more profitable to use biogases as a source of thermal energy instead of electrical energy, fundamentally because of their simplicity and the lower costs involved in running the facility.

The installation was designed as shown in Fig. 6.

4. Conclusions

- A solution has been given to the four major environmental problems through the creation of a hybrid system that combines the wastewater purification and revaluation functions via biomethanation.
- This system is completely novel and, as such, is expected to be subject of future studies.
- The purification line allows the total reuse of water, minimizing the external consumption and considerably reducing the emission of wastewater.
- It is expected to raise awareness and result in a change in the law, as the reuse of recycled water in the food industry is currently prohibited. However, it has been shown that the parameters that ensure health safety in a facility within the same plant can be obtained.
- The system essentially recovers all of the waste by using it as a source of energy, therefore reducing these two key environmental aspects.
- The co-digestion system is easy to implement. An aggressive tertiary treatment process and the elements of the cogeneration plant are the only modifications that need to be made to the WWTP. By adding these new parts to the final process, there would be no need to make any further changes to the rest of the plant.
- The hybrid system includes advantages that make both the line of purification and biomethanation more efficient. If these were installed separately, they would not be able to be harnessed.
- The separation of currents (Fig. 4) is necessary. This leads to the most contaminated current being separated from the one that is taken advantage of during the energy production.
- In the methanation line, the treatment sludge and the waste are digested at the same time. Thus, the synergy that is created through the production of biogas is exploited.
- Due to the current distribution, the purification stages size and energy needs have been reduced up to 50%.

References

[1] European Union (EU), Council directive of 21 May 1991 concerning urban wastewater treatment, 91/271EEC, 1991.
[2] A. Levine, T. Asano, Peer reviewed: Recovering sustainable water from wastewater, Environ. Sci. Technol. 38 (2004) 201A–208A.
[3] M. Blanco, M. Viladrich-Grau, The introduction of a water rights trading scheme in the Segre Basin and the contribution of reused irrigation water, ITEA 110 (2014) 374–399.
[4] M. Shaban, Drainage water reuse: State of control and process capability evaluation, Water Air Soil Pollut. 225(11) (2014) 2168.
[5] J.A. Contruvo, Direct potable reuse: Then and now, World Water: Water Reuse Desalin. 3 (2014) 10–13.
[6] G. Tchobanoglous, H.D. Stensel, R. Tsuchihashi, F. Burton, M. Abu-Orf, G. Bowden, W. Pfrang, Wastewater Engineering. Treatment and Resource Recovery, fifth ed., Metcalf & Eddy/AECOM, Mc Graw Hill Education, New York, NY, 2014.
[7] M. Seoánez, Manual de Tratamiento, Reciclado, Aprovechamiento y Gestión de las Aguas Residuales de las Industrias Agroalimentarias (Treatment, Recycling, Utilization and Management of Wastewater from the Agrifood Industry), Mundiprensa Libros SA, Madrid, 2003.
[8] M.H. Panjeshahi, A. Ataei, Application of an environmentally optimum cooling water system design in water and energy conservation, Int. J. Environ. Sci. Technol. 5(2) (2008) 251–262.
[9] M. MedioAmbiente, Guía de Mejoras Técnicas Disponibles en España del Sector Matadero y de los Transformados de Pollo y Gallina (Best available techniques for the Spanish poultry slaughtering and processing industry), Publicaciones del Ministerio de Medio Ambiente, Madrid, 2006.
[10] M. Medina-Herrera, A. Rodriguez-Garcia, L. Montoya-Herrera, J. Cardenas-Mijangos, L.A. Godinez-Mora-Tovar, E. Bustos-Bustos, F.J. Rodriguez-Valadez, J. Manriquez-Rocha, Anaerobic digestion of slaughterhouse solid waste for the optimization of biogas production, Int. J. Environ. Res. 8(2) (2014) 483–492.
[11] G. Esposito, L. Frunzo, A. Giordano, F. Liotta, A. Panico, F. Pirozzi, Anaerobic co-digestion of organic wastes, Rev. Environ. Sci. Biotechnol. 11(4) (2012) 325–341.
[12] C. Gomez-Lahoz, B. Fernandez-Gimenez, F. Garcia-Herruzo, J.M. Rodriguez-Maroto, C. Vereda-Alonso,

Biomethanithation of mixtures of fruits and vegetables solid wastes and sludges from a municipal wastewater treatment plant, J. Environ. Sci. Health A Toxic Hazard. Subst. Environ. Eng. 42 (2007) 481–487.

[13] H. Bouallagui, H. Lahdheb, E. Ben Romdan, Improvement of fruit and vegetable waste anaerobic digestion performance and stability with co-substrates addition, J. Environ. Manage. 90 (2009) 1844–1849.

[14] L. Neves, R. Oliveira, M.M. Alves, Co-digestion of manure, food waste and intermittent input of fat, Bioresour. Technol. 100 (2009) 24–28.

[15] Y. Hong-Wie, D.E. Brune, Anaerobic co-digestion of algal sludge and waste paper to produce methane, Bioresour. Technol. 98 (2007) 130–134.

[16] X. Dai, N. Duan, B. Dong, L. Dai, High-solids anaerobic co-digestion of sewage sludge and food waste in comparison with mono-digestions: Stability and performance, Waste Manage. 33 (2013) 308–316.

[17] G. Esposito, L. Frunzo, A. Panico, F. Pirozzi, Enhanced bio-methane production from co-digestion of different organic wastes, Environ. Technol. 33(24) (2012) 2733–2740.

[18] A. Contreras, M. Molero, Ciencia y Tecnología del Medio Ambiente (Environmental Science and Technology), UNED, Madrid, 2009.

[19] R. Rajakumar, T. Meenambal, Comparative study on start-up performance of HUASB and AF Reactors treating poultry slaughterhouse wastewater, Int. J. Environ. Res. 2 (2008) 401–401.

[20] J. Fierro, J.E. Martinez, J.G. Rosas, D. Blanco, X. Gomez, Anaerobic codigestion of poultry manure and sewage sludge under solid-phase configuration, Environ. Prog. 33 (2004) 866–872.

[21] H. Nie, H.F. Jacobi, K. Strach, C.M. Xu, H.J. Zhou, J. Liebetrau, Mono-fermentation of chicken manure: Ammonia inhibition and recirculation of the digestate, Bioresour. Technol. 178 (2015) 238–246.

[22] J.M. Owens, D.P. Chynoweth, Biochemical methane potential of municipal solid waste (MSW) components, Water Sci. Technol. 27 (1993) 1–14.

[23] Asociación Española de Normalización y Certificación (AENOR), Water quality. Evaluation of "ultimate" anaerobic biodegradability of organic compounds in digested sludge. Method by measurement of the biogas production, ISO 11734, 1995.

[24] American Section of the International Association for Testing Materials (ASTM International), Standard Test Method for Determining Anaerobic Biodegradation Potential of Organic Chemicals Under Methanogenic Conditions, E2170-01, 2001.

[25] IDAE, Digestores Anaerobios (Biomass. Anaerobic digesters), Ministerio de Industria Turismo y Comercio, Gobierno de España, Madrid, 2007.

[26] VVAA, Estudio Básico del Biogás (Basic Study of Biogas), Consejería de economía, innovación y ciencia de Andalucía, Sevilla, 2011.

[27] F.J. Molina, Comportamiento Dinámico de Digestores Anaerobios (Dynamic Response of Anaerobic Digesters), Universidad de Santiago de Compostela, Santiago de Compostela, 2007.

[28] VVAA, Guía de Utilización Agrícola de los Materiales Digeridos por Metanización (Guide of the Agricultural Utilization of Digested Materials by Methanation), Probiogas, Murcia, 2011.

[29] R. Isla, Proyectos de Tratamiento de Aguas. Aguas de Proceso, Residuales y de Refrigeración (Water Treatment Projects. Waste, Process and Refrigeration Waters), Ediciones Bellisco, Madrid, 2011.

[30] R. Marín, Procesos Fisicoquímicos en Depuración de Aguas. Teoría, Práctica y Problemas Resueltos (Physicochemical Processes in Water Purification. Practice and solved problems), Díaz de Santos, Madrid, 2012.

[31] R. Marín, Fisicoquímica y Microbiología de los medios Acuáticos. Tratamiento y Control de Calidad de Aguas (Physicochemical and Microbiology of Aquatic Environments. Treatment and Quality Control of Water), Díaz de Santos, Madrid, 2003.

[32] J.D. Murphy, N.M. Power, A technical, economic and environmental comparison of composting and anaerobic digestion of biodegradable municipal waste, J. Environ. Sci. Health A Toxic Hazard. Subst. Environ. Eng. 41(5) (2006) 865–879.