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Overview of water usage and wastewater management in the food and beverage industry

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ABSTRACT

Food and beverage industry is one of the major contributors to the growth of all economies. In European Union, it constitutes the largest manufacturing sector in terms of turnover, value added, and employment. However, the sector has been associated with various environmental issues including high levels of water consumption and wastewater production. In the present work, an overview regarding the production process, the water usage and the wastewater generation, and treatment of representative manufacturing industries from selected sectors of the food and beverage industry, is presented. The industries under investigation are: slaughterhouses, potato processing, olive oil production, cheese production, and beer manufacturing. As expected, between those different sectors, water consumption and wastewater generation vary greatly. Wastewater pollution load depends on the type of product being processed, the process and the equipment used, while the common characteristic is the strong organic content. In this view, the predominant treatment methods found in the recent literature are biological. This fact is reflected to the wastewater treatment technology employed which, in most of the cases, is biological with special attention to the application of the anaerobic digestion process.

Keywords: Food and beverage industry; Anaerobic digestion; Slaughterhouse; Potatoes; Cheese; Olive oil; Beer

1. Introduction

Food and beverage industry includes various sub-sectors aiming at manufacturing different types of products. Based on the Statistical Classification of Economic Activities in the European Community, food industry is identified by the two-digit numerical code C10 and includes the following sub-sectors: processing and preserving of meat, and production of meat products (10.1), processing and preserving of fish, crustaceans and mollusks (10.2), processing and preserving of fruit and vegetables (10.3), manufacture of vegetable and animal oils and fats (10.4), manufacture of dairy products (10.5), manufacture of grain mill products, starches and starch products (10.6), manufacture of bakery and farinaceous products (10.7), manufacture of other food products (10.8), and manufacture of

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prepared animal feeds (10.9). The beverage industry is characterized by C11 code and in four-digit analysis includes the following processes: distilling, rectifying, and blending of spirits (11.01), manufacture of wine from grape (11.02), manufacture of cider and other fruit wines (11.03), manufacture of other non-distilled fermented beverages (11.04), manufacture of beer (11.05), manufacture of malt (11.06), and manufacture of soft drinks; production of mineral waters and other bottled waters (11.07) [1].

The food and beverage industry is one of the most important sectors in European Union (EU) in terms of financial and social significance owing to its continuous and constant growth. Based on the latest statistical insights published by the "European food and drink industry" (FoodDrinkEurope), food and beverage industrial sector is the largest manufacturing sector in terms of turnover, value added, and employment in the EU ahead of the automobile and chemical industries. Throughout the economic recession, while a sharp decrease was reported in other key manufacturing sectors, the food and drink industry continued to increase with a turnover of €953 billion for the EU-27 in 2010 [2]. Over 99% of all enterprises of the EU food industry are SMEs (small and medium-sized enterprises), while large companies make up for only 1%; however, the latter contributes almost half of the value added of the food sector (48%) [3]. Food and drink sector inevitably has impact on the environment, since it requires considerable resources such as water and energy, and produces waste and wastewater. The European food and drink industry is responsible for approximately 1.8% of Europe's total water use. Water is a key input for the food and drink industry, as an ingredient, as an essential processing element, and as a cooling agent in many production processes. Wastewater is the most common waste in the food and drink industry. It is characterized by organic contamination, and is generally biologically treated before discharge [4].

The present research aims at reviewing key issues related to the water use and wastewater generation, and treatment in the food and beverage industry. Crucial information included volume of water consumed either per raw material processed or per finished product, volume and characteristics of pollutant load of wastewater produced as well as predominant wastewater treatment processes employed. To this end, the following representative manufacturing industries of the food and beverage industry were selected: slaughterhouses (meat production sector), potato processing (fruit and vegetables processing sector), olive oil production (vegetable and animal oils, and fats manufacturing sector), cheese production (dairy industry), and beer manufacturing (beverage industry).

2. Production process, water use and wastewater generation and treatment in the food and drink industry

2.1. Slaughterhouses: production process, water consumption, wastewater generation and treatment

Based on the "European food and drink industry," in 2010 for EU-27, the meat processing sector was the largest sub-sector, representing 20% of the total turnover of the European food and drink industry with 40,000 companies, 99% of which were SMEs. In 2011, exports were increased by 31% compared with 2010 from €7,914 million to €10,379 million [2]. Beef, pork, and poultry are the main types processed in Europe [5]. In meat processing, the first stages occur in the slaughterhouse (abattoir) irrespective of the species. At slaughterhouses, processing operations can vary depending on the species. For instance, pig skins are usually retained although bristles are removed and the surface of the skin is singed, while for cattle and sheep, the hide is removed [6]. Despite that, there are many common processes for the different slaughterhouses as presented in Fig. 1.

Initially, animal reception and lairage take place, allowing the animals to recover from the stress of the journey. In most of the cases, the lorries which transferred the animals, are cleaned in a dedicated wash area [6,7]. Following, animals are taken from the lairage to where they are stunned, slaughtered, and hung. Bleeding must be started as soon as possible after stunning and be carried out in such a way so as to bring about rapid, profuse and, complete bleeding. Typically, a total of between 2 and 4 L of blood is collected from each pig and about 10–20 L per cattle [6,7]. The blood is collected separately from the main wastewater stream in order to be further utilized. Then, according to the type of animal being slaughtered, different procedures are employed as illustrated in Fig. 1. For example, in pig slaughterhouses, scalding, removal of bristles and toenails, singeing, and finally, rind treatment are executed in sequence. The scalding aims to loosen the bristles and toenails, which are removed afterwards and is done in a scalding tank filled with water (58–65˚C) for 3–6 min. After hair and toenail removal, pig carcasses are singed to remove residual hair and are then passed through a machine to polish the skin and to remove singe hair and other debris [7]. Evisceration, which follows, involves manual removal of the respiratory, pulmonary, and digestive organs. After evisceration, carcasses

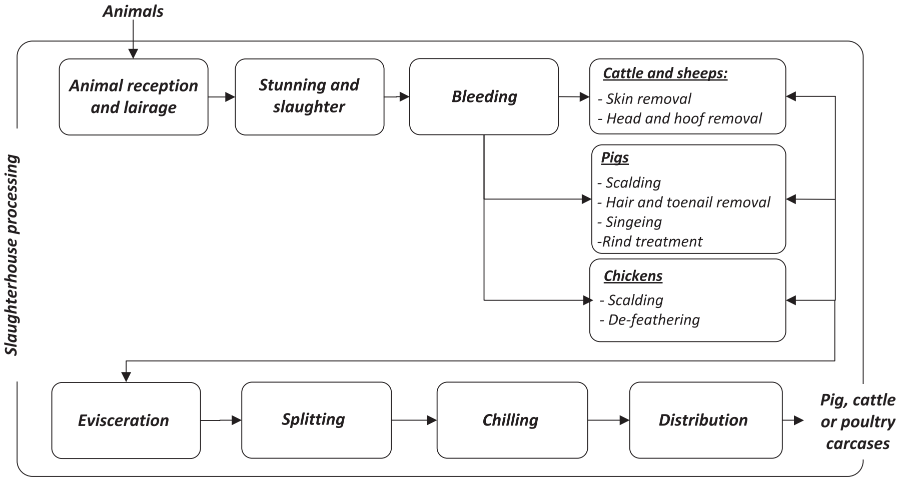

Fig. 1. Unit operations in a slaughterhouse.

are split along the spine using a saw. In some slaughterhouses, the carcass is given a final rinse with low-pressure water before chilling or freezing. The carcasses may then be held in a chilled meat store to further condition the meat prior to distribution to cutting plants, wholesalers, or to further processing [6].

For slaughterhouses, the key environmental issues are water consumption, the generation of high-strength organic wastewater, and the energy consumption [7]. Although the proportions of water used for each purpose can vary, a typical distribution of water consumption in pig slaughterhouses is illustrated in Fig. 2. Typical water consumption expressed as m^3 per tonne of product is 1.5–10 m^3/t for pigs, 2.5–40 m^3/t for cattle, and 6–30 m^3/t for poultry. The amount of wastewater generated and the pollutant load depend on the type and number of animals slaughtered. The wastewater from a slaughterhouse may contain blood, manure, hair, fat, feathers, and bones [8,9].

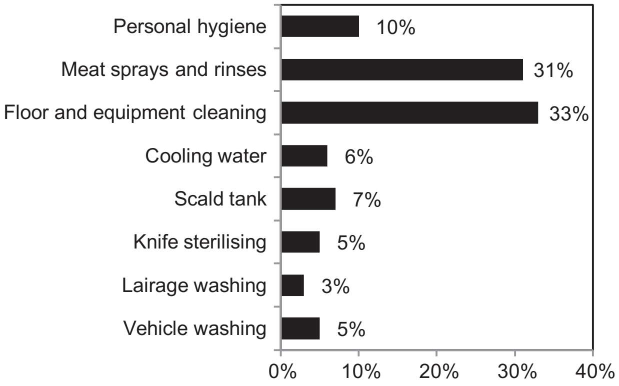

Fig. 2. Water use between different operations in a pig slaughterhouse [7].

Values of key pollutants of slaughterhouse wastewater are presented in Table 1.

Wastewater from slaughterhouses is normally subjected to a primary treatment which generally includes screening, settling, and fat separation, followed by secondary anaerobic treatment, usually by employing up-flow anaerobic sludge blanket (UASB) reactors [10]. Although the organic matter removal efficiencies, which is normally achieved through the application of anaerobic digestion (AD) processes, is high enough, the nutrients concentrations in the treated effluent usually need to be further treated through advanced oxidation processes (AOPs) or other appropriate treatment methods. Table 2 illustrates some of the most recent successful experiments for the treatment of slaughterhouse wastewater at laboratory; pilot and industrial scale derived from the literature.

2.2. Potato processing industry: production process, water consumption, wastewater generation and treatment

The potato processing industry belongs to the sector of the processing and preserving of fruits and vegetables. This sector also includes the manufacture of fruit and vegetable juices as well as the processing and preserving of other fruits and vegetables such as marmalades, table jellies, mixed salads, packaged vegetables, tofu, etc. [1]. Various types of products can be derived from potato such as potato chips, frozen french fries, and others, and as a consequence, the process lines vary greatly. In Fig. 3, the process line of a potato chips processing industry is presented according to European Commission [5].

Table 1
Pollutant characteristics in wastewater of slaughterhouses based on various published papers

Type of wastewater	Poultry slaughterhouse wastewater		Abattoir wastewater	
Reference	[15]	[18]	[16]	[11]
pH	5.6–8.1	–	6.8–7.4	7.31 ± 0.5
Alkalinity (mg/L)	775–2,100	–	–	–
COD (mg/L)	4,200–9,100	29,000–26,000	5,800–6,100 (Total) 1,800–2,500 (Soluble)	2,004 ± 240 (Total) 1,232 ± 80 (Soluble)
BOD (mg/L)	–	12,000–10,000		1,617 ± 88 (Total) 1,212 ± 66 (Soluble)
TSS (mg/L)	1,850–3,750	1,200–1,284	1,500–2,500	1,450 ± 95
TKN (mg/L)	565–785	–	530–810	550 ± 115 (N–Total)
NH_3-N (mg/L)	190–475	–	130–280	153 ± 52
TP (mg/L)	5.8–12.1	–	15–50	38 ± 12 (P–PO^{-3}_{4})

Water use during the potato processing strongly depends on the type of product being processed and the equipment used. According to Israilides et al., for a chip potato processing industry, 4.78 tonnes of water are required per tonne of influent potato [19]. Potato processing wastewater contains high concentrations of starch and proteins, in addition to high concentrations of COD, TSS, and total Kjeldahl nitrogen (TKN) [20]. Some values are presented in Table 3.

As indicated by [23], the majority of bioremediation processes reported for potato chips industry wastes are anaerobic digestion processes using mesophilic and thermophilic bacterial strains. Sentürk et al. employed high-rate mesophilic anaerobic contact reactors in different OLRs for the treatment of wastewater produced from a potato chips, maize chips, and other snacks factory that resulted in COD removal efficiencies from 78 to 92% with a methane content of the biogas of 80–89% [21]. Parawira et al. investigated the application of a laboratory-scale UASB reactor and an anaerobic packed-bed (APB) reactor at mesophilic conditions (37°C) for treating potato leachate at increasing OLRs [24]. The COD removal efficiencies of both reactors were greater than 90%, while the UASB reactor runs at higher OLR than the APB reactor and achieved a higher methane yield [24]. Kobya et al. examined the treatment of wastewater from potato chips manufacturing by electrocoagulation [25]. The application of aluminum and iron electrodes was evaluated and aluminum electrodes were found to be more suitable due to higher removal rate of COD, turbidity, and TSS. The removal efficiencies of COD and turbidity were high, being 60 and 98%, respectively [25].

2.3. *Olive oil production: production process, water consumption, wastewater generation and treatment*

Olive oil is the main fatty component of the Mediterranean diet. Average olive oil production in the EU in recent years has been 2.2 million tonnes, representing approximately 73% of world production. Spain, Italy, and Greece account for about 97% of EU olive oil production [26].

Olive oil is produced from olives in olive mills either by the discontinuous press method or by the continuous centrifugation method [27]. The production process is represented in Fig. 4. After reception of olives, the first step includes cleaning so as to remove impurities, such as stems, leaves, pieces of wood, twigs, and other debris left with the olives. Following, the olives are washed with water in order to take away chemical impurities, mainly pesticides and dirt. Cleaned and washed olives are then crushed either with stone mills, metal tooth grinders, or other types of hammer mills. The crushing process is important in order to guarantee the taste and aroma of the olive oil and also the yield of the extraction process. The paste, which is the result of crushing, undergoes malaxation. Through malaxation, the paste is slowly stirred resulting in the coalescence of small drops into larger ones and favors the disruption of the unbroken cells containing oil [5,28,29]. Afterwards, extraction of the oil takes place. Olive oil extraction is the core unit operation in an olive oil production process and is generally employed through pressing or centrifugation. Nowadays, most olive oil mills use the centrifugation process through three-phase or two-phase decanters. The former separates the oil, the vegetable water, and the

Table 2
Overview of recent treatment methods for slaughterhouse wastewater

Technology	Results	Date	Ref.
SMBR[1]	Average COD removal: 98%. Permeate COD < 25 ppm	2012	[11]
HUASB[2] reactor under mesophilic conditions (29–35˚C)	TCOD[3] removal: 70–86% and SCOD[4] removal: 80–92%	2012	[12]
UASB coupled with post treatment including: SBR[5], chemical-DAF[6] and UV[7]	UASB: 85% SCOD removal, 79% nitrogen conversion to ammonia, posttreatment: 99% P, 65% TSS removals.	2011	[13]
ABR[8]-UV/H_2O_2	Max: TOC[9], COD, CBOD$_5$[10] removal efficiencies > 90%	2011	[14]
SGBR[11] with anaerobic sludge	Average COD removal > 94%	2009	[15]
UAF[12] under mesophilic (37˚C) or thermophilic (55˚C) conditions after pretreatment in a CSTR[13]	COD removal of 80–90% was achieved for OLR[14] up to 4.5 g COD/L d in mesophilic, while the highest OLR 9 g COD/L d led to efficiencies of 70–72% in thermophilic conditions	2009	[16]
DAF-UASB	Average TCOD, SCOD and oil and grease removal efficiencies of 80, 91 and 81% while N and P were not removed	2007	[17]
EC[15]	The highest COD removal efficiency is reached with aluminum as 93%, and maximum oil and grease removal is obtained with iron electrodes as 98%	2006	[18]
UASB	COD removal varied from 77 to 91%, while BOD removal was 95%. The removal of TSS varied from 81 to 86%	2002	[19]

[1] Submerged membrane bioreactor (SMBR).
[2] Hybrid upflow anaerobic sludge blanket (HUASB).
[3] Total chemical oxygen demand (TCOD).
[4] Soluble chemical oxygen demand (SCOD).
[5] Sequencing batch reactor (SBR).
[6] Dissolved-air flotation (DAF).
[7] Ultraviolet (UV).
[8] Anaerobic baffled reactor (ABR).
[9] Total organic carbon (TOC).
[10] Carbonaceous biochemical oxygen demand (CBOD$_5$).
[11] Static granular bed reactor (SGBR).
[12] Upflow anaerobic filter (UAF).
[13] Continuous stirred tank reactor (CSTR).
[14] Organic loading rate (OLR).
[15] Electrocoagulation (EC).

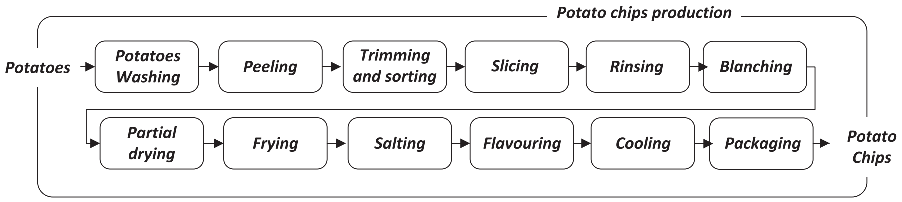

Fig. 3. Process flow diagram for a potato chips industry.

solids while, the latter separates the oil from a wet paste. Furthermore, in contrast to the three-phase decanter process, the two-phase does not require the addition of water to the olives [28]. In most cases, the oil coming out of the first centrifuge is further processed to eliminate any remaining water and solids by a second centrifuge that rotates faster. After final centrifugation, the olive oil is stored in large storage tanks that protect the oil from oxidation and by-products. Before bottling, the olive oil is commonly filtered with diatomaceous earth [28].

In the olive oil production process, water is mainly used for the washing of olives, malaxation, pressing, or centrifugation to three-phase decanters, final

Table 3
Characteristics of wastewater resulting from potato chips industry according to scientific papers

Reference	[21]	[22]	[23]
Type of wastewate (mg/L)	Potato chips, maize chips and other snacks factory (after peeling and cutting processes)	Potato chips industry	Potato chips industry
TCOD	5,250–5,750	4,000–7,000	8,122
SCOD	2,500–3,000	–	–
BOD_5	4,000–5,000	2,000–3,000	1,950
TSS	2,000–2,100	1,000–3,000	640
TKN	200–250	–	–
Total carbohydrates	–	–	19,470
Reducing sugars	–	–	40
Total protein	–	–	2,880

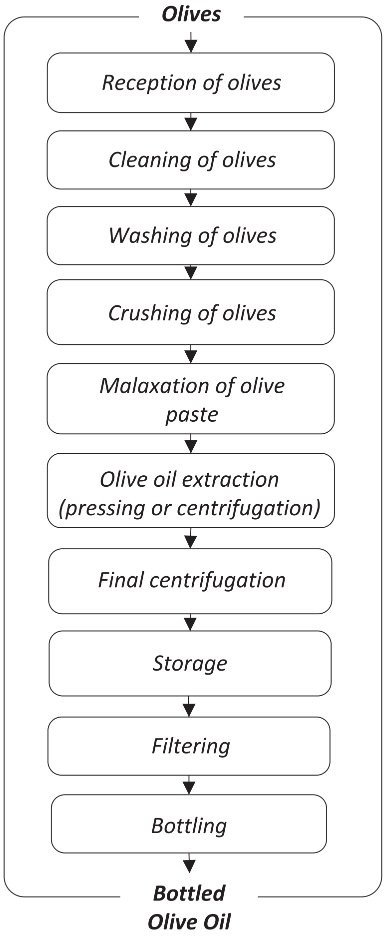

Fig. 4. Olive oil production process.

centrifugation, and for the general cleaning. In contrast to the three-phase decanters, in the two-phase decanters, no water is added. As a consequence, the two-phase production process is more ecological, not only because it reduces pollution but also because it is a less water demanding process [28]. Indicatively, in a three-phase process, the total effluent (L/kg olives processed) is 1.24, while for a two-phase process, this ratio accounts for 0.25 [30].

According to Niaounakis et al., olive mill wastewater (OMW) consists of vegetation water, soft tissues of the olive fruit, and water used at the different stages of oil production. The qualitative and quantitative characteristics of OMW depend on the composition of the vegetation water, the oil extraction process, and the storage time [31]. The vegetation water is the liquid residue separated from the oil by centrifugation or pressing, and its composition varies according to olive variety, olive maturity, water content of olives, soil cultivation, harvesting time, presence of pesticides and fertilizers, and climatic conditions [31].

OMW is characterized by an intensive violet-dark brown to black color and a strong olive oil odor. Moreover, it is rich in organic load in terms of COD with values up to 220,000 mg/L, and in some cases reaching 400,000 mg/L. Besides its strong organic content, it contains phenolic compounds and long-chain fatty acids, which are toxic to micro-organisms and plants. Such phenolic compounds can be either simple phenols and flavonoids, or polyphenols resulting from polymerization of the simple phenols [27,28,30,31]. The concentration of phenolic compounds varies greatly from 0.5 to 24 g/L [27,28]. Pollutant characteristics of the OMW varies significantly in literature; however, indicative maximum and minimum values for different extraction processes are illustrated in Table 4 as presented by Awad et al.

Olive oil mill wastewater has been extensively investigated as a waste stream, since the high recalcitrant organic load and the associated toxicity make its treatment imperative. Biological processes, aerobic, and anaerobic, including anaerobic co-digestion with other effluents and composting, are predominant in

Table 4
Indicative values for maximum and minimum concentration values of olive oil wastewater according to applied type of olive oil extraction technology [28]

	Centrifugation	Pressing
pH	4.55–5.89	4.73–5.73
Total solids (%)	0.95–16.12	1.55–2.66
Specific weight	1.007–1.046	1.02–1.09
Oil (mg/L)	410–2,980	120–11,500
Reducing sugars (mg/L)	1,600–34,700	9,700–67,100
Total polyphenols (mg/L)	400–7,100	1,400–14,300
O-diphenols (mg/L)	0.3–6	0.9–13.3
Hydroxytyrosol (mg/L)	43–426	71–937
COD (mg/L)	15,200–199,200	42,100–389,500
Organic nitrogen (mg/L)	140–966	154–1,106
Total phosphorus (mg/L)	42–495	157–915

the treatment of OMW [27]. Advanced oxidation processes have attracted much attention owing to the strong oxidation potential of the agents used, which can result in a high degree of treatment [27]. Badawy et al. have investigated either photo-Fenton as homogeneous photocatalytic oxidation or UV/semi-conductor catalyst as heterogeneous photocatalytic oxidation for the treatment of OMW. At the optimum conditions, photo-Fenton process achieved COD, TOC, lignin (total phenolic compounds), and TSS removal values of 87, 84, 97, and 98%, respectively, whereas the corresponding values for UV/TiO_2 were 69, 67, 40, and 49%, respectively, after 80 min irradiation time [32].

Furthermore, due to the high toxicity of the specific waste stream, researchers have developed novel approaches by combing different technologies. For instance, Gonçalves et al. have developed an innovative method for the energetic valorization and treatment of OMW, combining anaerobic digestion and electrochemical oxidation. The electrochemical treatment was proposed as the final step to mineralize the remaining OMW fraction from the anaerobic reactor [33]. Khoufi et al. have successfully applied the electro-Fenton method on raw OMW as pretreatment, anaerobic process as posttreatment and finally, electrocoagulation of the anaerobic digestion effluent as polishing step for improving the quality of the treated water for potential reuse [34]. Ochando-Pulido et al. have developed a depuration procedure which integrates an advanced oxidation process based on Fenton's reagent (secondary treatment) coupled with a final reverse osmosis (RO) stage (purification step) [35]. Lafi et al. investigated the combined processes of advanced oxidation, by UV and/or O_3, and biological degradation. In particular, biodegradation of UV/O_3 pretreated OMW, which exhibited the highest COD removal level of 91% [36].

The direct application of untreated OMW on soils has also been discussed in the literature. According to Barbera et al., direct application of OMW exerts a temporary positive effect on soil physical properties. However, in clay soils, the accumulation of salts from these wastewaters could lead to the disintegration of the soil structure resulting in decreasing the soil hydraulic conductivity. Based on Barbera et al., the most limiting factor for spreading OMW on soils is the polyphenolic content related to antimicrobial and phytotoxic effects. Nevertheless, these polyphenols are rapidly degraded depending on environmental conditions. Moreover, for many crops, spreading OMW benefits crop yield [37]. Diamantis et al. suggested that OMW has the potential to be used as a biosurfactant for reducing hydrophobicity in soils. However, the longer-term effects of applications are not clear [38]. Moreover, attention must be paid since the direct application of untreated OMW may also inhibit germination [37].

The current trend towards OMW is the valorization by recovering valuable phytochemical compounds with beneficial properties for the pharmaceutical, cosmetics, and food industries. According to Dermeche et al., OMW appears to be an affordable and abundant source of biologically active phenolic substances that hold promising potential as antioxidant, anti-inflammatory, and antimicrobial agents. Nonetheless, the qualitative and quantitative heterogeneity of phenolic compounds in these by-products is often a difficulty, i.e. in terms of finding feasible applications in this area [39].

2.4. Cheese production: production process, water consumption, wastewater generation and treatment

The dairy industry involves processing raw milk into products such as consumer milk, butter, cheese, yogurt, condensed milk, milk powder, and ice cream. Europe is the largest exporter of dairy products in the world, even excluding intra-EU trade. The EU dairy industry in 2010 was approximately 13% of the food and drink sector turnover in the EU. World trade in dairy products is concentrated in cheese, butter, and milk powder. In particular, 40% of EU milk is consumed as cheese, with 75% of cheese production concentrated in Germany, France, Italy, and the Netherlands [40].

Worldwide, there are many different types of cheese. While the basic principles of cheese making are common, many variations exist in all stages of the process, resulting in the production of many different varieties, often from the same factory [41,42]. In Fig. 5, the production flow diagram of hard and semi-hard cheese is illustrated. Cheese is produced by coagulation of the milk protein, casein, in a way that traps milk solids and fat into a curd matrix. Milk is mixed with a starter culture of bacteria, which converts milk sugars to lactic acid and the enzyme rennet, which catalyses the coagulation of casein [41,43]. The active principle in the rennet is an enzyme called *chymosine* [43]. Although coagulation of casein is the fundamental process of cheese making, even today the exact process is not fully understood. Nonetheless, it is generally accepted that the process involves the transformation of casein to paracasein and the precipitation of paracasein in the presence of calcium ion [43]. Following, the curd is cut into cubes and the mixture is stirred slowly so as to collect as much protein as possible into the curd. The cheese yield is approximately 10% with the remaining 90% a liquid by-product called "whey" [42]. The liquid whey is separated and drained from the curd. The curd is salted, pressed, cured, and packaged as cheese [41].

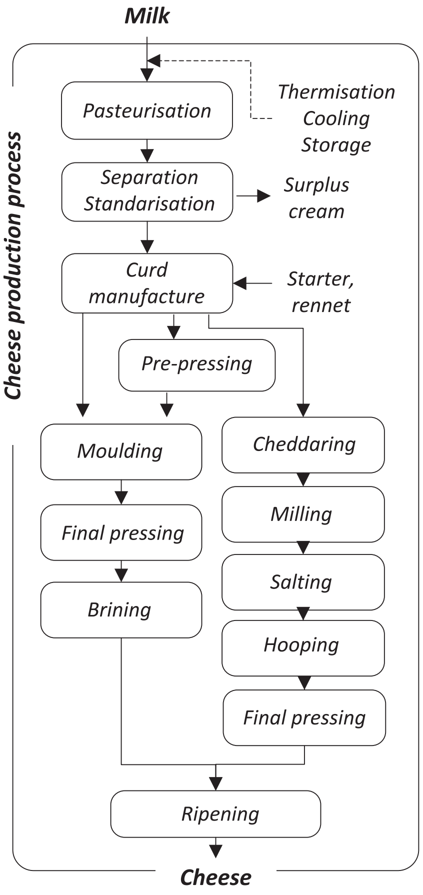

Fig. 5. The production process of hard and semi-hard cheese [43].

Published data on water consumption during cheese production vary. As an example based on European Commission, the ratio of water consumed per milk processed is 1–60 L/L [5], while according to foodefficiency, the ratio is between 1 and 4 L/L [44]. Carvalho et al. supports that three main types of effluents can be recognized; cheese whey (CW), which originates from cheese production; second cheese whey (SCW), which originates from cottage cheese production; and the washing water of pipelines, storage, tanks, and "clean in place" (CIP) systems. These three types generate a wastewater stream called cheese whey wastewater (CWW). CWW presents characteristics similar to CW; however, the contamination level of CWW is usually lower than CW. In Table 5, some of the most important pollutants of the wastewater from the cheese production process are presented.

On the word of Prazeres et al., CW management has been focused in the development of biological treatments without valorization, biological treatments with valorization, physicochemical treatments, and direct land application [45]. Fig. 6 summarizes the basic CWW wastewater treatment methods based on the recent review by Prazeres et al. CW contains the following nutrients from the original milk: lactose, soluble proteins, minerals, lactic acid, and fats, while significant amounts of other components, such as citric acid, non-protein nitrogen compounds, and vitamins, are also present [45]. As a result, the nutritional and medical characteristics of the protein concentrates have intensified the interest in CW valorization [45]. It must be also noticed that a number of researchers have claimed that the anaerobic process is essentially the only viable method of wastewater treatment with high organic load from cheese-making plants and as a result, the majority of studies have been conducted under anaerobic conditions using UASB reactors [41,42].

2.5. Beer production: production process, water consumption, wastewater generation and treatment

The European brewing sector has a very positive impact on the European economy. In particular, based on the European Association "The Brewers of Europe," the EU remains one of the major beer producing territories in the world producing yearly 383 million hl ($1\,\text{hl} = 0.1\,\text{m}^3$) of beer from 3,638 breweries.

Table 5
Pollutant characteristics of CW wastewater

Reference	[42]	[45]	[41]
COD (mg/L)	8,000–77,000	600–102,000	20,314 ± 9,186
BOD (mg/L)	6,000–16,000	–	–
Lactose	45,000	180–60,000	–
Protein	34,000	1,400–33,500	–
Fat	6,000	80–10,580	1,931 ± 1,391
TSS (mg/L)	100–5,000	10–1,700	5,000 ± 4,400
TS (mg/L)	65,000	–	–
TN (mg/L)	5–10.8	–	285 ± 118 (TKN)
TP (mg/L)	6–280	6–500	85 ± 35

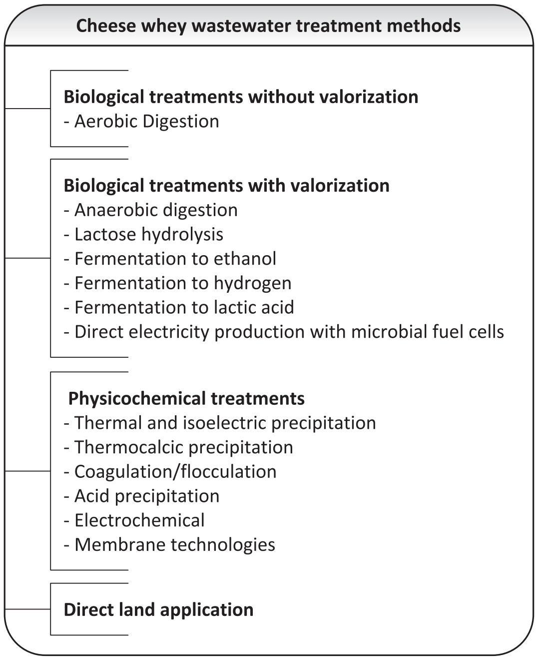

Fig. 6. CW treatment methods [45].

Germany is by far the first beer producer in EU-27, manufacturing the 25% of the total production (95 million hl), followed by United Kingdom (12%), Poland (10%), and Spain (9%). In 2010, the value added from the sector in the EU-27 was estimated to be €50.6 billion, while total sales reached €106 billion, including value added tax [46,47].

Beer is a fermented drink with a relatively low alcohol, usually around 4–6%, which is produced from malted barley, hops, yeast and water, while in some cases, other ingredients such as fruit, wheat, and spices are also included [5,48]. Instead or in addition to barley, other cereals can be also used such as maize, rice, millet, oats, rye, and wheat [49]. The malted barley is the result of the malting process, which mainly includes barley cleaning, barley size distribution, soaking, germination, kilning, and final cleaning. Only very large breweries malt their own barley, while most companies receive it already malted.

Fig. 7 outlines the process flow diagram at a malted barley brewery. Initially, the malted barley undergoes mixing so as to optimize the extraction of soluble substances such as starch and proteins [5,48,50]. The milled malted barley, known as grist, is then mashed in mash tuns. Mashing is the process of converting grist and water (mash) to a fermentable extract suitable for yeast growth and beer production in the presence of natural enzymes and temperature [50]. The product of mashing process enters the lauter tun where lautering takes place. This separation process results in the production of the mash liquor and

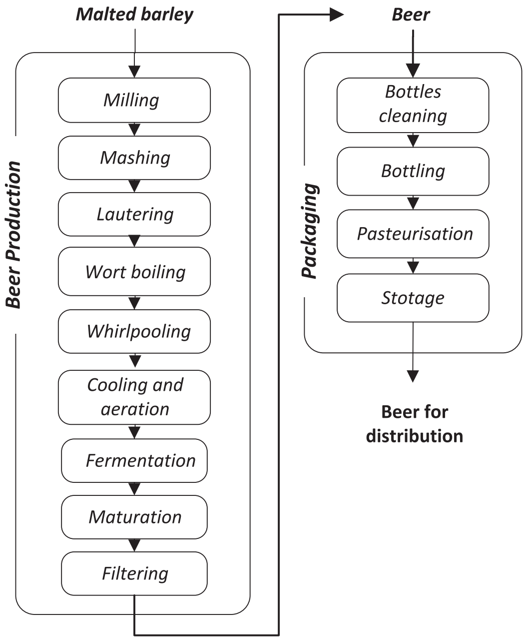

Fig. 7. Flow diagram at a malted barley brewery.

the extracted (spent) grains. Spent grains are traditionally sold to farmers for use as cattle feed [25,50,51]. In order to recover any remaining liquor, additional water is sprayed over the bed of the lauter tun, a process called sparging [50]. Then, water is added to the mash liquor and temporarily stored in vessels called underbacks and following, the mixture is introduced to the wort kettles for boiling [50]. Boiling ensures the sterility of the product, and thus prevents a lot of infections. During this process, hops or hops extracts are also added releasing bitter substances that are dissolved, while the heat of the boil causes proteins in the wort to coagulate and the pH to fall [5, 48–50]. Finally, the vapors produced during the boil volatilize off unwanted flavors that would negatively affect the finished beer. After boiling, the coarse coagulum of proteinaceous precipitated material called hot trub is separated from the wort in the whirlpool vessels [5]. The wort leaving the whirlpool is then cooled from 95˚C to approximately 9 and 10˚C, aerated, and a batch of yeast is pitched. The subsequent step is the fermentation process which lasts between 3 and 6 d [52]. The fermentation is an anaerobic process, during which the yeast utilizes wort sugars and converts them to ethanol and carbon dioxide. The characteristic flavor and aroma of any beer are, in large part, determined by the yeast strain and the fermentation conditions. During the fermentation process, yeast, carbon dioxide, and trub, which were not previously discharged, are removed. At the end of the fermentation, the product is called green beer or immature beer [50]. Afterwards, the green beer is transferred to vessels for maturation. This process can take from 2 to 4 weeks and includes centrifugal separation, chilling, and carbonation. Finally, the beer is filtered with mud-free kieselguhr, calcined and screened diatomaceous earth and perlite from ground, and calcined glassy rock of volcanic origin [5]. Filtering the beer stabilizes the flavor, and gives beer its polished shine and brilliance. Finally, the beer is packed. Finished beer is bottled, canned, or filled into kegs. Bottled and canned beers undergo pasteurization so as to stop the growth of the yeast that might remain in the beer after packaging.

Beer production is a water consuming process as water is the most important raw material used by the brewing sector [5,48,50,53,54]. The beer itself is composed of approximately 92% of water, while the remaining 8% is the ethanol and extracts from raw materials [55]. The brewing industry is supplied with water from private wells (groundwater), surface water, or from the municipal water supply system. For brewing in Europe in 2010, most water was originated from wells (54%) and municipal water (42%), while only 4% was derived from surface water [55]. Based on the Brewers of Europe, specific water consumption varied from 2.5 to 6.4 hl/hl with an average of 4.2 hl/hl in 2010 [55]. Water consumption varies depending on the type of beer, the number of beer brands, the size of brews, the existence of a bottle washer, how the beer is packaged and pasteurized, the age of the installation, the system used for cleaning, and the type of equipment used [5,48]. The main water consumption includes all water used in the product, vessel washing, general washing, and CIP, which are of considerable importance both in terms of water intake and effluent produced [50]. Based on water management investigation conducted at a malted barley brewery by AI Van der Merwe, 58% of water is consumed during beer production and the rest 42% for packaging. The latter contributed 56% to wastewater generation [50]. Based on the same study, water mass balance is presented in Fig. 8.

As shown above, the brewing industry is recording high wastewater generation, since almost 70% of used water ends up as wastewater. The amount of wastewater produced depends on the water consumed, while the pollution load depends on the processes that take place within a brewery [5,36]. Based on the Brewers of Europe, in 2010, for every 1 L of beer produced, an average of 2.7 L of wastewater was generated, 5.9% less compared to 2008 [55]. The organic load of wastewater is generally easily biodegradable and it mainly consists of sugars, soluble starches, ethanol, fatty acids, etc., while heavy metals are normally present in very low concentrations [5,56]. Table 6 illustrates characteristic values for some of the most important environmental parameters of the wastewater from the beer production industry [56].

Since the pollution load is mainly organic, biological processes, aerobic, and anaerobic are applied. It is common for breweries to use more than one type of treatment [55]. Based on Brito et al., the most preferable option for the treatment of brewery wastewater is anaerobic pretreatment combined with subsequent aerobic posttreatment for organic or nutrient removal. While several types of anaerobic reactors can be applied, the most commonly used full-scale systems are UASB combined with a sequencing batch reactor (SBR) [56]. Other interesting applications regarding the aerobic step are fluidished bed reactors and membrane bioreactors (MBR) [56]. The German Brewers Association encourages wastewater treatment with the anaerobic digestion process, since the brewery wastewater is the most suitable for anaerobic treatment [55]. Based on the Brewers of Europe, anaerobic digestion has created over 23.6 million m^3 of biogas per year in Europe, showing an increase of 7% in the period 2008–2010 [55].

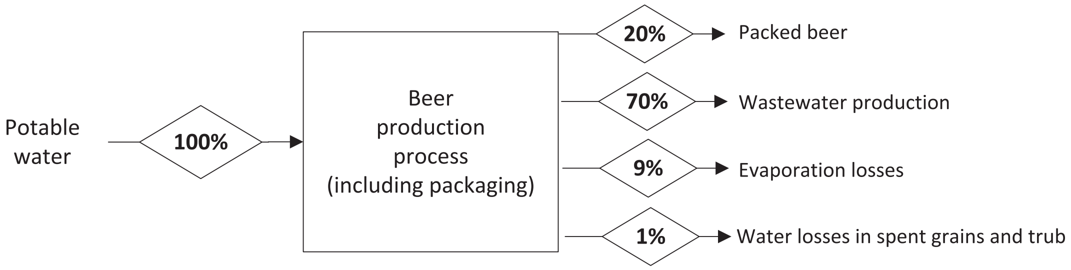

Fig. 8. Water mass balance at a malted barley brewery.

Table 6
Environmental parameters of wastewater from beer production industry [56]

Parameter	Value
COD (mg/L)	2,000–6,000
BOD (mg/L)	1,200–3,600
TSS (mg/L)	200–1,000
pH	4.5–12
Nitrogen (mg/L)	25–80
Phosphorous (mg/L)	10–50

3. Conclusions

Water is an essential input for the food and drink industry, as an ingredient, as a key processing element, and as a cooling agent. Water consumption varies depending on the type and number of end products, the capacity of the plant, the type of the processes applied, the equipment employed, the level of automation, and the system used for cleaning. Water usage in the food and drink industry is expressed either in volume of water consumed per finished product or per raw material processed. For slaughterhouses, great variations in water usage per end product were reported depending on the animal species i.e. 1.5–10, 2.5–40, and 6–30 m^3/t for pig, cattle, and poultry carcases, respectively. During the production of potato chips, approximately 5 m^3 of water is consumed for each tonne of raw potatoes processed. For olive oil production, less water in consumed if the two-phase centrifuge process is employed instead of the three-phase. Indicative water consumption values range between 0.25 and 1.24 m^3/t of olive oils. For the manufacturing of cheese, a conservative estimation ranges between 1 and 4 m^3 of water per m^3 of milk processed, while for the manufacturing of beer, 2.5–6.4 hl of water is consumed for each hl of produced beer. Used water is eventually ends up as wastewater except for the proportion which is utilized as a raw material, e.g. for beer production. Although the pollution load depends on the type of industry, a common characteristic of all food and beverage sectors studied was the high values of organic content of wastewater. The highest values in terms of COD were reported for the OMW and for CWW, while high values were also recorded for slaughterhouses, potato chip production process, and beer industry. Due to the high organic content, the biological processes are most commonly applied for the treatment of wastewater of those industries. In particular, the application of anaerobic process has been extensively employed in the literature, thus combining environmental protection and energy gain. Moreover, it was observed that for the case of some wastewater streams (olive oil wastewater, whey wastewater), the current trend is the valorization by recovering valuable compounds with beneficial properties for the medical, pharmaceutical, cosmetics, and food industries.

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