Innovative System for Brewery Wastewater Treatment

PROMISING TECHNOLOGY | The Life-ANSWER project (Advanced Nutrient Solutions With Electrochemical Recovery) aims to provide an innovative technology that integrates electrocoagulation and microbial electrochemistry for treatment of wastewater originating from the agri-food industry. The ANSWER system makes it possible to reuse the treated water, producing enriched biogas ($CH_4 + H_2$) and fertiliser from wastewater.

THE FOOD SECTOR needs large volumes of water to support its production activities (1.8% of all water in Europe is consumed by this sector). This inevitably gives rise to wastewater that has to be suitably treated before being returned into the environment. The brewing industry produces about 4 litres of residual water per litre of beer produced. Water consumption is divided into 2/3 for process and 1/3 for cleaning [1]. Elimination and recovery of nutrients in wastewater, mainly phosphorus, nitrogen and organic matter, are priority objectives set by the European Union in Directive 2000/60/EU establishing the basic rules for protecting the state of water bodies and for increasing the quality of rivers, lakes and ground waters in the European Union (EU).

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One of the problems arising from uncontrolled discharges of nutrient-rich residual water is eutrophication causing a decrease in oxygen present in water bodies and leading to serious environmental deterioration as biodiversity in the environment is lost. Currently, conventional treatment systems used for removal of these compounds in wastewater treatment plants (WWTP) are largely based on adding environmentally harmful chemical reagents and using biological systems that involve high energy costs and a high carbon footprint, limiting environmental friendliness. For example, aerobic solutions use 1.5-2.5 kWh of electricity to remove 1 kg of biochemical oxygen demand (BOD). However, strong process water streams contain up to 3 kWh of energy per kilogram of BOD, making anaerobic solutions particularly attractive for breweries [2].

The Life-ANSWER project was launched in September 2016 and is supported by the EU within the LIFE framework (LIFE 15 ENV/ES/000591) and carries a total budget of 973 403 EUR, of which 60 % has been co-financed. The consortium is coordinated by Mahou San Miguel, a brewing company on whose facilities the demonstration plant operates. Other members are Aqualia, a company active in the water management sector, the Bioelectrogenesis (Bioe) Group of the University of Alcalá and Recuperaciones Tolón as metal waste manager.

The ANSWER project proposes an advanced solution for treatment of wastewa-

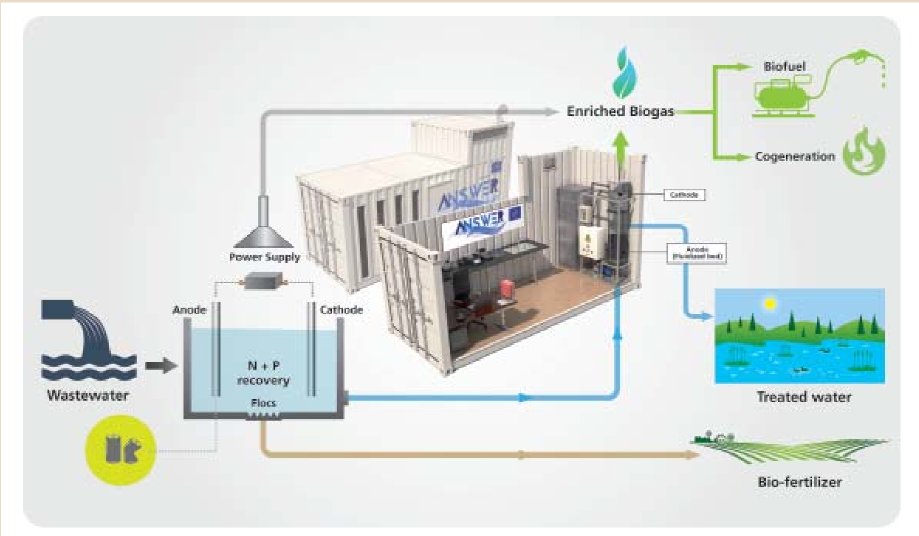

Fig. 1 ANSWER flow diagramme

ter originating from the agri-food industry. It contains high concentrations of nutrients (especially nitrogen and phosphorus) and a high organic load (see table 1). The process integrates two main units: an electrocoagulation system (reusing metal waste as a source of coagulant), followed by an innovative anaerobic technology including a microbial electrochemical unit for effective purification and maximisation of energy (enriched biogas) produced. In addition, the treated wastewater will be reused after having undergone ultrafiltration and UV disinfection in order to produce an effluent compliant with the legal requirements set out in Royal Decree-Act 1620/2007 (services quality) that can be reused as envisaged in the legislation. Such water reuse facilitates compliance with the European roadmap laid down the Europe 2020 Strategy and based on efficient consumption of resources. This is one of the most important environmental challenges facing the food and beverage industry in 2020. The project also proposes an ambitious objective to obtain an energy surplus of approx. 2.5 kWh/m^3. The demonstration plant has been in operation since the beginning of 2018 on the facilities of Mahou San Miguel (Alovera, Guadalajara) in order to study and optimise, both technically as well as economically, integration of the proposed technologies to validate the ANSWER solution for sustainable treatment of industrial wastewater. So far, the most outstanding achievements are a reduction of consumption of reagents traditionally used for elimination of nutrients; production of a high-quality effluent for reuse; production of enriched biogas to be used as a source of energy in the brewery; and obtaining sludge with high concentrations of nitrogen and phosphorus that can be used safely as fertiliser in agriculture.

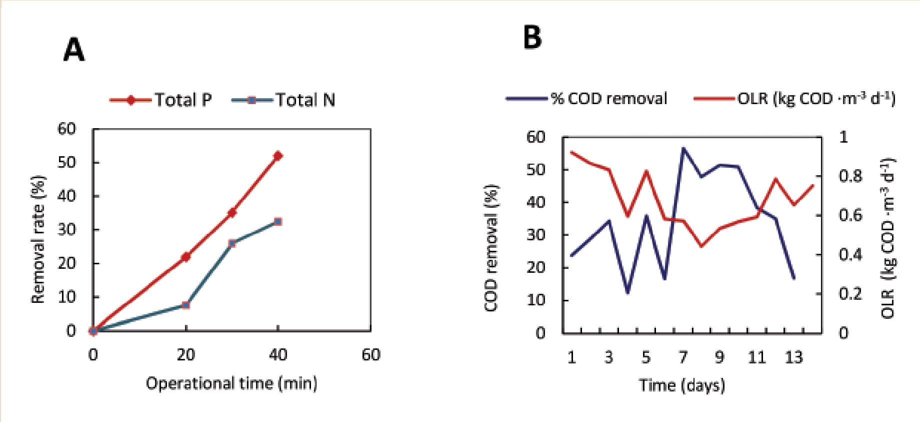

Fig. 2 A) Removal of TP and TN at a fixed current density of 2.5 mA cm^{-2} and at different retention times in the EC; B) COD removal and organic loading rate in the FBBR

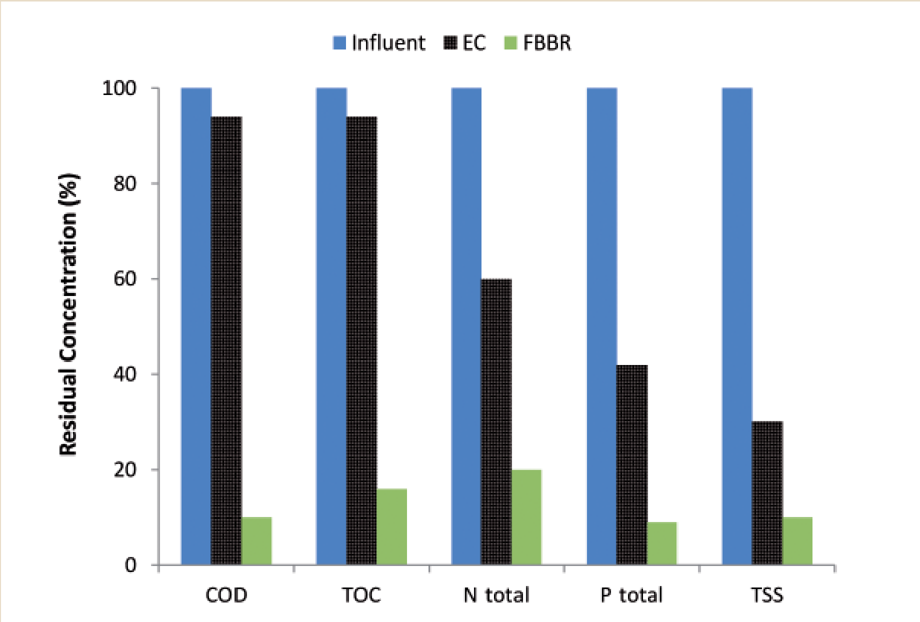

Fig. 3 Residual concentrations (%) of COD, TOC, TN, TP and TSS in wastewater after both treatment phases

Technology

The Mahou San Miguel production centre located in Alovera (Guadalajara) houses the demonstration site where the treatment plant based on the ANSWER solution has been installed. In order to address scaling of the process in the demonstration unit, it was necessary to carry out laboratory-scale and pre-pilot tests to optimise process operating conditions and maximise treatment capacity of the technology in the ANSWER demonstration project. The demonstration unit was designed and constructed as pictured in the flow diagram shown in fig. 1. The two fundamental stages of the process are the electrocoagulation unit (EC) and a bioelectrogenic fluidised bed reactor (FBBR).

- Stage 1: treatment by electrocoagulation with pellets of recycled aluminium to eliminate pollutants and produce fertilizer;
- Stage 2: treatment of effluent in the bioelectrogenic anaerobic reactor for transforming organic matter to enriched biogas (high concentration of methane and hydrogen);
- Stage 3: tertiary treatment based on ultrafiltration and photo-disinfection to meet the requirements of reuse and/or zero discharge.

The electrocoagulation unit, having a treatment capacity of 10 m^3/h, is composed of several in-line electrode modules. The negative electrode (cathode) is designed in stainless steel, and the positive electrode (sacrificial anode) is made of aluminium chip pellets as compacted raw material, coming from recycling of materials initially seen as waste (containers, cans, etc.). Three successive steps take place in this process. By applying a current density to the system, coagulant is formed by electrolytic oxidation of the sacrificial aluminium anode. It is then released into the residual water, causing destabilisation of contaminating particles (insoluble phosphorus and nitrogen and solids in suspension). Finally, flocs of aggregates are formed which, as a result of their weight, precipitate or are dragged towards the surface by hydrogen bubbles released at

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the cathode. These flocs will be part of the sludge that, after extraction, is dried and used as fertiliser in agriculture, thanks to its composition rich in phosphorus and nitrogen. The resulting effluent from the electrocoagulation unit is subsequently treated in an anaerobic fluidised bed reactor.

The concept of the FBBR system was patented under the title "Method for treating wastewater in a fluidised bed bioreactor" (EP 2927196 A1) and co-developed by Aqualia and the Bioe Group of the University of Alcalá (UAH) in the framework of the ITACA project. The system encompasses a microbial electrochemical unit in which bioelectrogenic processes promote transformation of organic matter. This technology is based on the interaction between electroactive bacteria and a fluidised, granulated conductive material. The fluidised particles can be colonised by microorganisms with an approx. 10 µm thick biofilm as shown by previous results obtained on a laboratory scale [3]. The organic matter is oxidised and the resulting electrons are transferred to the anode (particles of carbonaceous material), generating a circulation of electrons from the anode to the cathode where hydrogen is produced. Another product of organic matter oxidation is methane which is collected together with hydrogen to obtain biogas with a high calorific power value to be used in existing boilers in the brewery plant.

Results

From the beginning of the project to date, results have been very satisfactory, both on a laboratory scale as well as on an industrial scale, the phase in which we are currently working with prototypes operating continuously (fig. 2). It should be highlighted that the technology developed in the ANSWER project reduces treatment costs by 30 % compared to standard technologies used in the food and beverage industry.

The EC process with recycled aluminium achieves an efficiency in elimination of phosphorus of about 58 %, nitrogen by 40 % and 70 % of suspended solids precipitate (fig. 4). These numbers presuppose optimal operation conditions of the EC. Minimum energy consumption of up to $j = 2.5\ mA\ cm^{-2}$ was measured. Moreover, the design of the anodes makes it possible to easily replace the aluminium that is consumed in the reaction, thus avoiding complicated assemblies. Results achieved during the nine months in which the demonstration unit built in ANSWER project has been operated are very promising. This innovative system currently achieves organic matter removal of more than 90 %. As a result, less sludge is produced and the calorific value of biogas goes up by 10 % compared with conventional granular anaerobic reactors. The remaining nutrients in the EC are also effectively eliminated in the anaerobic reactor (approx. 80 %). In this way, the concentration required for discharge and/or reuse is obtained (fig. 3). Another positive aspect of the technology is verification that, during operation of the FBBR, energy production is 21% higher than the energy consumption of this unit. The FBBR system represents a technical breakthrough with a positive impact on the treatment process in terms of energy consumption and costs. These results allow us to conclude that the FBBR system offers a technological

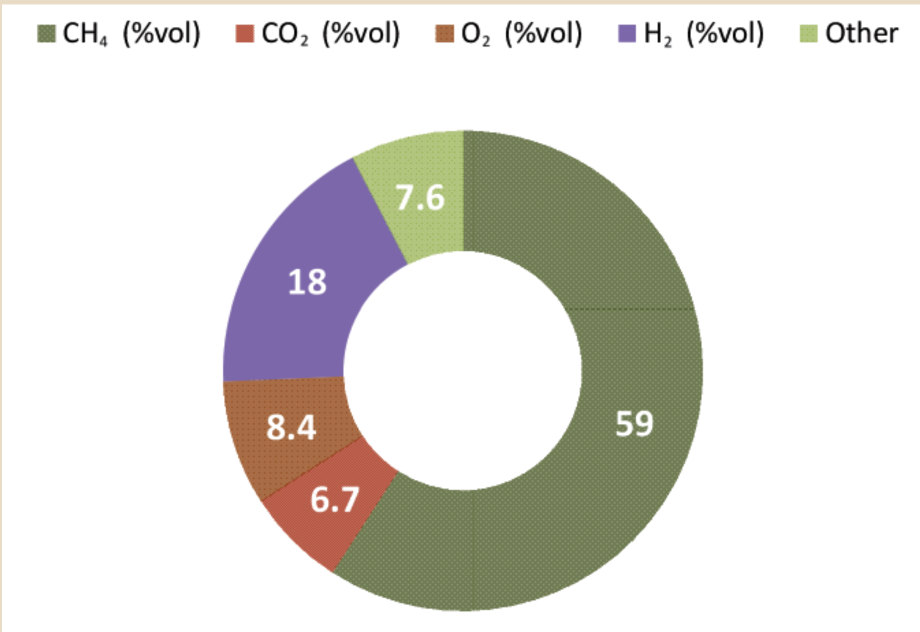

Fig. 4 Average enriched biogas composition during FBBR unit operation

solution for purification of wastewater with a net energy production and generation of a negligible amount of sludge. One of the key environmental factors of the project is the positive energy balance of the technical solution. Low energy consumption of the proposed units and production of hydrogen and methane (fig. 4) represent a significant advancement in the water sector, offering a viable solution that promotes sustainability and circular economy initiatives in water management.

Conclusions

It is expected that this technology will reduce use of chemicals. On the one hand, chemicals with a coagulant function used in WWTP's during primary treatment can be replaced by recycled aluminium in electrocoagulation. On the other hand, fertilisers for agriculture are substituted by sludge with high phosphorus and nitrogen contents obtained at the end of the process.

Another benefit is water saving because the water can be reused after having undergone tertiary treatment.

As energy is recovered from wastewater, emission of greenhouse gases is reduced and, thus, energy consumption goes down by up to 25 %.

The Life ANSWER project validates an innovative technology and optimises it under real conditions in order to improve quality of industrial effluents and benefit the environment. ■

CHEMICAL AND PHYSICAL PARAMETERS OF BREWERY WASTEWATER

Parameter	Value
pH	6.97
Conductivity (mS cm^{-1}, 25 °C)	2.73
COD (mg/L^{-1})	3065
Total suspended solids (TSS) (mg/L^{-1})	641
TOC (mg/L^{-1})	954
Colour (mg/L^{-1})	4180
Total nitrogen (TN) (mg/ L^{-1})	69
Total phosphorous (TP) (mg/ L^{-1})	15.2

Table 1

Literature

1. Fillaudeau, L. et al.: "Water, wastewater and waste management in brewing industries", Journal of Cleaner Production 14, 2006, pp. 463-471.
2. Aviles, C; Dean, W; Gobburi, B.: "Brewery water and Process Water Management: The golden, green opportunity found in anaerobic treatment solutions", Master Brewers Technical Quarterly, Volume 54, No. 1, 2017, pp. 41-44.
3. Tejedor-Sanz, S; Ortiz, J.M.; Esteve-Núñez, A.: "Merging microbial electrochemical systems with electrocoagulation pretreatment for achieving complete treatment of brewery wastewater", Chemical Engineering Journal 330, 2017, pp.1068-107.