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MINI REVIEW

Dissolved air flotation combined to biosurfactants: a clean and efficient alternative to treat industrial oily water

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Abstract The present review was motivated by the increasing demand of environmental regulatory agencies for the treatment of oily water generated during industrial activities. Flotation is a promising process for this purpose. Particularly, dissolved air flotation (DAF) is the most indicated technology due to its high efficiency and the possibility of controlling the physical variables, such as microbubble size, residence time and concentration of the effluent. DAF can also be optimised with the use of biodegradable tensioactive agents that increase the adhesion of oil particles, thereby enhancing the efficiency of the process. Among such tensioactive agents, biosurfactants are a viable, innovative, eco-friendly option with important properties, such as a reduction in surface tension, low toxicity and stability in the presence of adverse environmental conditions. Therefore, the aim of the present review is to offer a new perspective regarding the use of the flotation process combined with these specific biomolecules.

Keywords Oily water · Emulsions · Flotation · DAF · Biosurfactants · Environmental pollution

1 Introduction

The world's major energy sources, such as petroleum (and its derivates), coal and natural gas, among other non-renewable sources, have limited reserves and are rapidly declining because of the great exploitation that has been going on for many years. As a consequence of this use, the environmental impact, the social pressure, the limitation of natural resources, the risks of nuclear energy accidents, the difficulty and cost increase with environmental licensing of plants, human health, air pollution, climate changes and especially the rising cost of energy are making the search for renewable sources increasingly worldwide. In this sense, renewable energies are increasingly being inserted in the

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energy planning studies of several countries in order to increase their contribution in the energy matrix (Almeida et al. 2016).

The petroleum industry and industries that use petroleum products face the challenges of meeting increasingly rigorous standards with regard to the release of effluents (CONAMA 2005). Additionally, the discovery of new petroleum fields in the world requires the use of technologies that lend support to the treatment and reuse of industrial effluents and such treatment should itself not cause secondary negative environmental impacts due to its use.

Different contaminants are formed in the processing of crude oil, including an oily emulsion that is basically formed by oil, a surfactant agent and an agitating medium. Due to the stability of such compounds and the fact that gravitational separators are insufficient for this type of oil, the treatment of oily water can be a complex operation dependent on highly efficient processes. In this context, flotation is a widely accepted, commonly employed method for the treatment of different types of effluents in the most diverse industries.

Flotation was proposed since the early 1960s and it has been shown to be a promising method for the removal of metals and oils from aqueous solution (Edzwald 2010). Flotation is easy to operate and it is of low-cost production compared with conventional physicochemical separation processes. On the other hand, the chemical synthetic surfactants utilized in as flotation collectors bring a lot of problems, such as the toxic outcomes into the environment, unstable chemical property and expensive cost. All these deficiencies limit the large-scale application of flotation, especially in the environmental pollution remediation field. Biosurfactants, widely known as an environmentally friendly material, have been found plants and microbes. These green biomolecules have many advantages over synthetic surfactants including biodegradability and biocompatibility (Yuan et al. 2008). Combined with the advantages of biosurfactants, flotation could play an important role in oily waters treatment.

In this review, our main aim was to show the attractive relationship between biosurfactants and flotation techniques, since this combination remains an under-investigated topic. These two subjects have been widely explored over the years, but never together. We want to show that biosurfactants can be used in flotation devices to enhance the separation of contaminants and avoid the use of toxic collectors, such as synthetic surfactants. We address the potential of many potent biosurfactants for use in flotation methods so that engineering and biotechnology can be developed together in this new conception. The motivation for performing this review was based on results obtained in two research projects implemented in oil-fired thermoelectric plants (Rocha e Silva et al. 2015, 2018), during which a significant increase in the efficiency of the water–oil separation system was achieved with the combination of the techniques presented in this review article.

Thus, in this review we will show the scenario that involves the pollution caused by the oily waters, their impacts and the advantages of the association of DAF technique with biosurfactants. The present review will also offer a description of results recently obtained on the use of biosurfactants as collectors applied to the flotation process.

2 Oily industrial wastewater

The continual expansion of petroleum processing activities and the extensive use of petroleum products in the majority of industries (automobile industry, aircraft factories, chemical industries, mechanics offices, etc.) have increased the risk of hydrocarbon pollution. Oil exploration inevitably generates large volumes of oily wastewater. Both upstream (extraction, transportation and storage) and downstream (refining) operations generate large amounts of oily residue and environmentally acceptable disposal continues to be a challenge (Hu et al. 2013). Thus, the treatment of oily wastewater is an urgent and emergent need in the oil industry.

The term oily water is used for all types of water that contain different amounts of oil and grease as well as a wide variety of suspended materials, such as sand, clay and other dissolved colloidal substances (detergents, heavy metals, etc.) (Yang et al. 2015). Oily waters vary enormously in composition and characteristics. The oil content can be very low or very high, generally ranging from 1 to 50% (Pintor et al. 2016). After treatment, oily waters are commonly released into the ocean and can cause serious environmental contamination, especially when reaching the surface, soil and bodies of water (Santander et al. 2011).

Wastewater treatment depends on a variety of factors, such as efficiency, cost–benefit and environmental capacity, so that the polluting sources can meet the demand of environmental legislation aimed at reducing the impact on ecosystems (Costa and Olivi 2009). Different effluent treatment methods are employed with different technologies, such as flotation, electrochemical treatment, sedimentation, coagulation, filtration, ultrafiltraion and reverse osmosis (Krishnomoorhi et al. 2009). Oil and water are practically immiscible, which facilitates the separation process. Water that contains residual oil (suspended, emulsified or solubilised) is treated and sent to a final destination (Oliveira et al. 2017; Jamaly et al. 2015; Chen and He 2003).

The maximum concentration of oil permitted in effluents is stipulated by current legislation in each country. The laws that regulate the disposal of oily wastewater are becoming increasingly strict. In the United States, the disposal of oily effluents in the metal and machine production sector (aircraft, spacecraft, electronic equipment, hardware, industrial equipment and weapons) must obey a maximum monthly limit of 17 mg/L (Zhu and Guo 2016).

According to the Brazilian Environment National Council (CONAMA 2005), the concentration of oil in effluents should not exceed 20 mg/L in Brazil. According to Liu et al. (2015), oil can be found in liquid effluents in four forms: free, dispersed, emulsified and dissolved. The main characteristics are listed below:

- *Free-floating oil* Thick dispersion made up of droplets with a diameter larger than 150 µm. In this form, the oil is easily removed using conventional gravitational separation processes.
- *Dispersed* Droplet diameters normally between 50 and 100 µm; can also be removed using gravitational processes. However, separation efficiency fundamentally depends on the distribution of the droplet diameters and the presence of destabilising agents.
- *Emulsified* Droplet diameter normally less than 50 µm, which hinders removal using gravitational means.
- *Dissolved* Removal extremely difficult, requiring use of chemical and/or biological processes.

Legislation requires dissolved and non-dissolved components to be removed from effluents prior to disposal (Moosai and Dawe 2003). According to Gryta et al. (2001), many oily effluents are in a water–oil emulsion. The form of presentation is the main characteristic that defines the degree of difficulty with regard to separating the oil. The amount of suspended solids, distribution of particle sizes, pH, temperature, presence of chemical products, oil density and fluid density also exert an influence on the separation process (Arouca et al. 2005).

2.1 Emulsions

An emulsion is a system of two immiscible liquids in which one phase is suspended in the form of droplets (dispersed phase) within a second liquid (continuous phase). This is only possible in the presence of an emulsifying agent and sufficient energy (mechanical or otherwise) for the occurrence of dispersion. Emulsions are classified as either oil in water (O/W) or water in oil (W/O) (Fig. 1). O/W is the most common type of petroleum emulsion due to the hydrophobic nature of the stabilising agents in the oil. Emulsions are formed in different industries, such as the steel, aluminium, food, textile, leather, petrochemical and metal polishing industries (Rocha e Silva et al. 2017; Kelesoglu et al. 2012).

Emulsions can be stabilised either physically or chemically. Physically stabilised emulsions are those formed without the addition of surfactants; stability is maintained by electrical charges inherent to the system or other forces under the influence of stabilising agents (Zadymova et al. 2016). When water and oil are stirred mechanically, it is possible to produce a suspension of oil droplets in water—an emulsion (Wen et al. 2016). Studies conducted by Rocha and Silva et al. (2015) demonstrate the production of a synthetic O/W emulsion with a concentration of 50 ppm using a lubricating oil and stirring mechanisms, in which the affluent (industrial wastewater or seawater) is sent through a recirculation pump where the oil is mixed with the same input fluid and the emulsion formation process is simulated through mechanical stirrers. Zhang et al. (2016) created a stable emulsion using shear-induced hydrodynamic cavitation, with the achievement of physical stability for 8 months. According to Karhu et al. (2012), a synthetic O/W emulsion is more stable than a non-synthetic emulsion and diminishes some interfering agents, such as

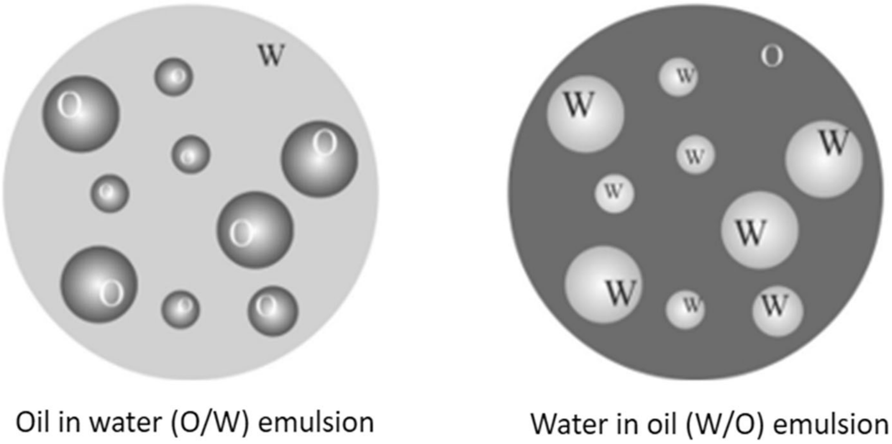

Fig. 1 Illustration of W/O and O/W emulsions

additives used in the process, which facilitates the removal of the oil from the water.

Emulsions with a mean concentration of 300 ppm are more representative and enable a better evaluation of the possibility of oil removal with the aid of tensioactive agents (Kulik et al. 2007). This concentration is a reference used in studies involving the flotation of oil dispersed in water (Santander et al. 2011), but is normally used when flotation is preceded by other methods, such as coagulation/flocculation.

2.2 Destabilisation of emulsions

The destabilisation of an emulsion can be performed using four different phenomena: coagulation, flocculation, sedimentation (creaming) and coalescence (Zhu and Guo 2016) (Fig. 2).

Creaming is the gravitational displacement of droplets to the surface of the continuous phase due to the difference in density between the two phases, not necessarily stemming from the coagulation and/or flocculation of the droplets. The droplets remain dispersed on the surface, but on the surface of the dispersing medium (Kamp et al. 2016).

Coalescence is defined as the joining of two or more droplets to form a larger volume with less interfacial area (Kamp et al. 2016; Tang et al. 2015).

Coagulation occurs when the repulsive interaction between the dual electrical layers is reduced enough to enable particles to approach each other until Van der Waals forces predominate (Tang et al. 2015). The coagulation process corresponds to the destabilisation of the colloidal dispersion obtained through the reduction in forces of repulsion between particles with negative charges by the addition of appropriate chemical products (Tansel and Pascual 2011).

Flocculation consists of the aggregation of particles by increasing the possibility of collisions to form

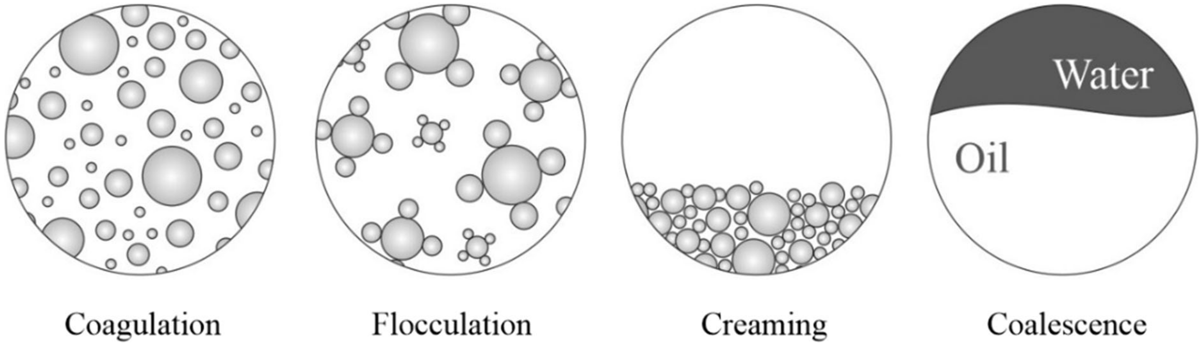

Fig. 2 Mechanisms employed for destabilisation of emulsions

larger, denser aggregations that can be removed by creaming or the action of gravity (Harif et al. 2012).

Crude oil generated by the transportation of residues, storage and refining processes forms highly stable mixtures due to the natural presence of surfactants (asphaltenes, resins, naphthenic acids, etc.), added chemical surfactants and natural solid particles (clay and wax) in its composition (Banat et al. 2010; Jiang and Brinker 2010). Such residues are normally composed of 30 to 90% oil, 30 to 70% water and 2 to 15% mass solid, forming a complex O/W emulsion (Yang et al. 2005; Zhang et al. 2012).

3 Treatment of oily waters

The methods employed for the treatment of oily wastewater may be physical (gravimetric separation, centrifugation or flotation), chemical (acidification or polymer-aluminium treatment), physicochemical, biological (microorganisms for the oxidation of the soluble oil), mechanical or electrical (electrocoagulation). Depending on the type of effluent and aim of treatment, more than one method may be performed on the same wastewater (Yang et al. 2015; Painmanakula et al. 2010). According to Hu et al. (2002), traditional methods are not efficient at separating emulsified oil, especially when the oil droplets are finely dispersed and at low concentrations. Thus, identifying the form in which the oil is immersed in water is fundamental to the determination of the method to be used for its removal.

The separation of oil by flotation is the best option for the treatment of oily water, whether the oil is free floating or emulsified. The low cost (compact equipment) and easy, efficient operation ensure compliance with environmental demands and often enable the reuse of the water, as discussed below.

3.1 Flotation

The conventional treatment of oily water is basically performed with water–oil separators, which employ the principle of gravitational force for the separation. Treated water reaches oil removal levels of around 200 mg/L, due mainly to the presence of emulsified oil, which is difficult to remove and requires more efficient processes, such as flotation (Yu et al. 2013).

Flotation is defined as a particle separation process involving the adherence to bubbles (Albuquerque et al. 2012). The particle-bubble bond has less density than the aqueous medium and floats to the surface of the flotation cell, where the particles are removed. Flotation is considered a clean technology, since it uses small quantities of coagulants and air to promote separation (Rocha e Silva et al. 2015). Figure 3 illustrates the separation of phases when oily wastewater is submitted to the flotation process.

Table 1 lists the main uses and objectives of flotation as a complete process and as pre-treatment combined with other methods.

The flotation process involves contact between air bubbles and the droplets in the dispersed phase, which are generically denominated particles. As air density is much lower than the density of the particles, the bubbles rise in the liquid mass, causing the occurrence of bubble-particle contact (collisions). As a result, the solute (organic matter or heavy metal, for example) floats to the surface with the addition of a collector, which is normally an appropriate surfactant, where the particles are recovered.

3.1.1 DAF

DAF is a process that separates suspended solids or droplets of oil in water by combining microbubbles injected from a saturator and flocs formed using an additional operation. The use of intense flows of microbubbles with smaller dimensions (mean diameter 50–100 μm) enhances the collision efficiency (Kim and Kwak 2014). Figure 4 illustrates the DAF process. Usually, the gas is dissolved in water in a saturator under pressure (typically 2–5 kgf/cm^2). When the water is saturated, air is injected at atmospheric pressure into the flotation chamber. Excess air is released in the form of microbubbles, which adhere to the dispersed phase, causing the particles to float.

DAF is a method that has diverse applications, such as in the mining industry, effluent treatment and the recycling of materials of economic value (Schoenhals et al. 2006). According to Edzwald (2010), the purpose of DAF is to clarify liquids; the process can be used for the removal of microparticles and even droplets of oil. The presence of dissolved air is the most important characteristic of oily industrial water, which justifies the use of DAF as an alternative to the gravimetric separation process. Moreover, DAF is widely

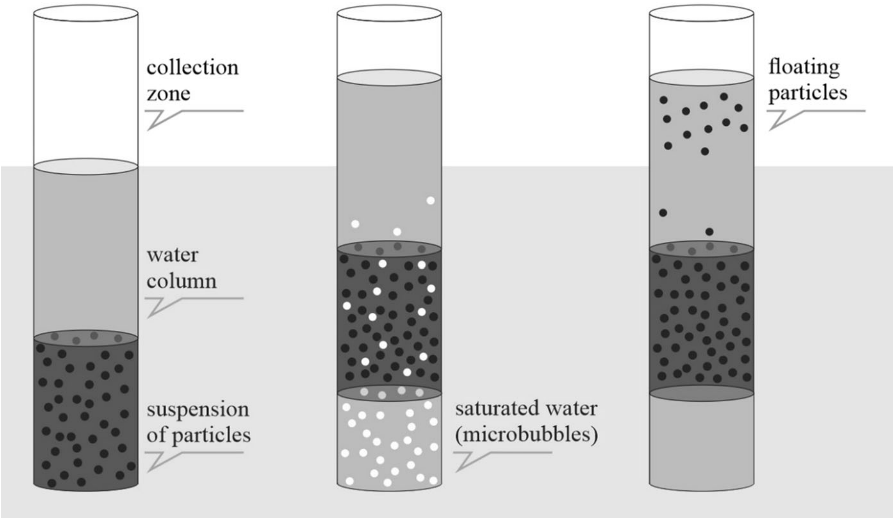

Fig. 3 Flotation process: suspended particles lifted to surface for removal, clarifying water in lower portion

Table 1 Uses and objectives of flotation (adapted from Tessele et al. 2009)

Use	Objective
Water	
Drinking supply	Removal of Fe, Mn, turbidity, colour and total soluble solids (TSS)
Recreational (lake, river and dam)	Removal of algae, oils, TSS, turbidity and colour
Sewage	
Pre-treatment	Removal of fats, TSS, gross particles (insoluble BOD)
Post-treatment	Removal of nutrients (NH_3, P), TSS, turbidity, algae and colour
Industrial effluents	Removal of fats, TSS, gross particles (insoluble BOD) and fibre
	Removal of nutrients (NH_3, P), TSS, turbidity, algae, colour, precipitated metals, oils, microorganisms, pigments, organic compounds and macromolecules
Others	Treatment of ore, cellulose, paper, reuse of paints, plastics and analytical grade chemicals

employed for the removal of finely dispersed matter due to the production of a large number of microbubbles (Haarhoff and Edzwald 2013).

Since flotation depends on the type of surface of the particulate matter, laboratory tests and pilot plants are generally designed to determine the project criteria. The factors that should be considered in flotation units are the concentration of the particulate matter (mean diameter of oil droplets in the present case), amount of air used and rising velocity of the particle (Edzwald 2010).

Kinetics is the main macroscopic mechanism of flotation and comprises the study of the behavior of the mass transfer rate of the liquid phase to the foam and the approximation of a steady state. The flotation velocity follows a behavior that can be recorded by a kinetic curve, drawn from experimental data (Asghar et al. 2015). Sampling and physical–chemical analysis allow the establishment of quantitative values of separation efficiency as a function of time, from which the kinetic models extract the kinetic constant of the process (k).

The major difficulties of the kinetic flotation study are in the scale-up procedure for continuous operations, whose particular approach constitutes the main difference between the kinetic models evaluated. The problem that these models intend to solve is to define the real profile of mass production velocities from the information obtained in the laboratory (Yovanovic 2004). For this purpose, the kinetic constants are used

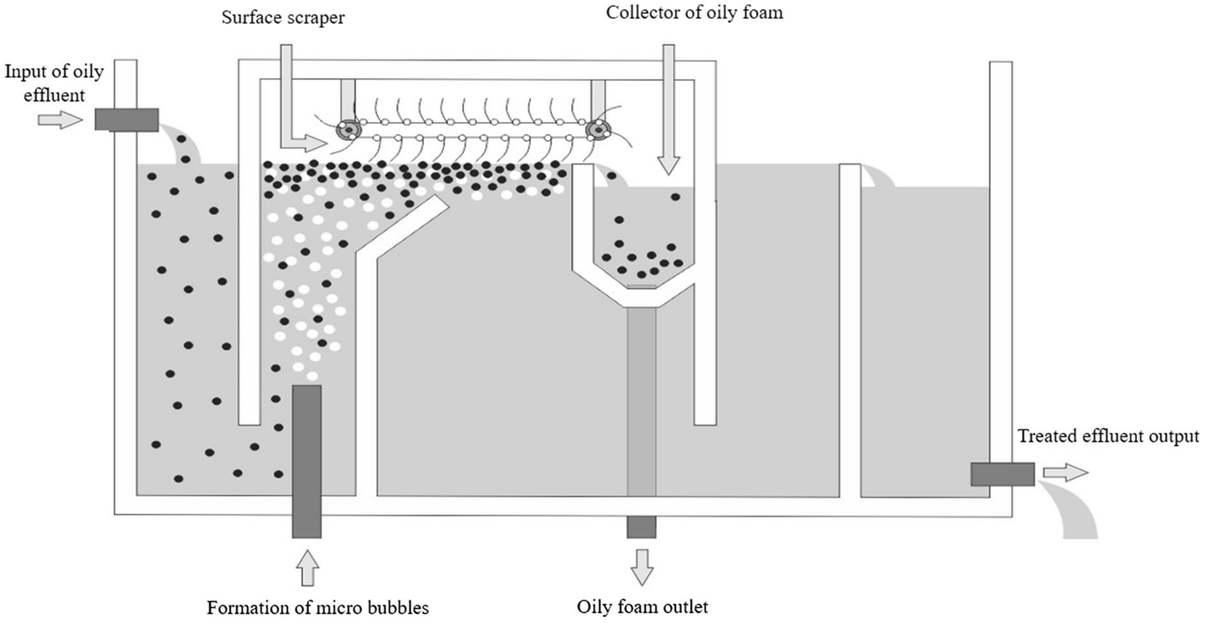

Fig. 4 Schematic of air-dissolved flotation

in analogy with the chemical reactions with the system operating in batch. This constant is usually extrapolated to the continuous processes. The study of this regime change is fundamental for a scale-up of a DAF process.

In a laboratory cell it is possible to obtain the content of the substance floated in the liquid phase for different flotation times, giving rise to the binary kinetic curve. This kinetic curve is a practical consequence of the mass transfer phenomenon by flotation, between the liquid and the floated foam. This mass transfer depends on the interaction of several typical variables such as changes that cause catalytic or selective effects (surfactant use) and physical characteristics (density, foam layer height, flow intensity and size of air microbubbles, pH, etc.) of the two phases involved (Allif Radzuan et al. 2016).

Unlike the laboratory system, in the continuous system the phases constantly flow through the contact equipment and, at steady state, there are no changes of concentration with respect to time, that is, time is not a variable and flotation happens as long as the foam flows through contact equipment. The distribution of the residence time in a stationary system is impaired by the effects of a short-circuit of the dispersed phase particle and other problems (mixing quality, hydrodynamic entry into the cell, speed of withdrawal of foam, etc.). Recovery in continuous processes is not only driven by the flotation rate, but by the hydraulic retention time of the liquid phase and the difference in concentration of the dispersed phase between liquid and foam (Ni et al. 2016).

Technological advances have led to the development of methods aimed at environmental wellbeing. The chemical surfactants used as collectors in flotation processes have a high degree of toxicity and there has been a tendency to replace such compounds with products that offer the same level of chemical action, but with greater aggregated biotechnological value. Thus, studies on the development of biosurfactants have intensified, as demonstrated by the growth in the commercialisation of such products. Indeed, the biosurfactant market was US$ 210 million in 2011 and expected to increase at a rate of 3.5% per year until 2018 (Satpute et al. 2010).

4 Biosurfactants and flotation

Although the main objective is pollution control, the use of flotation as a separation process has often been questioned when used for water treatment due to the toxicity of the chemical collectors (Zouboulis et al. 2003). The development of biodegradable surfactants emerges as an excellent option that can lend greater credibility to this separation process, although the use of such agents in flotation processes has been extremely limited (Vecino et al. 2013). The majority of commercially available surfactants are produced from petroleum products. However, the growing need to develop clean technologies have led to the quest for natural surfactants as an alternative to existing products (Santos et al. 2016).

Natural surfactants, also known as biosurfactants, are amphipathic molecules produced by microorganisms and are characterised by a diversified structure, excellent tensioactive properties, low toxicity and environmental compatibility. The amphipathic characteristics of these agents enable various properties, such as detergency, emulsification, de-emulsification, lubrication, foaming capacity, solubilisation and phase dispersion (Almeida et al. 2016).

A surfactant is normally evaluated commercially based on measures of surface tension and the critical micelle concentration (CMC) (Santos et al. 2016). Surface tension is a force of attraction between the molecules of a liquid and a surfactant is able to break this force due to its dispersing characteristics, thereby reducing the tension between phases and enabling the interaction between two immiscible liquids. A greater concentration of surfactant agents in a liquid leads to a greater reduction in surface tension, as which point micelles are formed (Fig. 5), which are surfactant molecular aggregates that enable the formation of emulsions. The point at which micelles are formed is denominated CMC, which is a measure of the efficiency of a biosurfactant and can range between 1 and 2000 mg/L, whereas interfacial (oil/water) and surface tensions are around 1 and 30 mN/m, respectively (Silva et al. 2014).

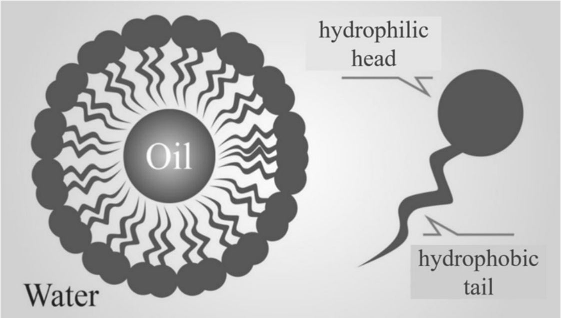

Fig. 5 Schematic of micelle formation due to attraction between surfactant molecules

The first studies on biosurfactants were conducted in the 1980s and research has since enabled the development and commercialisation of two products: Surfactin, which is a lipoprotein produced by the bacterium *Bacillus subtilis*, and rhamnolipids, which are a group of glycolipids produced by the bacterium *Pseudomonas aeruginosa* and sold by Jeneil Biosurfactants Company (USA) (Almeida et al. 2016). Although highly efficient, these biosurfactants have a high cost due to the substrates uses in the production process and the high degree of purity required for applications in the pharmaceutical and medical fields (Santos et al. 2016).

According to the literature, the typical cost of biosurfactants ranges from approximately US$ 10/mg for pure Surfactin (98% purity) used in medical research to US$ 24/kg for formulas proposed in the early 1980s for the cleaning of oil tanks and advanced oil recovery processes. Estimates in the past decades place the price of biosurfactants at US$ 3–20/kg, whereas the production costs of synthetic surfactants, such as ethoxylates and alkyl polyglycosides by the chemical industry are in the range of US$ 1–3/Kg (Santos et al. 2016).

One of the options for reducing the cost of biosurfactant production is the replacement of commonly used substrates for low-cost raw materials, such as industrial waste. Thus, vegetable oils and waste from cooking processes have been used as substrates for the production of biosurfactants (Luna et al. 2013; Rocha e Silva et al. 2014). In recent years, studies on biosurfactant production have intensified due to the attractive characteristics of these compounds, such as biodegradability, low toxicity, specificity and stability under extreme environmental conditions of temperature, pH and salinity (Marchant and Banat 2012). According to Silva et al. (2014), the lower toxicity and higher biodegradability of biological surfactants compared to their chemical counterparts is the main reason for their high acceptability. However, these features are often assumed as only direct consequence of their natural origin. For these reasons, the environmental features of novel biosurfactants should be carefully considered and investigated before their release into the environment.

The application of biosurfactants in the treatment of oily waste is one of the requirements for the occurrence of interactions between waste and microbial cells due to the reduction in surface tension between the oil and aqueous phase (Almeida et al. 2016). While the microbial toxicity of surfactants is a possible cause of bioremediation inhibition, many biosurfactants are not toxic to microorganisms at concentrations near their CMC values (Singh et al. 2007). Another possible cause of a reduced rate of bioremediation in the presence of (bio)surfactant is due to increased toxicity of the hydrophobic contaminant due to its increased (pseudo)solubility. (Bio)-surfactants increase the apparent aqueous solubility of hydrophobic substrates. In addition, some contaminants may exhibit selective toxicity toward specific pure cultures but may have a limited inhibitory impact in a remediation system (Singh et al. 2007; Sarubbo et al., 2015).

The vast structural diversity and properties of biosurfactants has led to a large amount of patent applications by interested companies. Several patents have been issued for biosurfactant production from a wide range of microorganisms. Patents filed in relation to the petroleum industry have been mainly related to uses linked to their properties including emulsification, phase separation, solubilization, foaming, de-emulsification wetting, corrosion inhibition, and viscosity reduction of heavy crude oils (Almeida et al. 2016).

Regarding the use of biosurfactants related to flotation devices, Menezes et al. (2011) demonstrated that a DAF operation using synthetic and biological surfactants tested under the same conditions achieved turbidity lower values than the limit established by Brazilian law, which is 5 NTUs (nephelometric turbidity units). Moreover, the biosurfactant produced by *Candida lipolytica* achieved better results in comparison to the chemical surfactant sodium oleate in heavy metal removal experiments. Albuquerque et al. (2012) found similar results with biosurfactants and sodium oleate for the removal of heavy metals. With these methods, the intention is to develop recycling processes for biosurfactants to become attractive replacements for synthetic collectors in the treatment of effluents with flotation, thereby reducing the environmental impact of this type of activity.

Rocha e Silva et al. (2015) analysed the influence of biotensioactive agents on the separation efficiency of the DAF system on a pilot scale. The process was effective with and without the use of the biotensioactive agents. However, the use of the biosurfactant produced by *Candida sphaerica* enhanced separation efficiency from 80.0 to 95.0%. Thus, flotation is a clean, efficient oil–water separation technology, but further studies on the collectors are needed due to the wide use of unsustainable chemical surfactants.

In studies conducted to determine the sorption kinetics of sediments using a biosurfactant produced by *Lactobacillus pentosus* and two synthetic surfactants, the biosurfactant demonstrated promising results and the nature of the molecule was the most important aspect to the achievement of satisfactory results. The synthetic surfactant SDS (sodium dodecyl sulphate) was not well adsorbed by the sediments, whereas Tween 20 and the biosurfactant were adsorbed due to their anionic and non-ionic nature, respectively (Zouboulis et al. 2003).

Some studies have addressed the use of flotation processes for the removal of metal ions from effluents. Two tensioactive agents produced by microorganisms (Surfactin-105 and Lichenysin-A) were used as collectors for the separation of metal agents from effluents. The tests demonstrated that the biosurfactants demonstrated better results than synthetic surfactants (SDS and dodecylamine) (Vecino et al. 2013).

The application of two biosurfactants from the bacteria *Bacillus* sp. and *Pseudomonas aeruginosa* and the dimensionless number of Damköhler (Da) in a DAF prototype allowed predictions of efficiency of oil removal in oily waters around 90% (Rocha e Silva et al. 2018).

Thus, biosurfactants demonstrate promising results when used in DAF processes and such molecules can be applied in diverse industrial sectors, which have become increasingly interested in clean products and processes. Innovations in this field will determine the sustainability and economic viability. Decisions related to strategic commercial development will play an important role in this respect. However, it is not always easy to implement clean technologies in established industries (Satpute et al. 2010).

5 Conclusions

Due to the requirements of environmental regulating agencies, a growing demand has been created for the treatment of oily water generated by different industrial activities. The recent pattern of expansion of the energy matrix is based on the more intensive use of renewable energy sources due to the need of processes with fewer environmental impacts and the need for the more rational use of materials that can ensure the improvement of the quality of human life. Additionally, the discovery of new petroleum fields in the world requires the use of technologies that lend support to the treatment of a broad variety of waste generated by such production processes and the treatment itself should not be a cause of secondary negative environmental impacts due to the generation of further, unnecessary waste. Oily emulsions are among the contaminants formed during the processing of crude oil. The stability of such emulsions and the inefficiency of gravitational separators make the separation process complex. DAF was described in this article as an adequate technology for the treatment of this type of effluent due to its low cost, ease of operation and efficiency, enabling compliance with environmental regulations and often permitting the reuse of the water. The use of biosurfactants was also described, which enable the expansion of innovative, sustainable practices and the possibility of using industrial waste as substrate. Thus, the development of studies involving the flotation process and the use of biodegradable collectors will offer further prospects in separation processes for oily wastewater.

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