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Research Paper

Application of Colloidal Gas Aphrons (CGAs) and their Bioprocess Separation Roles

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Abstract

Colloidal gas aphrons (CGAs) are surfactant-based microbubbles. They are described as microfoams approximately 10–100 μm diameter with special structure which is different from that of conventional foam. Although the size of aphron exceeds that of colloid, which ranges from 1 nm to 1 μm, the term colloid is used firstly because of small size of the microfoams and secondly because the bubbles show some colloidal properties. They exhibit unique properties which distinguish them from conventional foams and are as follows: large interfacial area per unit volume which is beneficial for the adsorption of molecules, high stability compared with conventional foam, similar flow properties to those of water e.g. being easily pumped from one place to another, and their easy separation from the bulk liquid phase due to buoyancy. Because of these properties they have a wide spectrum of applications and a large body of research has been published on CGAs applications in various fields. Application of CGAs in biotechnology has been gaining importance in recent years. Some studies focused on the separating role of CGA systems in bioprocesses and discussed their usage in separation processes such as protein and enzyme recovery, carotenoids recovery, removal of organic dyes from wastewaters, removal of dispersed oil droplets from water, and cell harvesting. But other sector of literature deals with CGA systems used in mass transfer promoting areas in bioprocesses which include oxygen delivery in bioreactors and bioremediation; that is separation of hazardous contaminants from soil and water. The main purpose of this article is to review the usage of CGAs in the realm of biotechnology in recent years and to open up new fields.

Keywords: Colloidal Gas Aphrons; Microfoam; Biotechnology; Mass Transfer; Separation

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Introduction

Biotechnology is a vast area of science in which biological processes, organisms, cells or cellular components are applied to develop novel technologies and research, agriculture, industry and the clinic make use of biological products. Using colloidal gas aphrons in biotechnological processes has been gaining importance in recent years. Colloidal gas aphrons (CGAs) are first introduced by Sebba as surfactant-based bubbles with structure and characteristics different from ordinary foam [1]. According to Sebba's postulation on the structure of CGAs, as shown in figure 1, they are microbubbles composed of multilayers of surfactant molecules. He proposed that CGAs consist of an inner core for gas surrounded by an aqueous surfactant thin film or shell which is

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composed of two surfactant layers (inner surface and outer surface of shell) surrounded by a third surfactant layer [1]. Jauregi et al. concluded that the soapy shell consisted of multiple layers of surfactant molecules but the exact number could not be specified. It was also noted that the shell did not have enough space for a finite inner water phase as postulated by Sebba [2].

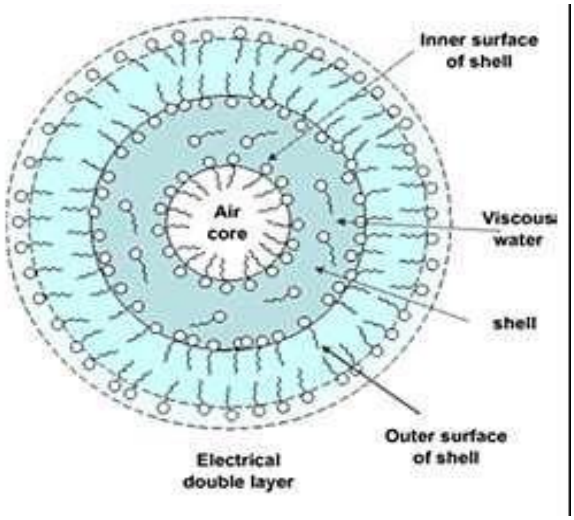

Figure 1. Structure of CGA (sebba 1987)

The existence of surfactant molecules with hydrophilic part pointing inward and hydrophobic part outward is the feature of the inner surface whereas the outer surface consists of surfactant molecules that are hydrophobic outward. Surfactant ions from bulk water are absorbed by the hydrophobic outer surface and form a diffuse electrical double layer. Two different mechanisms are responsible for removal of particles of a solution with CGAs. One is by 'bubble-entrained flotation' in which under the buoyant action of numerous small bubbles relatively large particles float up. 'Ion flotation' is the second mechanism. According to ion flotation, charged species form a complex with surfactant molecules.

Because of the special characteristics of CGAs, they have a broad spectrum of applications particularly in biological processes. The main role of CGAs is in bioseparation while mass transfer is another sector of their application in biotechnology. The objective of this paper is mainly to introduce CGA-applied bioprocesses.

Characterization of CGAs

CGAs exhibit unique properties which distinguish them from conventional foams and are as follows:

Large interfacial area per unit volume

Because of their small size (aphron diameters are typically 10–100 mm) and high gas hold-up (typically 50%), CGAs have large interfacial area per unit volume to adsorb charged and/or hydrophobic molecules and particles to the encapsulating shell. It is possible to modify the surface properties of CGA by using different types of surfactant. This way, the selectivity of adsorption can be determined by using the right type of surfactant [3].

Relatively high stability

In comparison to conventional foam CGAs exhibit relatively high stability. Once stirring is stopped it normally takes 300 seconds for half the initial volume of liquid to drain from the aphron phase (half life).

Can be pumped easily, without collapse

Flow properties of CGAs are similar to those of water, that is, they can be pumped easily, without collapse, from the location of generation to that of application [4].

Flotation column for fractionation and flotation in the removal and/or recovery of products makes use of this property.

It should be noted that CGAs are relatively stable when under flow conditions. As soon as the flow stops or is not enough to prevent CGAs separation due to buoyancy, CGAs will rise to the surface and liquid film will drain resulting in bubble collapse [4].

Easy and rapid separation

The aphron phase can separate easily from the bulk liquid phase by the buoyancy of encapsulated gas. It usually takes less than a minute for CGA to rise and this makes them a good candidate for separation processes where time is important. No centrifugation is needed to separate the two phases and this is economically important. On the other hand simply stirring should be kept on in order to avoid separation of two phases.

Production of CGAs

Sebba developed the first system for CGAs production where a surfactant solution is forced through a venturi throat along with air [4]. Later on, a more efficient method of generating CGAs by the spinning disc in a baffled beaker was developed [5,6].

A rotating disc was deposited below the surface of the surfactant solution. The disk rotation at high speeds (higher than a critical speed below which

CGAs are not produced) creates strong waves on the liquid surface. As a result of waves striking the baffles, surfactant solution reenters the liquid along with a thin film of air. The gas trapped between the liquid and the baffle, is an unstable thin film which break up into myriad minuscule droplets of gas, encapsulated by soapy shells and is termed CGAs or microbubble dispersion [1].

In addition to this classic method, sonication, homogenization, electroflotation, rotational porous plate and many other techniques have also been developed to generate microbubble dispersion which has been reviewed elsewhere [7].

Application of CGAs in biotechnology

CGAs as separating agent

The main procedure for separation of the desired product by CGAs includes generation of CGAs, addition of CGAs to the broth, agitation of CGAs and solution. As soon as mixing stops, the aphron and liquid phases separate. And the aphron phase contains the desired particle or product. Jauregi and Varley suggested that electrostatic interactions have a significant part in the adsorption of protein to CGAs, although hydrophobic interactions could also take place, especially at high ionic strengths [8].

Owing to CGAs small size, large interfacial surface area and high fluidity, they are perfect candidate for enhancing flotation-based separation processes. They have been used in protein recovery [8], fine suspension removal, removal of fine metals [9,10], removal of dyes from waste water, separation of fine particles [11-13], oil removal [19] and organic dyes from water streams [14], recovery of astaxanthin [15] and recovery of yeast cells [16]. Common methods for the recovery of cells are centrifugation and filteration. Flotation technique is a way to increase speed and efficiency of cell recovery. And it requires less power than centrifugation and filteration do [17] And applying CGAs as a flotation technique has advantages over conventional flotation such as more efficiency due to large interfacial area, shorter operating time and higher yields resulting from minimized redistribution of what is to be removed into the initial solution [18].

CGAs as mass transferring agent

Two parts of biotechnology in which CGAs can be applied as mass transferring agent include oxygen delivery in bioreactors and bioremediation. Due to their small sizes CGAs offer a larger interfacial area than conventional air bubbles [18]. Kaster et al., found that the mass transfer rate of oxygen in fermenters was enhanced when sparged with microbubble dispersions. According to them the main benefit of using microbubbles was the enhanced mass transfer at very low agitation rates as a result of the increased interfacial surface area offered by the microbubbles. Plus the decreased bubble size improved the gas hold-up in the reactor due to slower bubble-rise velocities [20].

Another aspect of CGAs being as mass transferring agent is their wide usage in bioremediation, which is utilization of microorganisms to remove contaminants from soil. The aerobic biodegradation of pollutants inside the matrix can make benefit of the ability of microbubbles to deliver oxygen, microorganisms and micronutrients to a target site. Oxygen delivery by microbubbles in the subsurface can facilitate aerobic biodegradation of organic compounds. The aerobic biodegradation of phenol, p-xylene and pentachlorophenol as well as microorganism transport in a soil column were the subject to several studies [21,22].

Concluding remarks

CGAs are spherical microbubbles with some colloidal properties. They can be pumped through pipes and from one place to another and owing to their small size and thick surfactant shells in their structure they are more stable than conventional foams.

Because of the special characteristics of CGAs such as large interfacial area per unit volume, relatively high stability and easy and rapid separation, they have a broad spectrum of applications particularly in biological processes. The main role of CGAs is in bioseparation while mass transfer is another sector of their application in biotechnology. Using CGA suspensions are advantageous as they can be applied comparatively easily and at low cost. Moreover, applying CGAs made from non-toxic organic and natural surfactants guarantee the eco-friendliness of the process.

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