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The Important Scope, Objectives and Applications of Bioconvection Phenomenon

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1. Applications

Bioconvection is a relatively new area of fluid mechanics and has been observed in several bacterial species, including aerobic, anaerobic, magnetotactic organisms as well as in algal protozoan cultures. The phenomenon has a very wide applications because world's major portion consists of bio-mass.

Bioconvection is of intrinsic interest because it is based on dynamic synergism between physics and biology:

(1) Individual swimming micro-organisms convert energy available at low concentration into growth, division, and power for motion.

(2) The organisms possess and use sensory apparatus for guidance toward improving or more appropriate environments.

(3) Individual organisms interact with the local and remote physical world through viscosity and gravity.

(4) The suspension, of organisms and water, is subject to fluid dynamics and constraints at the boundaries.

(5) The dynamics of motion and concentration of the suspension are driven by the anisotropy generated by the behavior that depends in part on these dynamics.

(6) The behavior of the microorganisms is not deterministic, but can be modeled by probability density functions.

Bioconvection has been observed in several bacterial species, including aerobic, anaerobic, and magneto tactic organisms, as well as in algal and protozoan cultures (Kessler and Hill (1997). All have in common the sudden appearance of a pattern when viewed from above that requires cell swimming to be sustained.

The recent researchers carried out with regard to environmental sciences have revealed the interesting fact that, the microorganism like yeast and fungus are responsible for the formation of clouds (sci.art 2012). In fact it is really amazing that, in one cubic meter of the atmosphere there exists 10 millions of microorganisms and in one liter of air we breath ,there exists one lakh micro organisms. One should not conclude that, all the bacteria/ microorganisms are responsible for the spreading of serious diseases. Actually, we should appreciate the role played by these microorganisms. In their short span odf life they work day and night to get their food and increase their population, which in turn is responsible for the existence of many wonderful hidden secrets in nature. In recent years scientists and researchers are showing enormous interest in the study of micro organisms. 'University of Oragon ' a prestigious university in America is having a centre for bio-sciences called 'Biology and the Built Environment'.

In most natural aquatic ecosystems, microorganisms are advected more or less passively in the large-scale flows generated by various imbalances of the environment. In a quiescent fluid, however, even their slow motion (typically a couple of meters per day) and physical interactions can result in considerable spatial rearrangements, and influence the dynamics of the system (Mendelson, 1999). Bioconvection is one of the oldest documented collective behaviors of independent microorganisms (Wager, 1911; Loeffer and Mefferd, 1952; Platt, 1961; Plesset and Winet, 1974), arising spontaneously in suspensions of diverse swimming microorganisms such as bacteria, algae or ciliated protozoa (Kessler, 1985; Pedley and Kessler, 1992; Kessler and Wojciechowski, 1997).

Typically, bioconvective pattern formation occurs in shallow suspensions at high cell concentration if the density of cells is 5–15% larger than that of water and the average direction of the microorganisms' swimming is upward in response to some external stimulus, e.g. gravity, light or oxygen-concentration gradient. For instance, in non aerated suspensions of *B. subtilis* (aerob, soil-living bacteria) upward swimming is a chemotactic behaviour directed by the oxygen gradient (Taylor *et al* 1999).

The continuous upward swimming results in a density inversion, i.e. the surface layer of the suspension becomes denser than the bulk. This configuration is mechanically unstable, and through a Rayleigh-Taylor instability (Plesset and Winet, 1974) the top layer sinks in vertical plumes. As the velocity of the emerging fluid motion is larger than the swimming speed of the microorganisms, they are dragged along from the surface into the bulk of the liquid.

Aquatic micro-organisms form a large fraction of the earth's biomass and are of fundamental importance at the bottom of the food chain, both as nourishment for higher links in the chain and, sometimes, as a source of toxicity. Some species are also exploited technologically, for example in bioreactors. Many species are motile, and the swimming behavior of the cells inevitably has an influence on their interaction with each other and with other species.

The understanding of such behavior and interactions in enough detail to make a useful quantitative prediction of future population levels, in a natural or a man-made environment, requires the use of **mathematical models**, such as large-scale simulations designed to describe plankton ecology (e.g. Fasham et al., (1990)) or very idealised models, designed to highlight particular mechanisms (e.g. Truscott and Brindley, 1995; Matthews and Brindley (1997)).

Bioconvection is a fascinating phenomenon of fluid mechanics that is driven by the swimming motion of micro-organisms. Typically the velocity and spatial scale of the fluid motions are much larger than those associated with the swimming speed and size of an individual cell, resulting in rapid transport of cells and the formation of complex spatial patterns in cell concentration. Motile microalgae are ubiquitous in aquatic systems, and the understandingof how they are spatially distributed at a wide range of length and time scales is an important ecological task.

In the natural environment, bioconvection is a little studied but potentially important mechanism influencing the vertical distribution, and therefore the growth and productivity, of motile micro algae at centimeter to meter scales. However, in order to make predictions about when and where bioconvection might occur, we need to understand how other physical factors, such as salinity stratification, will affect swimming behavior, fluid flow, and the resultant spatial distribution of cells.

Aquatic micro-organisms, many of which are active swimmers, play a vital role in life on earth. Phytoplankton (algae, diatoms, etc: length scale 10- 100¹m, are the bottom link of the food chain in oceans and lakes, absorbing energy from sunlight and elementary nutrients from the water. They contain and are surrounded by even smaller bacteria (2- 10¹m) which break down metabolites and detritus into those elementary nutrients and no doubt have many other effects which have not been described. The phytoplankton are themselves the prey for some- what larger micro-organisms (zooplankton such as ciliates and heterotrophic agellates)which in turn are eaten by larger zooplankton. The phytoplankton absorb co_2 from the water, most of which comes from the atmosphere via complex mixing processes, and thus they play an important role in the global carbon cycle and hence in phenomena such as global warming.

Bioconvection in porous media may be an important phenomenon in many applications. Kessler [1986] suggested the utilization of upswimming of algal cells to concentrate the cells, to purify cultures and to separate vigorously swimming subpopulations. Utilizing upswimming, it is also possible to separate dead and live cells. For these applications, bioconvection is undesirable, because it would prevent upswimming cells from concentrating near the surface of the culture. In experiments carried out by Kessler [1986], a porous medium (a surgical cotton wool) was utilized to suppress bioconvection. According to Kessler [1986], **the porous medium must satisfy two requirements; it must be sufficiently permeable** to allow cells to swim through it but also **sufficiently tight to damp** out bioconvection. For practical purpose it is desirable to have the permeability of the porous medium as high as possible (otherwise the microorganisms may cut their tails off while swimming through the porous medium). Also, having the permeability as high as possible maximizes the flux of the cells in the upward direction and reduces the duration of the process.

One class of phenomena for which mathematical modeling is well advanced is spontaneous pattern formation, which has been observed in laboratory suspensions of swimming microorganisms from a variety of phyla, including algae (Wager, 1911; Kessler, 1985; Bees and Hill, 1997), protozoa (Platt, 1961; Childress et al., 1975) and bacteria (Kessler et al., 1994). The mechanism of pattern formation is a convective one, driven by the up-swimming of cells that are denser than the medium in which they swim, and is called bioconvection (Platt, 1961), the mathematical modeling of which has been discussed by Pedley and Kessler (1992a,b). An essential ingredient of such mathematical models is a quantitative description of the random swimming behavior of the cells. For algal cells such as the biflagellate Chlamydomonas nivalis, the mechanism for up-swimming in a still fluid is thought to be that the cells are bottom-heavy (Kessler, 1985). The consequence in a moving fluid is that the average orientation of the cells, and hence their swimming direction, is governed by a balance between the gravitational torque and a viscous torque proportional to the vorticity in the ambient flow (called gyrotaxis: Kessler, 1985).

2. Scope and objectives

As discussed earlier, Bioconvection is a fascinating phenomenon of fluid mechanics that is driven by the swimming motion of microorganisms which are denser than the fluid in which they are suspended. In the natural environment, bioconvection is a little studied but potentially an important mechanism influencing the vertical distribution and therefore the growth and productivity of motile microalgae at centimeter to meter scales. In order to make predictions about when and where Bioconvection might occur, it is absolutely necessary to understand the influence of the physical factors, such as salinity stratification on the swimming behavior, fluid flow and the resultant spatial distribution of cells. The investigation is carried out with regard to the following objectives:

(i) Although bioconvection is a fascinating and a beautiful phenomenon to observe, in many practical situations it must be controlled or suppressed. For example, the concentration of the cells, purification of cultures, separation of different subpopulation or separation of living and dead cells etc., can be adjudged by making use of the property of motile organisms to swim in a particular direction. Certainly, in these applications, bioconvection would prevent successful separation because of the fact that, it would cause mixing between different types of cells. In such cases porous media can be used to control bioconvection. *Kessler (1986)* suggested and experimentally proved that a porous medium (a surgical cotton) can be utilized to suppress bioconvection in order to separate or eliminate fungus from Dunalliella cultures and to concentrate vigorous cells of chlamydomonas nivalis and Chlamydomonas rosae. These examples demonstrate the importance of investigating bioconvection in porous media and understanding the effect of permeability number on the phenomenon.

(ii) The determination of how the rates of cell deposition and declogging affect the critical value.

(iii) The interaction of bioconvection and natural convection under different types of constraints.

(iv) In general, 2D – systems are more amenable to experiments and simulations with regard to thermoconvection, when compared to 3D-systems. This is because, of the significant reduction in dimensions reduces the amount of data required to specify the flow. Accordingly, experiments can determine 2D – scalar fields in a straightforward manner and 2D – calculations also can be performed at Rayleigh numbers much higher than those in 3D – systems.

(v) Furthermore, there does not exist much quantitative analysis of experiments for testing any theoretical developments that take place.

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