

Algae harvesting and extraction using structured cavitating jets (DYNAJETS[®])

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Microalgae have great potential for sustainable production of fuels, chemicals, feed stocks, and pharmaceuticals. However, significant technical hurdles still exist in the harvesting of algae from dilute solutions and in the extraction and recovery of valuable bioproducts. Currently available technologies such as microfiltration, centrifugation, drying, milling, or ultrasonic cavitation are energy intensive and uneconomical. Controlled hydrodynamic cavitation can be used to generate micro-bubbles (<50 μm) for bubble flotation to harvest and dewater algae, or to lyse cell walls of algae in dilute solution with lower energy inputs.

Hydrodynamic cavitation occurs when large fluctuating pressures in a submerged jet shear layer causes preexisting microscopic bubble nuclei in the liquid to grow and collapse explosively (cavitation). DYNAFLOW is developing the DYNAJETS[®], specially designed nozzles to generate intense cavitation at relatively low pressures to address two aspects of algae production: harvesting using micro-bubble flotation, and lysis of algae and recovery of the bioproducts from the dilute growth solution.

Cavitation in the presence of dissolved gas results in the production of clouds of very small bubbles with lower energy inputs than other processes. These bubbles are equivalent in size to those of algal cells and can attach to them. The resulting bubble-algae cell complexes are buoyant and will rise through the water column and collect at the free surface.

Conversely, when less gas is present the cavitation intensity increases and the lysis of algae cells in dilute growth solutions occur. Operating in this manner, the DYNAJETS[®] have also been used to recover lipids, terpenes, and carotenoids from several species of microalgae including *Nannochloropsis*, *Tetraselmis*, *Isochrysis*, and *Chlorella* in the growth media without the need for prior concentration or drying of biomass. Hydrodynamic cavitation can be scaled up easier than ultrasonic cavitation making it more amenable to industrial scale processes.

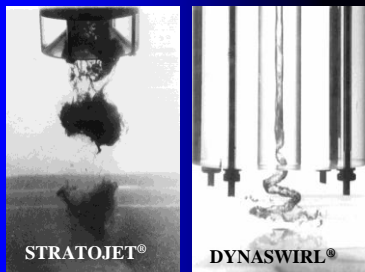


ALGAE HARVESTING AND EXTRACTION USING STRUCTURED CAVITATING JETS (DYNAJETS®)

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Applications

- **Extraction:** Cavitation lyses algae in growth media and the bio-products are recovered via foam fractionation
- **Harvesting of Algae:** Cavitating jet bubble generators produce clouds of microbubbles for air flotation and harvesting of algae



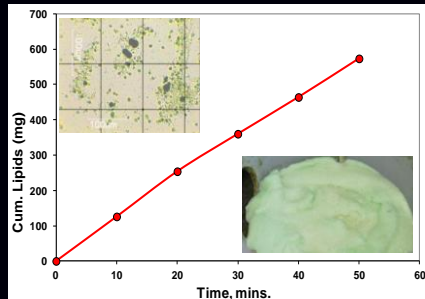
Specially designed nozzles generate intense cavitation at lower pressures using passive acoustic excitation or swirling flow.

Cavitation

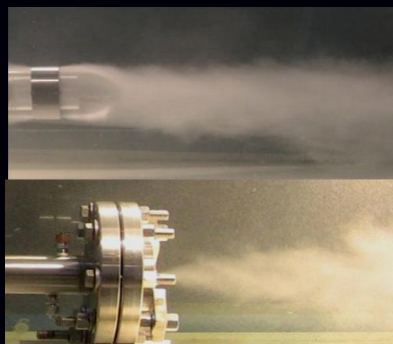
- Strong controlled pressure fluctuations cause bubble nuclei to expand & collapse
- Bubble dynamics generate high local pressures, shear, and temperatures
- High cavitation intensity will lyse algae cells and other microorganisms and release oil
- Cavitation in bubble generators enable release of large volumes of very small microbubbles and help lift oil to the surface for extraction

Algae Extraction

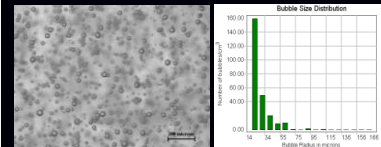
- Wet extraction method >90% water
- Cavitation lyses algae cell membranes and releases oil
- 1-unit process
- No pre-concentration or drying
- Low energy liquid-liquid extraction or foam fractionation can be used
- Scalable specialized nozzles
- based on patented DYNAJETS® technology
- Water recycled



Recovery of lipids from 0.18% algae solution



DYNAJETS® Micro-bubble generators produce clouds of bubbles < 50 µm diameter



Micro-bubbles produced by DYNAJETS® cavitation

Harvesting by Bubble Flotation

- Microbubbles attach to algae and lift them to surface for harvesting
- Microbubbles of the same size as the algae cells can be produced using cavitation .
- Bubble < 50 µm diameter at tens of psi pumping pressure.



Algae floated using DYNAJETS® micro-bubble generator

Conclusions

- Cavitation can be applied to algae processing for different tasks
- Cells can be lysed directly in growth media
- Bubbles can be generated by cavitation to harvest intact cells
- Energy savings
- Process simplicity