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**An assessment of inexpensive methods for recovery of
microalgal biomass and oils**

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Tawan Chatsungnoen

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ABSTRACT

Inexpensive processes for harvesting the microalgal biomass from the culture media and recovering oils from the harvested biomass are necessary for economically viable production of low-value products such as fuels. This study focused on harvesting of microalgae biomass from the culture broth by flocculation–sedimentation and recovery of oils from the harvested biomass using solvent-based extraction. Flocculation–sedimentation was explored for several marine and freshwater microalgae including *Choricystis minor* (freshwater), *Neochloris* sp. (freshwater), *Chlorella vulgaris* grown in freshwater; *C. vulgaris* grown in seawater; *Nannochloropsis salina* (seawater) and *Cylindrotheca fusiformis* (seawater), as a means for substantially concentrating the biomass prior to further dewatering by other methods. Aluminum sulfate and ferric chloride were investigated as cheap, highly effective, readily available in large quantities and innocuous flocculants. Flocculation–sedimentation behavior of the microalgae was evaluated with several flocculation conditions. The optimal microalgal biomass harvesting conditions identified in batch flocculation studies were applied to design and characterize a continuous flocculation–sedimentation system. The effect of the flocculant used and the water in the biomass paste on the extraction of oils were assessed in comparison with controls. The optimal solvent composition for extraction of the biomass paste was established. Using this solvent composition, the optimal extraction conditions (i.e. the volume of the solvent mixture relative to biomass, the extraction temperature and time) were identified using a 2³ factorial experimental design.

Removal of more than 95% of the biomass from the broth by flocculation–sedimentation was shown to be possible for all the microalgae, but the required dosage of the flocculant depended on the following factors: the microalgal species; the ionic strength of the

suspending fluid; the initial concentration of the biomass in the suspension; and the nature of the flocculant. Irrespective of the algal species, the flocculant dosage was found to increase linearly with increasing concentration of the biomass in the culture broth. The flocculant dosage for a given level of biomass recovery under standardized processing conditions increased with an increase in the cell specific surface area in the range of 26–450 $\mu\text{m}^2 \text{ cell}^{-1}$. Al^{3+} was a better flocculant than Fe^{3+} for some algae, but the situation was reversed for some others. The continuous flow biomass recovery was performed with *N. salina*, as this alga had the highest oil productivity among the species studied. With an aluminum sulfate dosage of 229 mg L^{-1} and a total flow rate of 22.6 mL min^{-1} , almost 86% of the *N. salina* biomass could be recovered from the broth within 148 min in the sedimentation tank. A prior flocculation–sedimentation treatment could greatly reduce the energy demand of subsequent dewatering by other methods. The flocculants adsorbed to the biomass were not removed by washing, but this did not hinder oil recovery from the biomass paste by solvent extraction. A modification of well-known Bligh and Dyer method could be used to recover more than 96% of the oils from *N. salina* biomass paste. The single-step modified extraction procedure was much superior to the Bligh and Dyer original. The optimal extraction conditions for *N. salina* biomass paste included a solvent mixture (chloroform, methanol and water in the volume ratio of 5.7:3:1) volume of 33 mL per g (dry basis) of the algae biomass; an extraction temperature of 25°C; and an extraction time of 2 h.

This work represents the first detailed study of the continuous flocculation–sedimentation process for harvesting *N. salina* biomass from the culture broth and the specific suitable solvent combination of chloroform, methanol and water for extracting algal crude oils from the *N. salina* biomass paste without a prior drying step.

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