Abstract

The process of photosynthesis is of great importance as it is the reaction of carbon dioxide (CO_2) and water with the help of light, 'free' energy from the sun, to form useful carbohydrates and oxygen. Photosynthesis is therefore useful both in carbon dioxide mitigation and growing bio-feedstocks towards making biofuel.

This thesis aims to address two areas for analysing the photosynthesis process:

1. Looking at the physical limits of the growth; and

2. Improving the production rate of some aquatic plants, such as duckweed and microalgae.

To address the first aim, the fundamental concepts of thermodynamics were used to analyse the photosynthetic process. It was found that the theoretical minimum number of moles of photons (NP) required (9–17) is less than the values reported by other researchers, suggesting that the photosynthesis process is highly irreversible and inefficient (operating at 35% efficiency or less). This is because the number of moles of photons will increase with greater process irreversibility (when the entropy generated is greater than zero). If the photosynthesis process is indeed that irreversible then the removal of heat (the heat not used by other cellular processes) by the plant becomes a major problem. It is suggested that transpiration, and other cellular processes, are the processes by which that is done, and it is shown that the water needs of the plant for transpiration would dwarf those needed for photosynthesis. Knowing the fundamental limits to growth could also be of use because if an organism was growing at a rate close to this value there would be no advantage to try to do genetic modification to improve its rate.

Following the ideas presented above a spectrophotometer was used not only to obtain the absorption spectrum of algae, but it was also used to grow small samples at specific light wavelengths. The algae species researched was *Desmodesmus* spp., which, for example, is used to remediate waste water or as a

source of feedstock for biofuel production. It also tolerates high CO_2 concentrations. This simple experimental method demonstrated that a specific light wavelength (in particular the Secomam Prim spectrophotometer) 440 nm was preferred for the algae growth. It was recommended that this specific light wavelength would be best for growth. It might also be useful to know this fact particularly when designing photobioreactors, as this could reduce the amount of heat released into the surroundings and thus make the process more energy efficient. Interestingly, the wavelength for maximum growth corresponded to one of the peaks in the absorption spectra but there was no increase in growth rate corresponding to any of the other peaks.

To address the second aim, the author determined how well predictions on improving the growth of algae (*Desmodesmus* spp. for example), based on a theoretical model, would work when tested experimentally. What the researcher found was that the method improved algae production, using the same set of equipment. The production was improved by a factor of 1.28 and 1.26 (at product concentrations 1000 mg/L and 600 mg/L respectively) when retaining 40% of the algae suspension. The method may be particularly useful when large amounts of biomass are required as there is no extra cost of purchasing additional equipment. The same model was applied to a growth profile of duckweed (*Spirodela polyrhiza* 8483, which is convertible into biofuel or a source of food), and the author showed that the model could work if the duckweed was provided with an added carbon source. In order to find an economical and reliable alternative to bridge the scale gap between laboratory and industrial production, the author checked if duckweed species (*Spirodela polyrhiza* 8483, *Spirodela polyrhiza* 9509, *Lemna gibba* 8428, *Lemna minor* DWC 112, *Wolffia cylindracea* 7340 and *Wolffia globosa* 9527) could be cultivated in media less expensive than the basal laboratory medium (Schenk and Hildebrandt). The author found that duckweed can be cultivated more efficiently, and in a more cost-effective manner, in the alternative media types, while maintaining growth rates, RGR $\approx$ 0.09 day^{-1}, and starch contents, 5–17%(w/w), comparable with that obtained with the conventional laboratory media.

Thus, by looking at the photosynthesis process thermodynamically and experimentally, it is shown to be possible to improve the process by using concepts presented in this thesis.