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Low-cost harvesting of microalgae biomass from water

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Abstract

Microalgae harvesting is known to be a major problem in the water industry. This is attributed to the minute nature of the algae cells and the often low concentration of the species in water and wastewater. While various chemical and mechanical harvesting techniques have been developed for algae harvesting, their application have been limited by prohibitive costs. There is also the disadvantage of not utilising the harvested microalgae as feedstock when it has accumulated significant amounts of chemicals (coagulants) employed during the harvesting operation. This work investigates the low cost harvesting of microalgae biomass from water using physical (non-chemical) method. Four fabric filters: stretch-cotton, polyester-linen, satin-polyester and silk were investigated to determine their microalgae harvesting efficiencies using filtration method on three algae communities with cell size of 2- 20 µm. For the three algae communities investigated, stretch-cotton filter showed a harvesting efficiency of 66- 93%, followed by polyester-linen (54- 90%), while satin-polyester and silk fabrics achieved harvesting efficiencies of 43- 71% and 27- 75% respectively. The research revealed that for wastewater generation of 1500m^3/day and algae concentration of 200mg/l, microalgae harvesting cost per sq. meter per kg of algae per cubic meter would be ≤ £0.15 using stretch cotton filter.

Keywords: Microalgae, Fabric filter, Stretch-cotton, Physical harvesting, harvesting efficiency, Wastewater treatment

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1. Introduction

"Microalgae are prokaryotic or eukaryotic photosynthetic microorganisms that can grow rapidly and live in harsh conditions due to their unicellular or simple multicellular structure" (Shalaby, 2011, p. 111). Algae are basically "a large and diverse group of simple, typically autotrophic organisms, ranging from unicellular to multi-cellular forms. These have the potential to produce considerably greater amounts of biomass and lipids per hectare than any kind of terrestrial biomass" (Singh and Gu, 2010, p. 2597). Green algae can have high lipid contents, as well, generally over 50%, which can be an excellent source for biodiesel production and is ideal for intensive agriculture (Dermibas and Dermibas, 2011). However,microalgae assimilate high quantities of nitrogen and phosphorus during their growth due to the high protein concentration in the cells (45-60% dry weight) (Demirbas and Demirbas 2010). Algae present considerable problems for river quality managers and water suppliers and methods to predict their behaviour, growth and transport can assist in operational management (whitehead et al., 1997). Algae are reported to impart colour and odour to water (Faust and Aly, 1983). Microalgae by their small size (5-50μm), their negatively charged surfaces and in some cases their mobility, form stable suspensions and hereby difficulties in their separation and recovery (Tenny et. al, 1969).

"Based on current knowledge and technology projections, third generation biofuels specifically derived from microalgae are considered to be a technically viable alternative energy resource that is devoid of the major drawbacks associated with first and second generation biofuels" (Brennan and Owende, 2010, p. 557). The use of staple crops as alternative energy resources placed a significant strain on the availability of food for human and animal needs. That also impacted on the availability of land for food production, making the exercise a non-profit venture with the current global warming being experience on earth and the need to source for alternative and renewable energy sources. This coupled with the statement that the world population may grow from 6.5 billion to 9 billion people (Koning et al.¸ 2008), microalgae biofuel remains undeniable alternative solution. It is reported that fossil-fuel-fired plants account for about one-third of the emissions caused by human activities (Demirbas, 2010), and this trend will remain well into this century if more energy efficient plants are not found. The effect of desertification has also exacerbated the problems caused by in-balance in the amount of carbon dioxide generation and utilization. The use of microalgae to sequestrate the quantity of carbon in the atmosphere may be feasible.

However, separating algae from water has always been faced with several difficulties. As the density of microalgae is close to that of water, flocculation can lead to the formation of flocs with low densities (especially when the concentration of the flocculant is low) (Uduman et al., 2010). Harvesting of microalgae in a cost-effective way is major issue of the different processes, such as wastewater treatment and algal-mass production by industries. Methods that have been used to harvest or concentrate algae often lead to significant expenses mostly due to the volume of chemical flocculants required if meaningful success is needed. Whether in water or wastewater treatment, harvesting efficiency and cost is a critical problem in algal control. Sheehan et al. (1998) stated that "not only did the algal biomass represent a potential resource for the production of biogas, but the algal solids discharged from the ponds were pollutants that resulted in eutrophication and dissolved O2reduction in the receiving bodies of waters". It is therefore necessary that a clear understanding and assessment of various harvesting techniques be made in order to enhance the potential for algae resources in biofuel production. Development of a low-cost harvesting technique is therefore vital if the algae needs for biofuel and enhance water quality standard are to be realised. This can enhance cost minimisation to a large extent.

This research focuses mainly on low-cost harvesting of microalgae biomass from water. To this end the specific objectives are:

1. To determine the concentration of algae in the water sample.
2. Evaluate the efficiency of algae filtration using various fabrics filters by comparing the total suspended solids (TSS) of the raw algae-water and filtrate.

2. Experimental methodology and set up

Cell densities of three algae communities: Larchfield algae community Middlesbrough, cultured using Bolds Basal Medium (BB) for freshwater algae; Marine Science School Community, Newcastle University; and Civil Engineering and Geosciences laboratory, Newcastle Univesity were determined. Measurement of algae growth was done using the Larchfield algae sample to determine the Cell densty-Absorbance regression curve. Microscopy test was done to determine the pore sizes of four fabric materials of interest: Stretch-cotton, Polyester, Satin-polyester, and Silk fabrics. Filtration experiment was performed for each of the fabric type using the various algae community samples followed by determination of total suspended solids (TSS) and microscopy test to determine the cell densities and size distribution of the filtrates. Turbidity and Optical Density (OD in the form of Absorbance) measurements for the raw and filtrates were also taken. Harvesting efficiencies were determined by a comparison of raw and filtrate quality and time of filtration (Figure 1). A further comparison was made between fabric filtration and other conventional filtration techniques.

Proposed design of stretch-cotton fabric filter for microalgae harvesting from a waste stabilization pond and the cost estimate were made based on the amount of algae (in kg) harvested per kilogram of influent wastewater per unit area of filter material.

Microscopy test was used for micro algae quantification. However, special attention was given to sampling and dilution of the medium. The microalgae cells were viewed using a compound microscope at the Medical Bio-imaging laboratory of Newcastle University. The pictures of the cells, at a suitable scale, were taken according to desired scales following the procedure in APHA, 2005.

3. Results and discussions

3.1. Algae growth and constant biomass concentration

Figure 2 below shows the result for algae growth measured as the TSS (mg/l) and the corresponding Absorbance (as OD) of the medium. The result indicates that algae growth is highly correlated with

Absorbance (R^2 = 0.998) implying that quantitative estimate of one parameter could be reasonably made from the other. The regression equation enabled a constant algae biomass concentration of 0.2g/l to be maintained for all experiments by applying appropriate dilution factors to the raw sample.

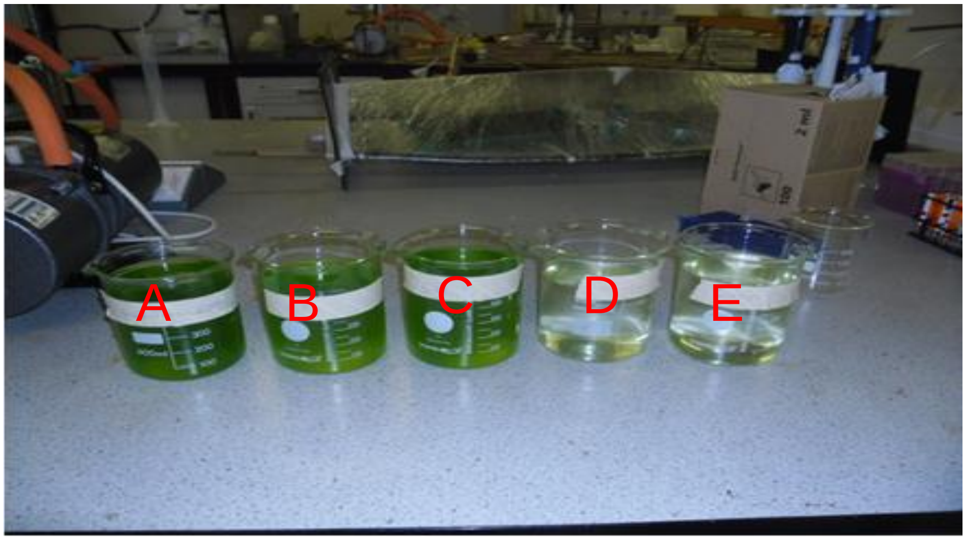

Figure 1. Comparison of raw (A) and filtrate quality for Satin-polyester (B), Silk (C), Polyester-linen (D) and Cotton (E).

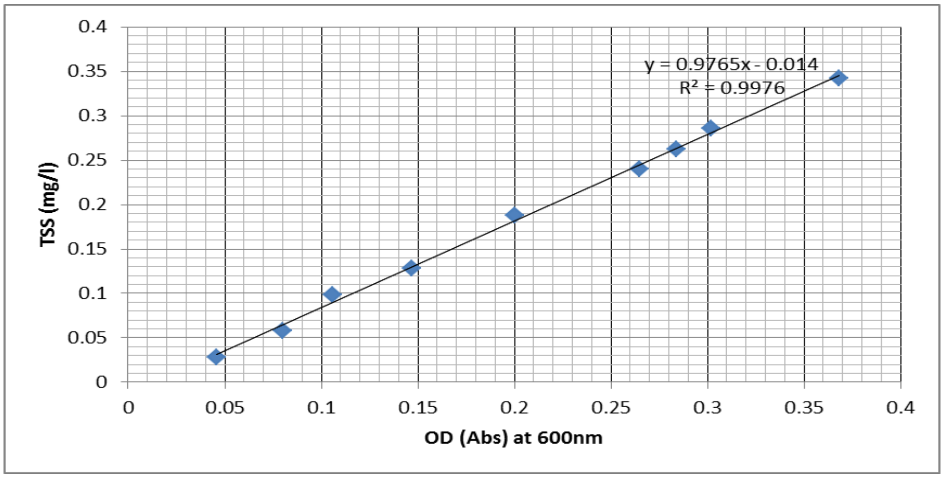

Figure 2. Result of total suspended solids against absorbance for a 9-day growth period.

4. Algae harvesting efficiencies for different fabric filters

4.1. Algae size and fabric harvesting efficiencies

Figure 3 shows the average performances of all fabrics on the three algae communities tested. The result shows that Stretch-cotton fabric demonstrated the highest algae harvesting efficiency (~94% ± 2) for both Larchfield and CEG communities followed by Polyester-linen fabric (84–90%±3).

These results indicate that for the range of algae species commonly found in water and wastewater effluents, the Stretch-cotton filter could be effectively used as a harvesting tool, while the Polyester-linen could best be used for pre-treatment purposes where reduction in algae biomass concentration is needed before further algae harvesting/ removal by downstream treatment.

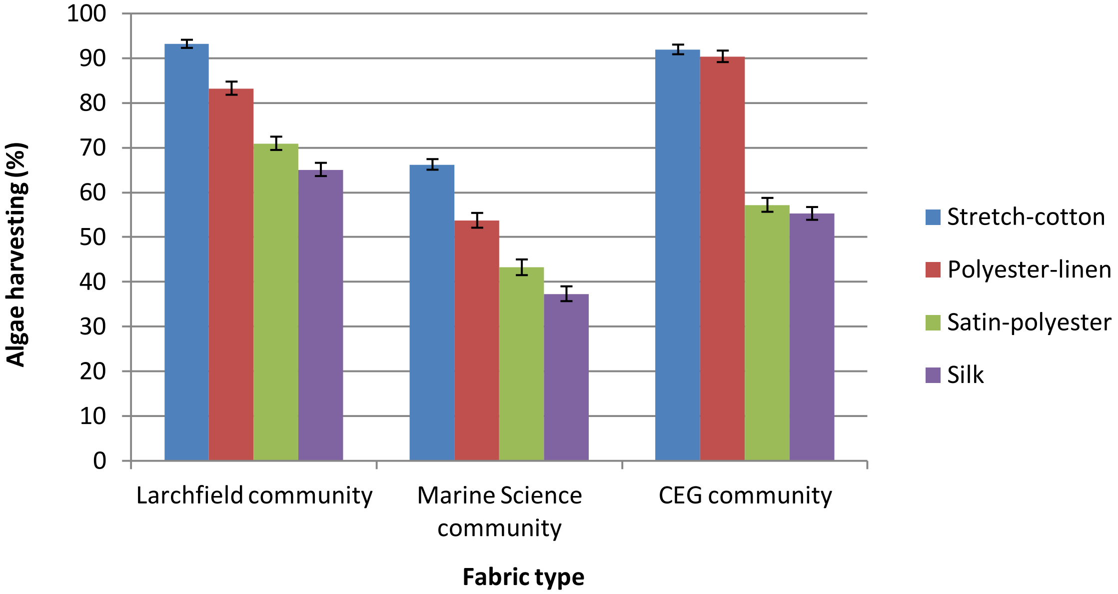

Figure 3. Average harvesting efficiencies of fabric filters tested on three algae communities.

There was a general decline in harvesting efficiency for Marine Science community apparently due to a large proportion of the algae having a size of ≤ 10 µm.

Figure 4 shows that for all the fabric materials tested, much of the algae composition in the filtrate are those with cell size of 1–5 µm.

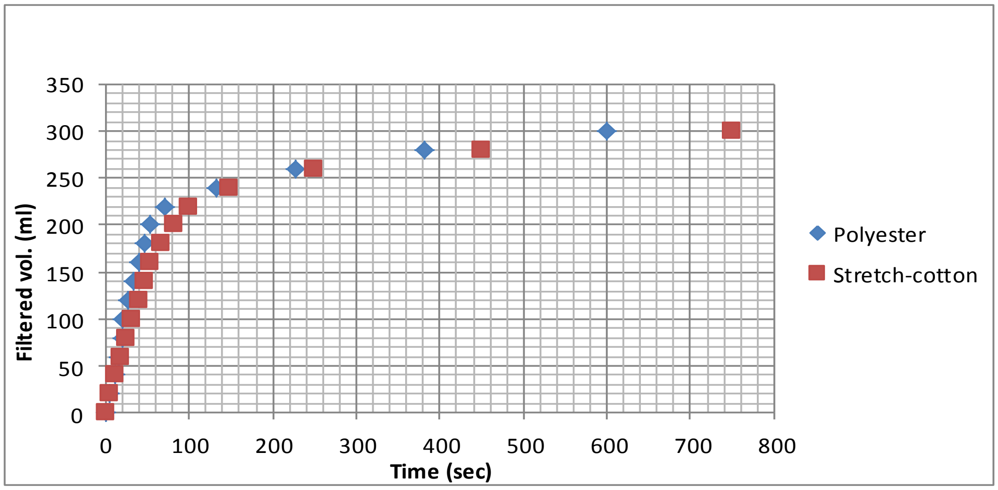

Figure 4. Filtration kinetics for algae samples using polyester and stretch-cotton fabrics

Table 1. Summary of mean performance of all experimented fabric types in algae harvesting

Filter type	Mean filter size (µm)	Algae identity, size and percentage removal			Avg. filtration capacity at 50% headloss
		Larchfield (2- 25 µm)	Marine sci. (2- 17 µm)	CEG (2- 15 µm)	($m^3/m^2/sec$)
Stretch-cotton	7.5	93 (0.81)	66 (0.46)	92 (0.59)	0.00042
Polyester-linen	58.5	83 (0.79)	54 (0.81)	90 (0.63)	0.001
Satin-polyester	64	71 (0.66)	43 (1.03)	57 (0.40)	0.00425

Values in bracket indicate standard errors

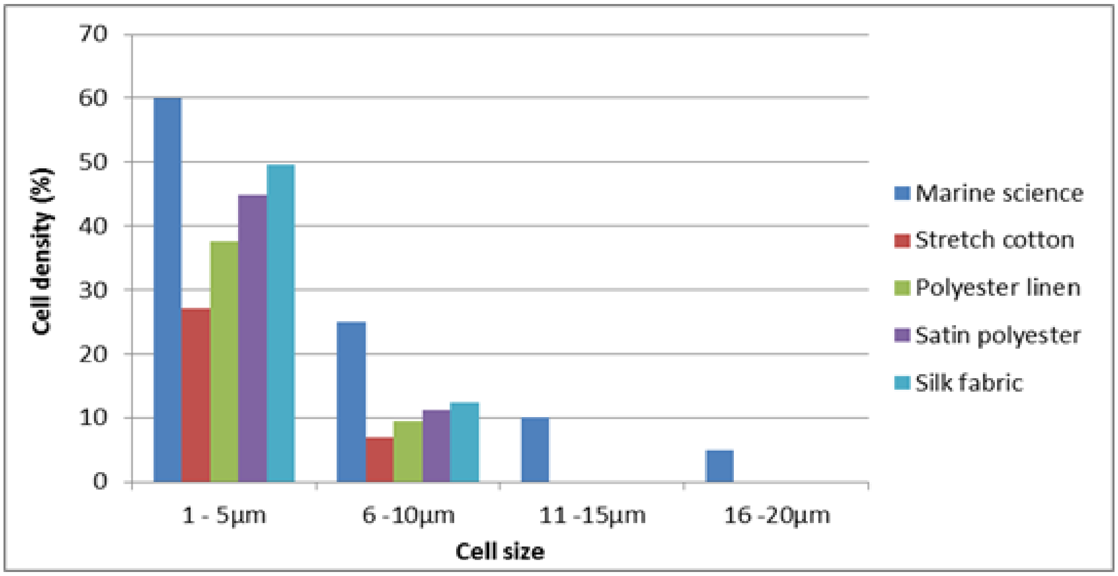

Figure 4. Cell size distribution of filtrate from Marine Science community.

5. T-test analysis of mean

Table 2. T-Test mean analysis of stretch-cotton and polyester-linen fabrics for Larchfield community algae sample.

t-Test: Two-Sample Assuming Unequal Variances		
	Stretch cotton fabric	Polyester linen Fabric
Mean	92.875	83.57143
Variance	6.410714	5.285714
Observations	8	7
Hypothesized Mean Difference	0	
df	13	
t Stat	7.457329	
P(T<=t) one-tail	2.39E-06	
t Critical one-tail	1.770933	
P(T<=t) two-tail	4.78E-06	
t Critical two-tail	2.160369	

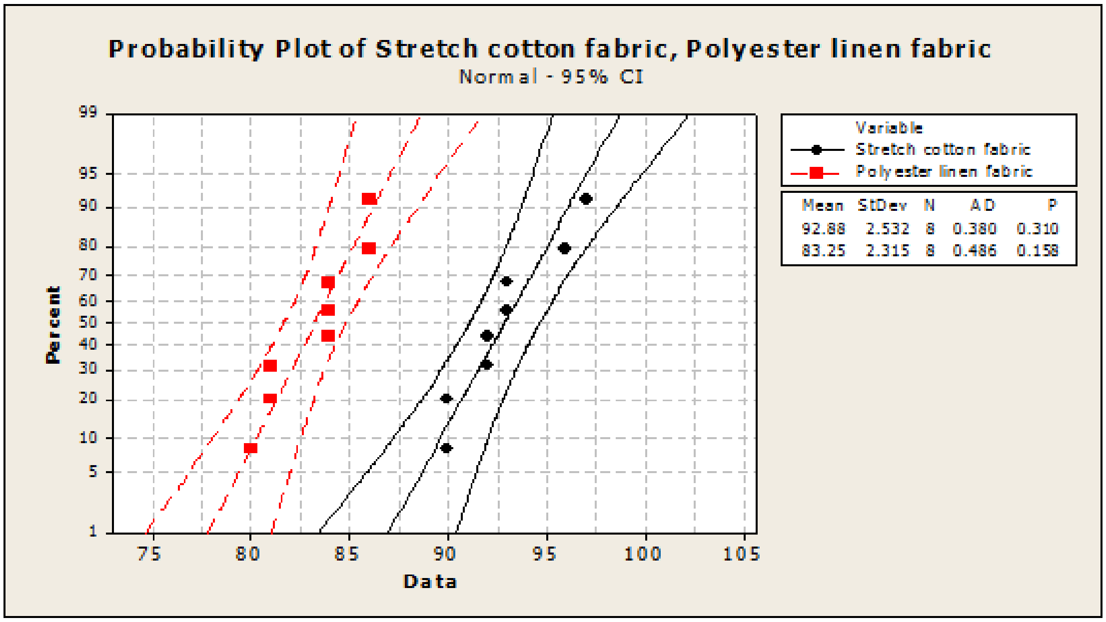

Figure 5. Probability plot of stretch-cotton and polyester-linen fabrics using mean filtration efficiencies for algae water sample from Larchfield community.

The t-test analysis of variance is used to compare the individual mean of two variables to determine their level of significance. A test is said to be significant if the absolute t-value is > then the critical t-value. A comparison of the Stretch-cotton and Polyester-linen on the Larchfield algae community at a 95% confidence interval (Table 2 and Figure 5) shows that at alpha level of 0.05, p-value of 0.0 < 0.05, the absolute t-value of 7.45 > then the critical t-value of 2.16 which implies that the two means are not equal.

A T-test analysis of the performance of the Stretch-cotton fabric indicates that there is no significant difference ($P < 0.05$) in the performance of the fabric using the Larchfield algae community.

6. Estimated cost of algae harvesting per m^3 of wastewater using stretch-cotton filter

Total amount of wastewater generated = $1500 m^3/day$

$$\text{Amount of wastewater filtered per unit area of fabric} = \frac{\text{Wastewater generated per day}}{\text{Total area of the fabric}}$$

$$= \frac{1500 m^3/day}{41 m^2} = 36.6 m^3/m^2.day$$

Algae concentration in wastewater = 200mg/l

Algae concentration (in cubic meter) of wastewater generation = $200 \times 10^{-3} = 0.2 kg/m^3$

$$\text{Algae concentration per cubic meter} = \frac{0.2kg \times m^3}{m^3} = 0.2kg$$

Amount of algae harvested per area of the filter per day per cubic meter of wastewater generation = 0.2kg x 36.6m^3/m^2.day = 7.32kg/m^3/m^2.day

Cost of stretch-cotton fabric filter = £4.20/m^2

A Fabric Media can endure between 2,000 and 5,000 backwash events before degradation (Shipard, 2006).

Estimated useful life of fabric = 50cycles

Estimated recycling cost per cycle of usage = £1.00

Note:

1. A cycle is the time between successive cleaning and replacement of the same fabric.
2. Useful life is the number of cycles the fabric is used before a change in effluent quantity and significant head loss is noticed .This corresponds to the length of time during which the fabric is discarded and replaced.

Total recycling costs of fabric for entire useful life = numbers of cycles x recycling cost per cycle = 50 x 1 =£50.00

Cumulative cost of fabric = purchased cost + total recycling cost = 4.20 +50 =£54.20

Assuming fabric is recycled after 1day.

Hence,

Total amount of algae harvested during useful life of fabric = amount of algae harvested per cycled x number of cycles = amount of algae harvested in 1day x number of cycles 7.32kg/m^3 /m^2day x 50 = 366kg/m^3/m^2

This implies that £54.20 is the amount spent in harvesting 366kg/m^3/m^2

Therefore cost of harvesting per meter per kg of algae per cubic meter of wastewater treatment

$$= \frac{£54.20}{366} \sim 15p$$

7. Conclusion

This research has shown that for most algae sizes commonly found in water and wastewater samples, efficient harvesting could be achieved using the Stretch-cotton fabric material, whereas the Polyester-linen would be best suited for pre-treatment purposes.

Algae cell counts of raw and filtrate samples indicated cell sizes in the order of 2-25 μm for Larchfield community sample, 2-17 μm for Marine Science sample, and 2-15 μm for the Civil Engineering and Geosciences Laboratory samples. The stretch-cotton filter showed the highest harvesting efficiency of 66-

93% for all algae communities tested, followed by polyester-linen (54-90%), satin-polyester (43-71%), and silk (27-75%) respectively.

From the proposed algae harvesting design for the stretch-cotton fabric at a wastewater generation of 1500m^3/day and algae concentration of 0.2g/l (typical of a waste stabilization pond), microalgae harvesting cost per sq. meter per kg of algae per cubic meter of wastewater would be ≤ £0.15. Therefore, algae harvesting using fabric filters are proven to be a cheap and reliable harvesting technique especially in areas where skilled labour is rarely feasible.

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