Minimising the energy requirement of dewatering *Scenedesmus sp.* by microfiltration– performance, costs and feasibility

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2 Tables

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Supplementary data

A schematic representation of the pilot-scale filtration unit is given in Figure S1.

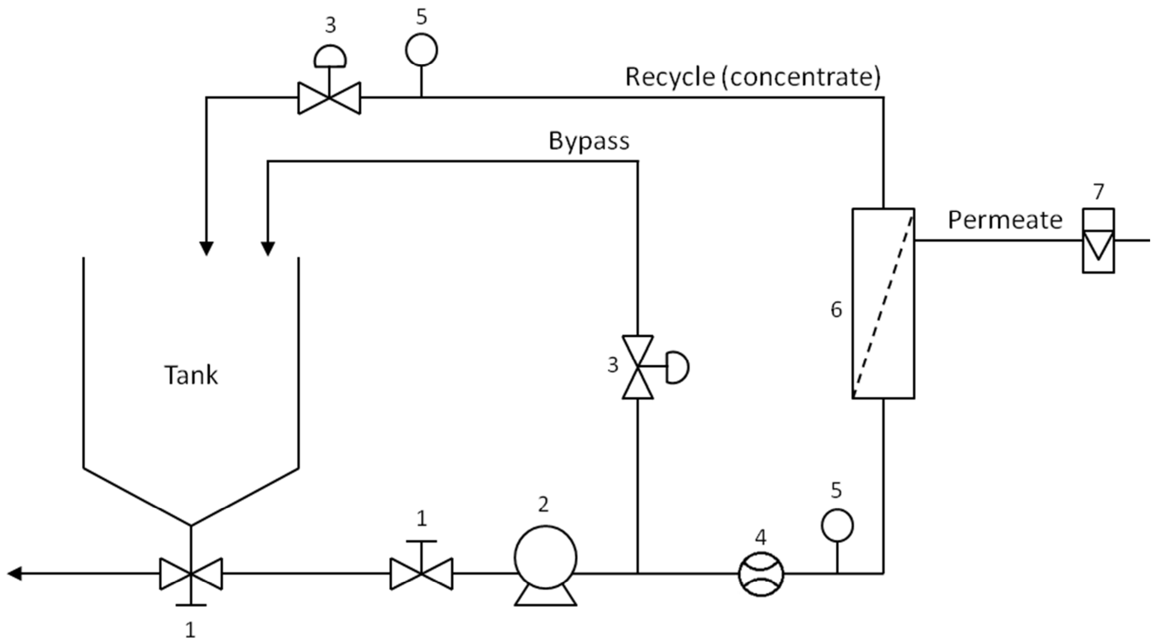

Figure S1. Schematic diagram of the microfiltration membrane system. 1 – diaphragm valve, 2 – centrifugal pump, 3 – butterfly valve, 4 – flow meter, 5 – pressure and temperature probes, 6 – membrane filter, 7 – permeate flow meter.

Pump efficiency and power usage

The pump efficiency (η) curve for the Lowara SV408 1.5 kW is shown in Figure 1 and has a maximum η of 58 % at 5.2 m^3/h. The measured pump output flow was effectively 4.24 m^3/h and according to the η curve corresponds to 57 %. This justifies the difference between the 0.70 kWh measured power intake and the theoretical pump hydraulic power of 0.68 kWh at 4.24 m^3/h and 3.5 bar.

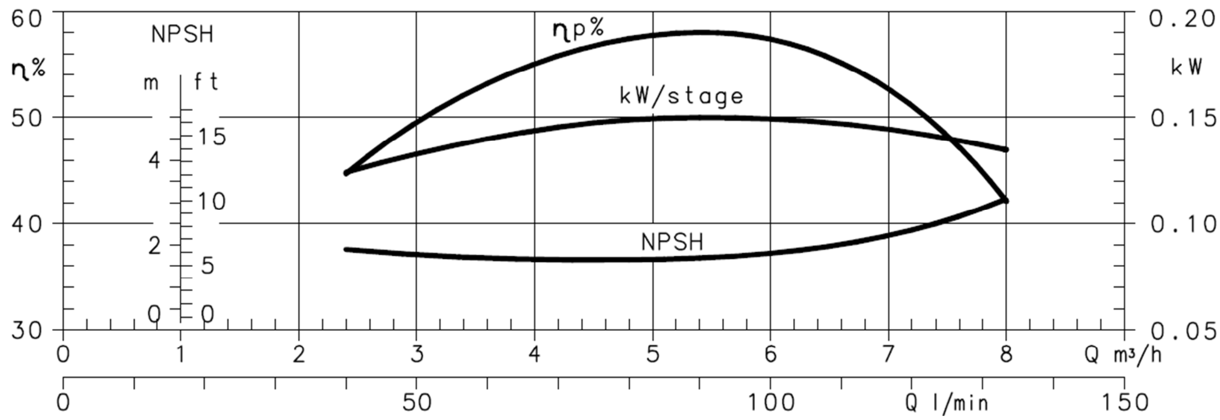

Figure S2. Pump efficiency (ηp) across a range of possible flow for a Lowara SV4 series pump operating at 2900 rpm, 50 Hz.[1]

<u>Filtration study</u>

Following the determination of *Rm*, constant hydrodynamic conditions were imposed by running the filtration system with biomass at constant concentration of 0.85 g DCW/L, i.e. in a closed loop mode, until the permeate flux was stable. Membrane fouling was studied under constant hydrodynamic conditions at 20±1 ^{o}C, 1.01 m/s, inlet pressure of 3.5 bar and ΔP of 1.95 bar. Operating the system in closed loop so that the concentration was constant, permeate flux was measured against time until stationary conditions were achieved. This is illustrated in Figure S2 and shows a sharp decline in flux until around 15 minutes after which the loss in flux is about 16 % of that initially observed (96.1 LMH). After 120 minutes no further variation of flux was observed at 72.4 LMH and the system was considered to have achieved steady-state. This insured that during the subsequent studies the filtration process only depended on biomass concentration and ΔP. The investigation of the filtration parameters of *Scenedesmus species* using the pilot-scale cross-flow microfiltration system was performed across a range of concentrations and ΔP.

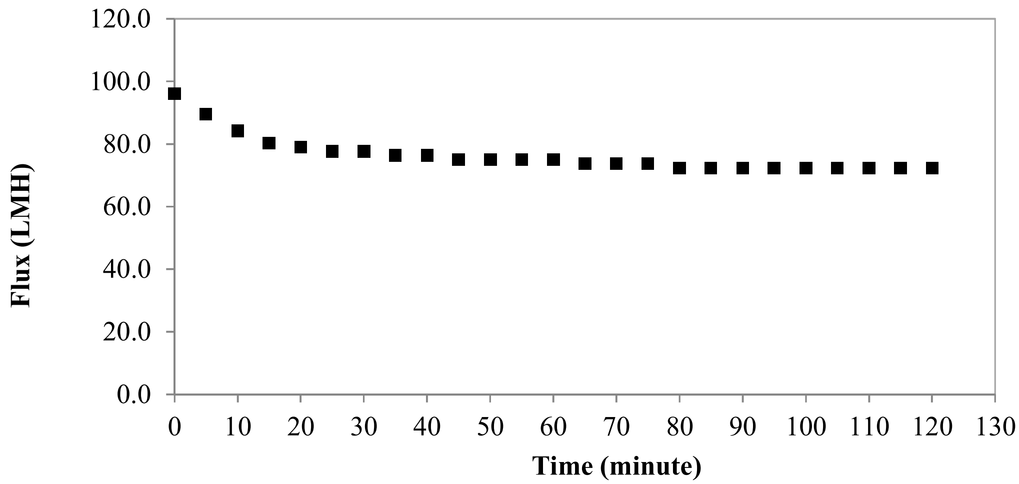

Figure S3. Loss of permeate flux in relation to time at constant concentration for *Scenedesmus species* at 0.85 g DCW/L.

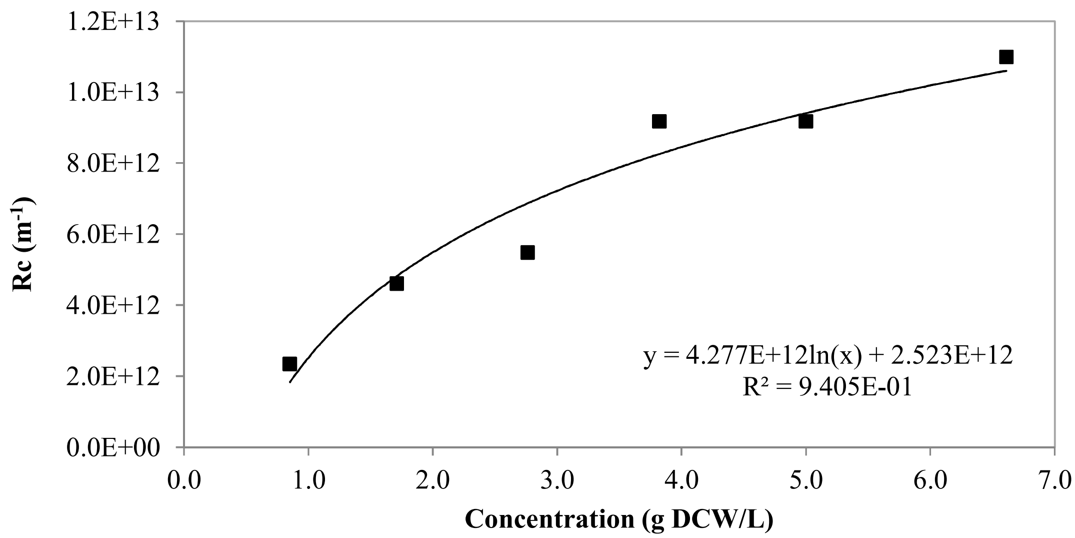

Figure S4. Influence of the biomass concentration on cake resistance. Logarithmic regression was the best possible fit.

Iterative method

Taking the model as a true prediction of the flux, the processing times to reduce a 600 L microalgae culture down to 10 L under a different set of operating parameters were determined. This is determined by iterative steps in the following mode:

1. A fixed set temperature is given so that viscosity value is adjusted by Equation 4, e.g. 20 ^{o}C.

2. Rc is determined by Equation 8 at any given biomass concentration, e.g. starting concentration of 1.0 g biomass/L.

3. R_c value, pressure and viscosity feed into Equation 1 and thus one flux data point is determined.

4. The volume remaining after the first iterative step using certain specific membrane area, e.g. 7.6 m^2 is given by Equation 3. Since water is removed, the new biomass concentration can be calculated by a simple mass balance (C1 x V2 = C2 x V2).

4. The new biomass concentration allows calculating the subsequent R_c and flux data points. At each iterative step (10 seconds) the decrease in the remaining volume increases biomass concentration and thus R_c increases over time and the flux will decline (see table below and Figure 4).

5. The steps above are repeated for every single 10 second iteration until the remaining volume is 10 L. This allows determining the processing times for each set of operating parameters.

For each case scenario (Baseline to case E and scale up) the operating parameters pressure, membrane area and temperature and kept constant during the iterative steps. This ensures that only one variable is influencing the estimation of the processing times for each case scenario. See below a short table for the data resulting from this iterative exercise in relation to case scenario D increased membrane area:

$\mathbf{P_{in}}$ = 3.5 bar

$\mathbf{P_{out}}$ = 2.4 bar

Starting Volume = 600 L

Initial concentration = 1.00 g/L

Membrane area = 7.6 m^2

Step = 10 s

Temperature = 293 K

Viscosity = 1.005E-03 Pa.s

Δ**P** = 2.95E+05 Pa

$\mathbf{R_m}$ = 6.18E+12 m^{-1}

$\mathbf{R_c}$ = 4.277E+12*ln(concentration) + 2.523E+12 m^{-1}

Power consumption = 0.70 kWh

Optimal power consumption = 0.46 kWh

Electricity cost = 0.085 £/kWh

t (s)	Flux (m^3 m^{-2} s^{-1})	Flow (L/s)	V (L)	R_c (m^{-1})	Conc (g DCW/L)	Time (min)
0	**3.371E-05**	0.256	600.0	2.523E+12	1.00	0.00
10	**3.364E-05**	0.256	597.4	2.541E+12	1.00	0.17
20	**3.357E-05**	0.255	594.9	2.560E+12	1.01	0.33
30	**3.350E-05**	0.255	592.3	2.578E+12	1.01	0.50
1700	**2.308E-05**	0.175	235.0	6.531E+12	2.55	28.33
1710	**2.302E-05**	0.175	233.3	6.563E+12	2.57	28.50
1720	**2.297E-05**	0.175	231.5	6.596E+12	2.59	28.67
1730	**2.291E-05**	0.174	229.8	6.628E+12	2.61	28.83
3310	**1.177E-05**	0.089	13.5	1.874E+13	44.32	55.17
3320	**1.164E-05**	0.088	12.6	1.903E+13	47.46	55.33
3330	**1.150E-05**	0.087	11.8	1.934E+13	51.03	55.50
3340	**1.135E-05**	0.086	10.9	1.967E+13	55.13	55.67
3350	**1.120E-05**	0.085	10.0	2.003E+13	59.87	55.83

Table S1. Data from the iterative method for case scenario D. The decline in flux with time is highlighted in bold. Filtration process terminates at 10 L remaining volume.

Note: Once the processing times are known for each case scenario the power consumption and relative costs to microalgae harvesting can be determined.

<u>Initial biomass concentration</u>

Changing the initial concentration from 0.5 to 2 g/L leads to a 4-fold increase of the filtration load, i.e. for the same amount of starting volume (600 L) more biomass is present. Therefore, when changing the initial concentration from 0.5 to 2 g/L the processing times/costs are substantially increased. Nevertheless, at the end of a 600 L batch with 2 g/L initial concentration more biomass is present and thus biomass cost is lower than that observed for a 600 L batch with 0.5 g/L initial concentration. Data from the manuscript is summarised in the table below and illustrates such trends.

Initial biomass concentration (g DCW/L)	**Processing cost (kWh/m^3)**	**Biomass cost ($/kg microalgae)**
0.5	1.66	0.429
1.0	2.23	0.282
2.0	2.68	0.154

Table S2. Influence of initial biomass concentration on processing times and final costs

It is very interesting to analyse how higher initial biomass concentration leads to higher processing costs while the finall biomass cost follows an inverse trend.

References

1. Vertical Multistage Electric Pumps equipped with high efficiency PLM motors. In ITT, L., Ed. Lowara ITT: 2009.