Operational and Training Manual for Algal-Based Tertiary Treatment in Maturation Ponds of the Motetema Wastewater Treatment Works

Report to the Water Research Commission

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OPERATIONAL AND TRAINING MANUAL FOR ALGAL-BASED TERTIARY TREATMENT IN MATURATION PONDS OF THE MOTETEMA WASTEWATER TREATMENT WORKS

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EXECUTIVE SUMMARY

Pond systems are ideally suited for use in small rural communities, because they are simple and economical to operate and maintain. The algal-based tertiary treatment (phycoremediation) used in this project utilises a specific consortium of algal species to remove nutrients and create conditions for effective solar disinfection to reduce pathogens. The intention is to implement a self-sustaining system that is independent of electricity or expensive chemicals and that can be effectively operated within financial and capacity constraints.

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1. PURPOSE OF THE MANUAL

The purpose of this manual is to present operational guidelines and maintenance for phycoremediation treatment in rural wastewater treatment plants employing waste stabilisation ponds as tertiary treatment in the absence of electricity. The guideline is specifically set out for municipal plant operators and analytical services to manage an algal-based tertiary treatment system on a daily basis.

2. GLOSSARY

Term	Definition
Aerobic	Biological process which occurs in the presence of oxygen
Algal bioreactor	A container to grow algae to high biomass concentrations
Anaerobic	Biological process which occurs in the absence of oxygen
Effluent	Treated wastewater flowing out of the wastewater treatment system
Inlet	Opening providing an entrance of untreated wastewater
Outlet	Opening providing an exit of untreated wastewater
Overload	Load exceeds the capacity of the treatment system
Ponds	Shallow bodies (<2 m) containing wastewater in an earthen basin
Screen	A device that is used to retain course solids found in wastewater
Sludge	Semi-solid material deposited during the treatment of wastewater

3. BACKGROUND AND LAY-OUT OF THE MOTETEMA WASTEWATER TREATMENT WORKS

The Motetema Wastewater Treatment Works (WWTW) is situated in the Elias Motsoaledi Local Municipality in the Sekhukhune District of the Limpopo Province of South Africa. Due to the lack of proper WWTW infrastructure and electricity, a series of ponds are employed at the Motetema WWTW to treat domestic waste. The system operates without mechanical aeration and the average total effluent that need to be treated (for a population of approximately 11 400 people) by the Motetema WWTW is ~2.5 ML/ day. It consists of 12 ponds organised in two series of six each; where six ponds are operated at a time, while the other six ponds are re-earthed. The pond system is based on natural overflow from one pond to another, using gravity. The Motetema WWTW consists of four types of stabilisation ponds, namely (1) anaerobic ponds, (2) primary facultative ponds, (3) secondary facultative ponds and (4) aerobic (maturation) ponds (Figure 1). All of these ponds have different actions and design distinctiveness as summarised below:

3.1. Anaerobic Ponds

These ponds operate without the presence of dissolved oxygen with high organic loads. In anaerobic ponds, the biological oxygen demand (BOD) is achieved by sedimentation of solids and subsequent anaerobic digestion in the resulting sludge. A short retention time of one, to one and a half days is commonly used.

3.2. Facultative Ponds

In these ponds aerobic conditions prevail at the water surface and below, while anaerobic conditions prevail in the bottom sediment. Facultative ponds can be differentiated into primary and secondary facultative ponds. Primary facultative ponds receive raw water and secondary facultative ponds receive particle-free wastewater. Facultative ponds are designed for BOD removal on the bases to allow for the development of a healthy algal population, since the oxygen for BOD removal by the pond bacteria is generated primarily via algal photosynthesis. The bottom layer of primary facultative ponds includes sludge deposits that are decomposed by anaerobic bacteria.

3.3. Aerobic (Maturation) Ponds

These ponds receive their effluent from the secondary facultative ponds. Maturation ponds show less vertical stratification and are well oxygenated throughout the day. A larger algal diversity can be found in maturation ponds compared to the facultative ponds, with non-motile genera tending to be more widespread. Algae are one of the main driving forces behind treatment within maturation ponds by taking up phosphates, carbon dioxide and nitrogen compounds, while it provide oxygen for heterotrophic bacteria to degrade organic material.

Figure 1: The Motetema Wastewater Treatment Works consist of four types of stabilisation ponds, namely (1) anaerobic pond, (2) primary facultative pond, (3) secondary facultative pond and (4) aerobic (maturation) ponds

4. PHYCOREMEDIATION: OPERATION AND MAINTENANCE

4.1. Mass Culturing, Lay-out Operation and Maintenance

Two species of microalgae from the phylum, Chlorophyta, namely *Chlorella vulgaris* and *Chlorella protothecoides*, were isolated, cultured on mass-scale in the laboratory and transported to the Motetema WWTW. These species are used for the phycoremediation of the pond systems (Figure 9). The plant operators at the WWTW will use the algal cultures to dose the selected ponds on a continuous basis by mass culturing of the algae in a step-wise procedure using onsite algal reactors.

Five reactor tanks (JoJo tanks with a capacity of 5 000 ℓ each) are installed at the WWTW and numbered from 1 to 5. Clear markings to indicate the different volumes (1 000 ℓ, 2 000 ℓ, 3 000 ℓ, 4 000 ℓ and 5 000 ℓ) are made on these tanks. In each of these tanks a volume of 5 000 ℓ of the two algal species is added.

For the dosing of the pond system, the steps described below need to be followed (Figure 2):

***Very Important!**
Reactor tanks 1 and 2 will be used to dose Pond 4.
Reactor tanks 3 and 4 will be used to dose Pond 5.
Reactor tank 5 is used for back-up (in case the other tank's algal concentrations are too low).

Figure 2: Lay-out of the ponds at the Motetema Wastewater Treatment Works, indicating the piping from the reactor tanks and the ponds to be dosed

1. At the start of inoculation:
Open the taps of Reactor tanks 1 and 3. Then open the taps at Ponds 4 and 5 (Flow path 1). Allow 4 000 ℓ of algae to flow from the tanks into the pond. Close the taps at the tanks and the pond.

2. Two weeks later:
Open the taps of Reactor tanks 2 and 4. Then open the taps at Ponds 4 and 5 (Flow path 2). Allow 4 000 ℓ of algae to flow from the tank into the pond. Close the taps at the tanks and the pond. (Reactor tanks 1 and 3 have up to now matured for two weeks since the initial dosing.)

3. After an additional two weeks:
Reactor tanks 1 and 3 will be ready for dosing again. Thus, every two weeks the ponds will be dosed using Reactor tanks 1 and 3, and Reactor tanks 2 and 4, alternatively.

This protocol will be the same for both flow paths

These steps need to be repeated to ensure the continuous dosing (and thus treatment) of the sewage ponds. Reactor tank 5 is used as a spare reactor to have extra algae available at all times. However, it needs to be used from time to time and dosed with fertiliser, to ensure a constant supply of algae. When used, Reactor tank 5 can be released into Pond 3.

***Please Note!**
It is important to dose only two ponds at a time and to use only the specified Reactor tanks for each pond, so as to ensure a constant supply of healthy algae at all times.

The algal culturing steps described below need to be followed for each Reactor tank in order to maintain a healthy supply of live algae to dose the pond system (Figure 3):

1. Release 4 000 ℓ of the total of 5 000 ℓ of algae from the Reactor tank into the selected pond.
2. After dosing the selected pond, add 1 000 ℓ of tap water into the Reactor tank (thus, a total volume of 2 000 ℓ in the Reactor tank), together with 20 g fertiliser.
3. Allow the algae in the Reactor tank to grow and become greener (Figure 4). This may take more or less one week, depending on the climate.
4. Once the algae have reached the desired colour, add another 1 000 ℓ tap water into the Reactor tank (thus, a total volume of 3 000 ℓ in the Reactor tank), together with 20 g fertiliser.
5. Allow the algae in the Reactor tank to grow and become greener (Figure 4). This may take more or less one week, depending on the climate.
6. Once the algae have reached the desired colour, add another 1 000 ℓ tap water to the Reactor tank (thus, a total volume of 4 000 ℓ in the Reactor tank), together with 20 g fertiliser.
7. Allow the algae in the Reactor tank to grow and become greener (Figure 4). This may take more or less one week, depending on the climate.
8. Once the algae have reached the desired colour, add another 1 000 ℓ water to the Reactor tank (thus, a total volume of 5 000 ℓ in the Reactor tank), together with 20 g fertiliser.
9. Allow the algae in the Reactor tank to grow and become greener (Figure 4). This may take more or less one week, depending on the climate. The algae are now ready to be dosed again into the selected pond.
10. Repeat steps 1 to 9 to ensure a continuous supply of algae.

The filter located at the water tap must be replaced every six months, because it is responsible to dechlorinate the tap water.

To ensure optimal growth, the algae in each Reactor tank need to be stirred manually at least every four days

***Very Important!**
The time frames given are only an indication. The growth of the algae will depend on various factors (e.g., temperature, light, etc.) that may increase or decrease the time it takes to grow and become greener. Thus, the colour codes indicated in Figure 4 need to be used.

4.2. Algae Bioreactor Lay-out and Flow Diagram

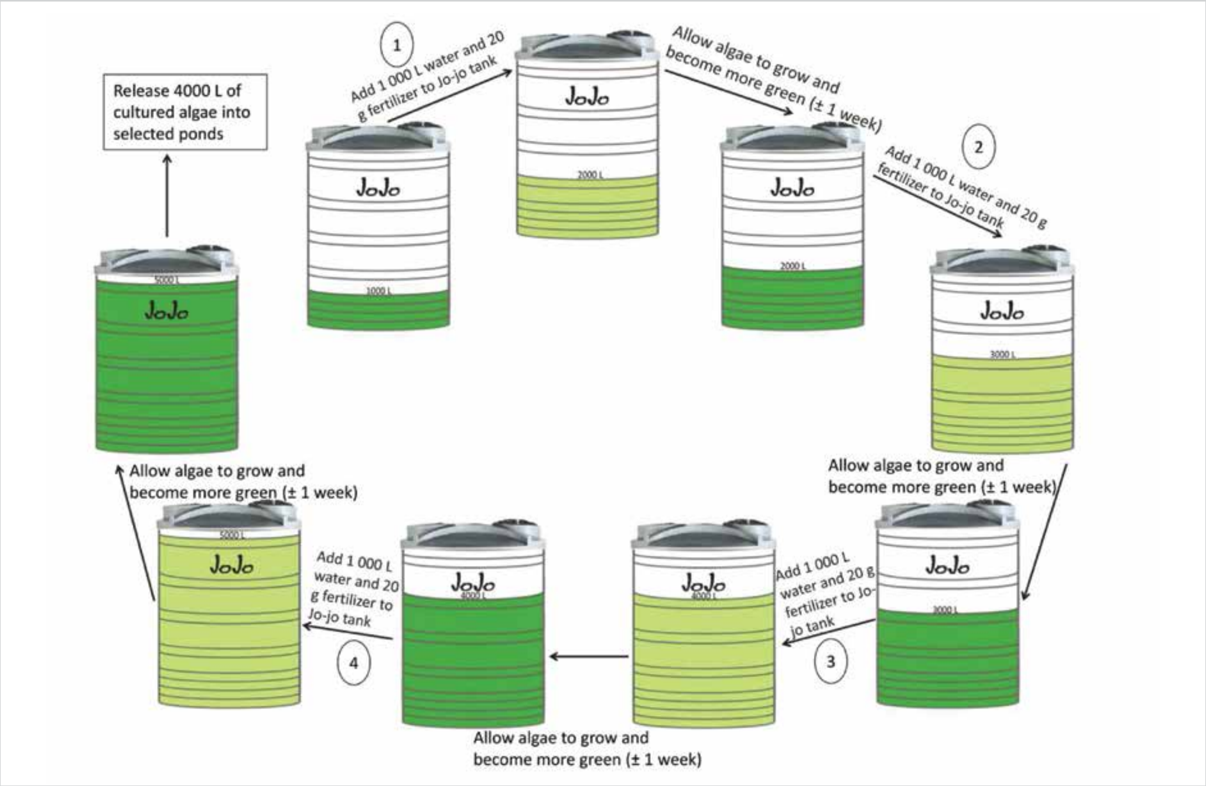

Figure 3: The step-wise procedure to follow for each algal reactor tank to maintain a healthy supply of algae

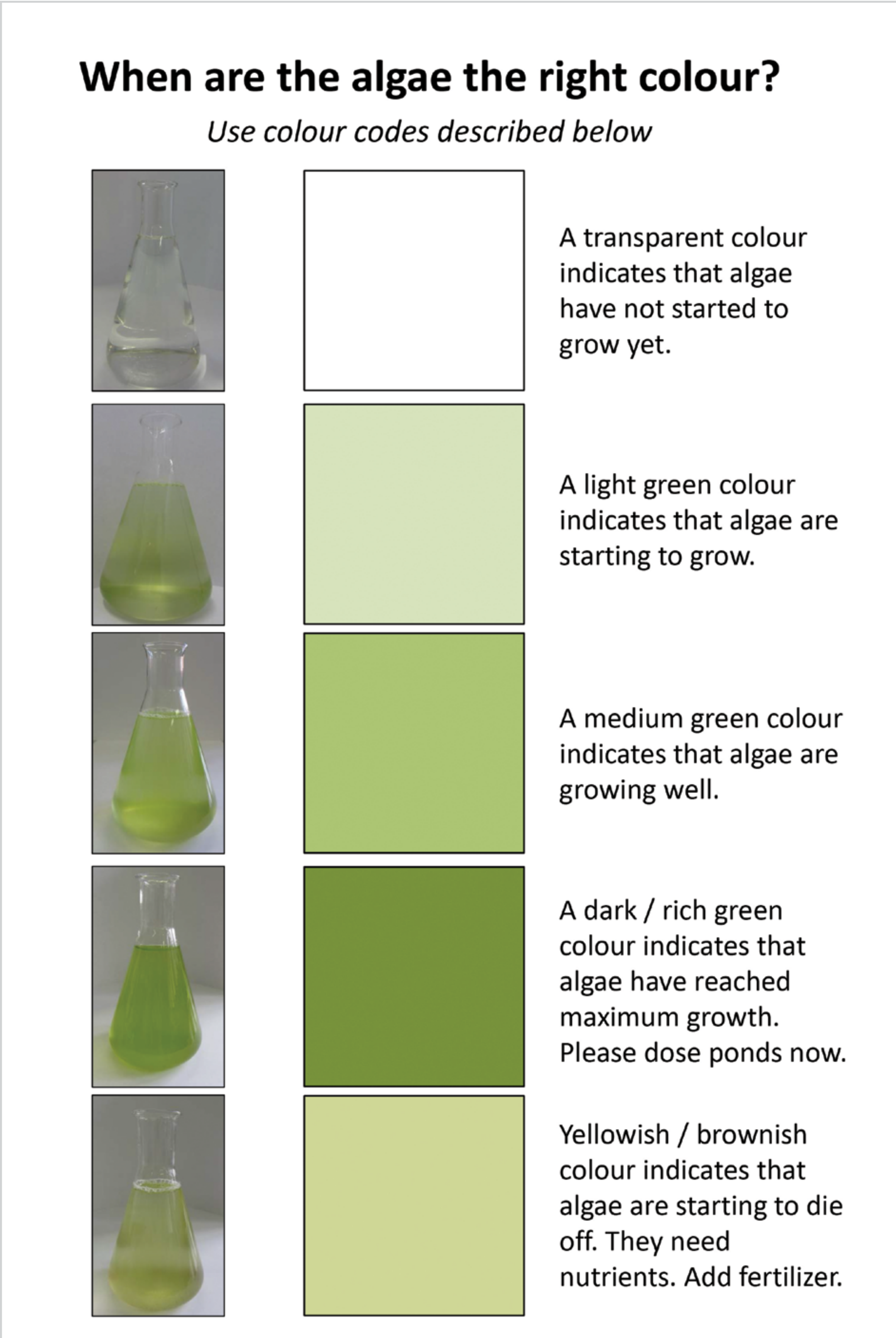

Figure 4: A colour code chart to explain the different types of colour in the algae

5. GENERAL OPERATION AND MAINTENANCE

5.1. Daily Operation (according to EPA, 1997)

The following needs to be attended to on a daily basis:

1. Attend to the screen and detritus channel.
2. Keep the minimum desired water depth to help control rooted plants like, for example *Typha sp.* (Figure 5).
3. Keep the embankments free of vegetation, especially at the verges. Remove floating plants on the water or tall plants at the water's edges or that droop into the water. Rooted plants in the water promote mosquito breeding and add to sludge. Bacteria are essential for good treatment in secondary facultative and maturated ponds and they require oxygen. Sunlight must penetrate the water and reach the algae to produce the oxygen. Floating plants like duck weed intercept the light, causing the oxygen levels to drop and then change the pond's colour from green to brown (Figure 6).
4. Look out for leakage from rat and crab holes and close them. Inspect the berm slopes for erosion or damaged spots, especially after intense rain periods.
5. Mow vigorous and dense perennial grass cover growth on embankments every two weeks.
6. Clear floating debris from pond surfaces and clean overflows if necessary (Figure 7).
7. Inspect on a daily basis, the conditions of the series of maturation ponds by using Table 1 as guideline:

Table 1: Colour as indicator of maturation ponds condition

Colour	Condition	Cause or Symptom
Dark sparkling green	Good condition	Enough dissolved oxygen (DO) and high pH
Dull green to yellow	Not so good	DO and pH are less than optimum
Blue-green algae may become predominant		
Red or pink	Poor	Slightly over loaded
Grey to black	Very bad	Anaerobic conditions prevail, odours likely. Too much sludge is possible.

Figure 5: Water depth too low, causing rooted plants to invade pond

Figure 6: Floating duckweed in the ponds, with tall plants at the water's edge

Figure 7: Floating debris on the pond surface

6. DEPTH OF SLUDGE LAYER

The depth of the sludge layer in the anaerobic, primary and secondary facultative ponds needs to be tested on a six-month basis using the ‘white towel test’. The white towelling material is wrapped around one end of a wooden pole which must be 1 m longer than the pond depth. The pole must be lowered in the pond vertically with the towel end first, until it reaches the bottom of the pond at inlet and outlet points Figure 8. The pole must be slowly and carefully withdrawn to measure the sludge-liquid interface layer. This layer will be clearly visible since some sludge particles will be entrapped in the towelling material. Measurement of sludge depth is essential and important for the successful performance of the system, because the build-up of sludge at the outlets of the anaerobic pond and in- and outlets of the primary and secondary facultative ponds can block or reduce wastewater flowing from one pond to another (Mayo et al., 2010).

Figure 8: Outlet of the secondary facultative pond

7. GENERAL SANITARY ANALYSIS PROGRAM FOR PHYCOREMEDIATION TREATMENT

7.1. Routine Parameters

Table 2 summarises a list of the parameters that should be monitored on a monthly basis. Samples must be taken by a grab sampler.

Table 2: The parameters that should be sampled on a monthly basis.

Parameters	DWA Guidelines for Effluent	Ideal Phycoremediation Treatment Conditions	Location of Sampling
5 days, 20°C, biological oxygen demand		< 12 mg/ℓ	Maturation ponds
Chemical oxygen demand	75 mg/ℓ		Effluent
Suspended solids	25 mg/ℓ		Effluent
Faecal coliform	1000 / 100mℓ		Effluent
Nitrogen: Nitrate/Nitrite	15 mg/ℓ		Effluent
Ortho-phosphate	1 mg/ℓ		Effluent
pH	5.5 - 9.5 (effluent)	7.5 - 10.5	
Electrical conductivity	70 mS/m		Effluent
Oxygen (mg/ℓ) for aquaculture conditions		>2 mg/ℓ	Final maturation pond
Temperature		30	Maturation ponds
Suspended chlorophyll a		>500 µg/ℓ	Excluding final maturation pond
Algal speciation * (disruption of algae speciation)			Not final maturation pond

7.2. Algal Speciation

Algal species' diversity should be determined by microscopic examination on a monthly basis to verify the dominance of the inoculated algal species. The aliquot for microscopic examination should be taken from a well-stirred sample of each of the maturation ponds. The water samples must be kept cool and in the dark during transfer from the field to the laboratory. Strip counts must be made until at least 300 individuals of each of the dominant phytoplankton species have been counted. Figure 9 shows the characteristics of the inoculated algae. These algal species usually range in size between 2 to 15 µm in diameter and are spherical or ellipsoidal with a thin and smooth cell wall. They usually consist of small, non-motile unicells and rarely aggregate into small groups (Janse van Vuuren et al., 2006).

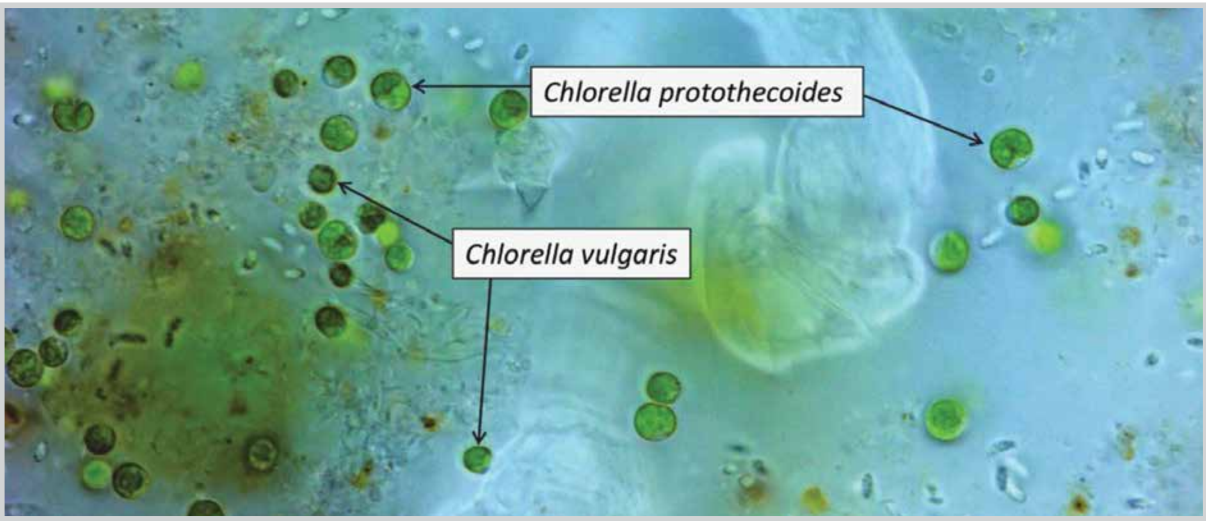

Figure 9: A microscopic view (600 times magnification) of the characteristics of the inoculated algae, *Chlorella protothecoides* and *Chlorella vulgaris*.

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