KNOWLEDGE IN ALGAL CULTIVATION TECHNOLOGY

3. POND SENSORISATION, MONITORING AND CONTROL

Sensors and systems to be used were defined according to the specific needs of each site. A modular system was designed as a base, and different implementations for each site were carried out.

The system components are:

- An electronic commercial receiver/controller per pond
- A set of sensors in each pond. The set of sensors can be moved to another pond easily.
- A set of sensors for the pre-treatment.
- A phosphate analyser in the harvesting to monitor the depletion of Phosphorous.
- All the data from the sensors is collected in a PLC control system.

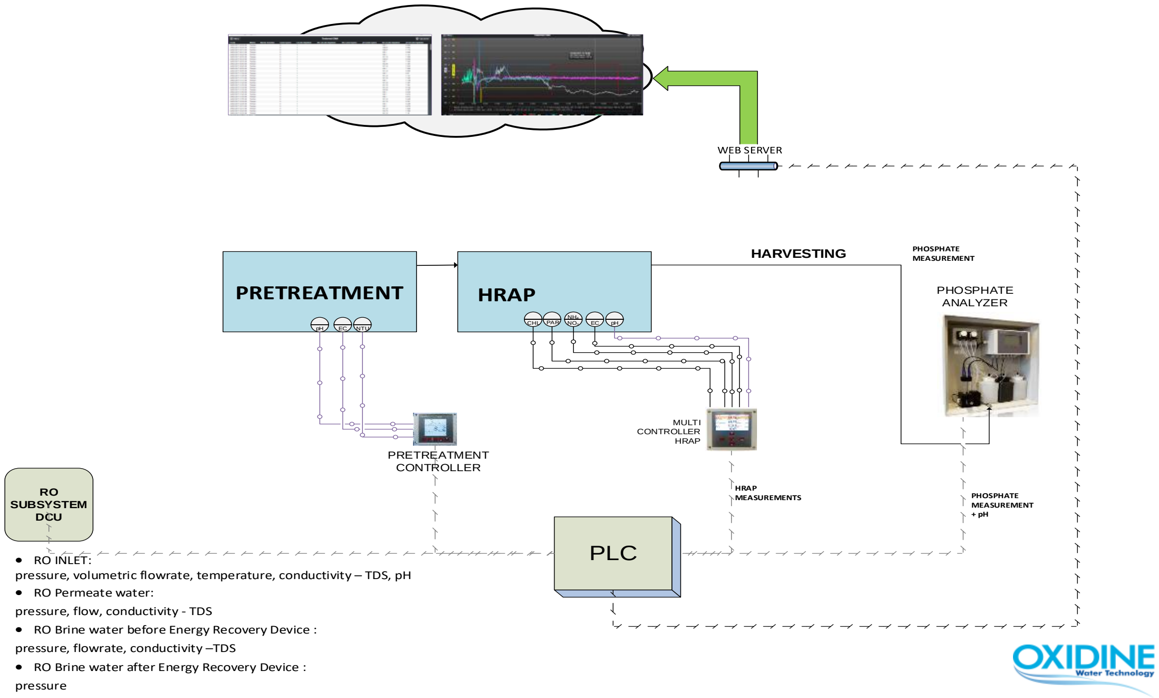
The selection of the system was done considering the maintenance effort, the availability of the sensors and the robustness.

Regarding the sensors:

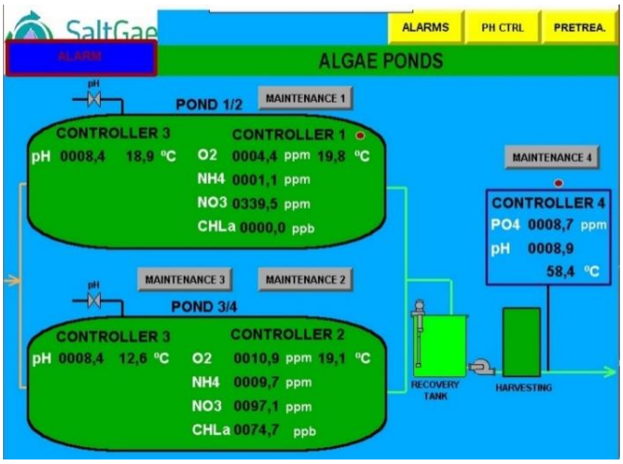
- The measurement of Chlorophyll is integrated in the pond's sensor set, as a submersible sensor. The sensor is capable of measure Chlorophyll A content in the ponds in a range from 0 to 200 microg/l.
- Phosphate is analysed using a photometric method with reagents. The range is 0 – 50 mg/l P-PO_4.
- Conductivity is measured with inductive submersible probes.
- For the pH, low maintenance electrolytic gel electrodes were chosen.
- Nitrate and ammonia using ISE packed in a single probe, including a reference electrode.
- Oxygen: Optical sensor using luminescence quenching effect of oxygen.
- Photosynthetic Active Radiation is measured in the surface of the ponds and underwater, using suitable optical sensors with photodiodes.

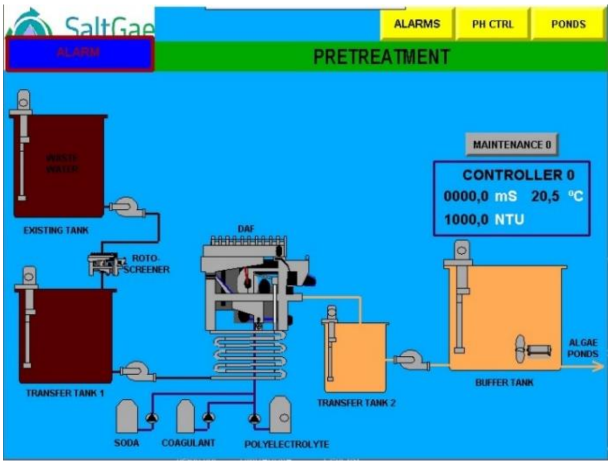
All the sensors are industrial grade and designed for wastewater treatment plants.

A general scheme of the sensoring strategy is shown next:



The system design was made including an industrial grade PLC from Allen-Bradley, with a touch Screen. The communication with other subsystems was done with digital signals. For example, from the Biboaqua pre-treatment units, we can see the system status, (running, idle or alarm) in the PLC touch screen of the control system.





3.1 Chlorophyll and Phosphate measurement.

As part of the work to be done, we had to develop a cost-effective way of measuring phosphate and chlorophyll in algal ponds. After doing some research of the state of the art of existing technology, we found out that available sensors in the market were expensive and focused on application.

a) Chlorophyll Sensor

The existing sensors were designed to be used in continental or sea water applications, where there is no power supply available and the sensors are located even at high depths. Another fact is that sensors also are develop for in situ “one time” measurements, and not for continuous “on line” measurement.

In the other hand, there were available instruments for lab use, but totally out of the scope of this project. According to the chlorophyll levels initially expected, we chose a sensor in the range of 0-200 microg/litre of Chlorophyll A, capable of doing underwater continuous measurements based on fluorescence phenomena.

The probe is a fluorometer, submersible and miniaturized for highly precise and selective measurement of CDOM (colored dissolved organic matter, yellow substances), chlorophyll A and phycocyanin in cyanobacteria. Long-term stability of measurements is ensured by the combination of low power consumption and innovative coating of the optical window, as an energy efficient and environmentally friendly antifouling solution. Internal reference signals of the high-performance LEDs used for fluorescence excitation compensate ageing effects and temperature influences.

Table 1: Chlorphyll sensor specifications

Measuring range	0-200 µg/L as FDOM or Chlorophyll
T100 response time	< 2 s
Measurement accuracy	± 3 %
Measurement interval	< 1 s
Light source	LED
Measurement principle	Fluorescence
Detector	Photo diodes
Analytical methods	Fluorescence
Power supply	12-24 VDC (± 10 %)
Interface digital	Ethernet (TCP/IP), RS-232 or RS-485 (Modbus RTU)
Interface analog	4...20 mA or 0...5 V
Power consumption	< 1 W
Sample temperature	+2...+40 °C
Ambient temperature	+2...+40 °C
Inflow velocity	0.1-10 m/s
Maintenance effort	Typically > 0.5 h/month
Calibration/maintenance interval	24 months
Protection type	IP68
Housing material	Stainless steel (1.4571/1.4404) or titanium (3.7035)

b) Phosphate Analyzer

The phosphate measurement is usually done by photometric methods, where total Phosphorous or orthophosphate can be measured depending on the method used. The total phosphorus method involves a peroxidation of the sample that makes the method very expensive to develop and automate. Existing commercial units are quite expensive as they are designed for specific task in wastewater treatment plants or in process water.

Orthophosphate measurement is method that best fit into the Saltgae project, as it is simple and reliable. In acids, ortho-phosphate ions react with ammonium molybdate and ammonium vanadate to form yellow ammonium phosphoric vanadio-molybdate. This can be photometrically analysed at 445 nm. Method is based in the vanadate/molybdate method (yellow method) for determining the orthophosphate content. A reagent reacts with phosphate in the sample to colour the sample solution to yellow. The intensity of this colour is measured photometrically and evaluated as a measure of the phosphate content.

Table 2: Phosphate analyser specifications

Measurement range	PHOSPHATE P-PO4 445 nm: 0 .00 ÷ 50.00 ppm - Resolution: 0.1ppm - Accuracy: 1% f.s. (colorimetric method (yellow reagent)) Temp.: 00.0 ÷ 50.0 °C - Resolution: 0.1°C – Accuracy: 1% f.s.
Internal Data Logger	Flash 4 Mbit storage equal to 16.000 recordings Type: circular / filling. Visualisation: table/chart (1 for every parameter)
Analogue outputs	Quantity: ppm PO_4, Temperature. Typology: 0.00 / 4.00 ÷ 20.00 mA galvanically isolated. Max load: 500 Ohm
Relay Outputs	Programming of Hysteresis and operational time: 000 ÷ 999 sec. Or daily activation on a hour basis: with programming of switching on and off hour.
Alarm Relay Output	ON-OFF: Min/Max, set point delay, defects (lack of sample water, reagents exhaustion, burnt projector, dirty cell) Delay time: 00:00 ÷ 59:99 mm:ss at minimum step of 15 seconds
Digital Input	Contact fed at 24Vdc for dose disabling
Analogue Input	0/4 ÷ 20mA for auxiliary measurements
RS485 Serial Output	MODBUS RTU protocol with programmable velocity 1200 ÷ 38400 Baud Rate. for set-up, Real Time condition, or data download
Functioning conditions	Operational Temperature 0÷50°C; Storage and Transportation -25÷65°C; Humidity 10-95% not condensed
Measuring cell	Photometric measuring cell with RS485 serial interface card. Black PVC body composed by two parts: • LED light emitting • Silicium photosensor Hydraulic flow 60 l/h, max pressure 1 Bar. Gravity discharge for clean water and polluted water (separately)

To full fit the requirements in the project, we looked for a reliable instrument yet low priced. We decided to use an industrial grade instrument, that is being used for Free and Total Chlorine, peracetic acid and chlorine dioxide measurements in process and industrial water. To do such job it was necessary to change the optics of the original unit, both LED source light and the receiver. Also, the analytical method was tested to verify the applicability.

Once the method was confirmed, the electronic control board had to be changed as well as the software and firmware of the unit. The unit as fitted with MODBUS RTU communication protocol, so it was perfect for the project.

The methodical of the analytical method was confirmed in the industrial unit, adjusting optics, reaction times, wash times, zero adjustment, etc. Subsequent comparison of the analyser with reference methods and external instruments were performed.

Phosphate analysis (orthophosphate) will be done in water after harvesting. Samples will be prefiltered through 100 microne filter and measured on the analyzer. Analyzer is being tested with actual waste water samples from ARCHIMEDE and KOTO prior to the deployment on demo sites.

3.2 Testing of sensors and control

Sensor and they control system were tested in demo plan. Ammonia/nitrate probes were sensor was installed jointly with potassium and chloride electrodes for drift compensation. Chlorophyll sensor can be included in the same probe if necessary or by separate. The sensors where placed in submersion lances and fitted into the Wastewater recovery pond to monitor the evolution of the Nitrogen species in the wastewater outlet

Ammonia/Nitrate sensor. Reference electrode in the centre, where a black spot can be seen due to fouling.

Detail of the phosphate analyser.

The following results were obtained:

- Phosphate gave an accurate measurement, but weekly maintenance of the unit was necessary to clean the rest of algae from the process.
- Nitrate probe range is not enough to measure in the pond, with values up to 300 mg/l. A probe with higher range is needed.
- Ammonia measurements were affected by the media, and weekly calibrations are necessary. Probe has to be substituted after 3 months of operation.

- The recommended calibration interval for ISE probes (ammonia and nitrate) is every 1- 2 weeks, and the replacement of the sensor, every 4 – 6 months. The probes are affected by fouling in the medial. More maintenance is suggested in the sites.

- Chlorophyll. Final chlorophyll values obtained at demos sites and measure in the lab are much higher than the range of the probe. It will be necessary a dilution system to get the measure inside the probe range or use an alternative correlation.