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NTE SA

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1. Introduction

The objectives and requirements of the liquid-solid separation systems (LSSS) in the MELISSA project aim to concentrate the cells of *Arthrospira platensis* alga to a certain extend depending on the final processing and uses of the biomass. In the Melissa-Adaptation for Space contract, it was decided to concentrate the biomass up to a factor 10 and eventually to 20 folds.
Selection requirements for the LSSS for *Arthrospira platensis* are widely described in technical note 72.6. A list of the most important criteria for LSSS, discussed in this note, is given here:

1. Biomass concentration and cell dilution
2. Breakthrough of the cells
3. Cells integrity
4. Energy requirements
5. Water recovery
6. Salts recovery
7. Consumables
8. Mass of the system
9. Safety issues
10. Potential improvement for space

The two last criteria (safety issues and potential improvement for space are widely discussed in technical note 72.10. A summary of selection criteria and requirements for the LSSS is presented in Table 1.

Table 1. Selection criteria and requirements of the LSSS for *Arthrospira platensis* harvesting

Selection criteria for the LSSS	Requirements of the LSSS
Biomass concentration	At least 75% to 90%
Breakthrough of the cells	Not allowed, except if the algal suspension in the liquid stream is pumped back to the photobioreactor
Cells integrity	Ensure end product without any disturbances in the shape or quality of the alga aimed for consumption.
Energy requirements	High energy consumption means a lot of heat production (should be minimised)
Water recovery	Possiblity to 90%
Salts recovery	Advisable in case the liquid stream is aimed to be recycled back as feed for the alga
Consumables	The frequency of cleaning, type of chemical used and life time of the elements in the system should be described
Mass of the system	10 to 50 kg/m^3 at least to facilitate the upgrading of the system to space uses
Safety issues	Low pressure, low velocities, low temperature
Potential improvement for space	Study the possibility for upgrading the system for microgravity conditions

The results of the operational and functional tests performed during the operation phase on the selected breadboard are presented and discussed in technical note 72.9.2. An overview of the breadboard designed by EPAS and VITO and constructed by VITO is presented in Figure 1.

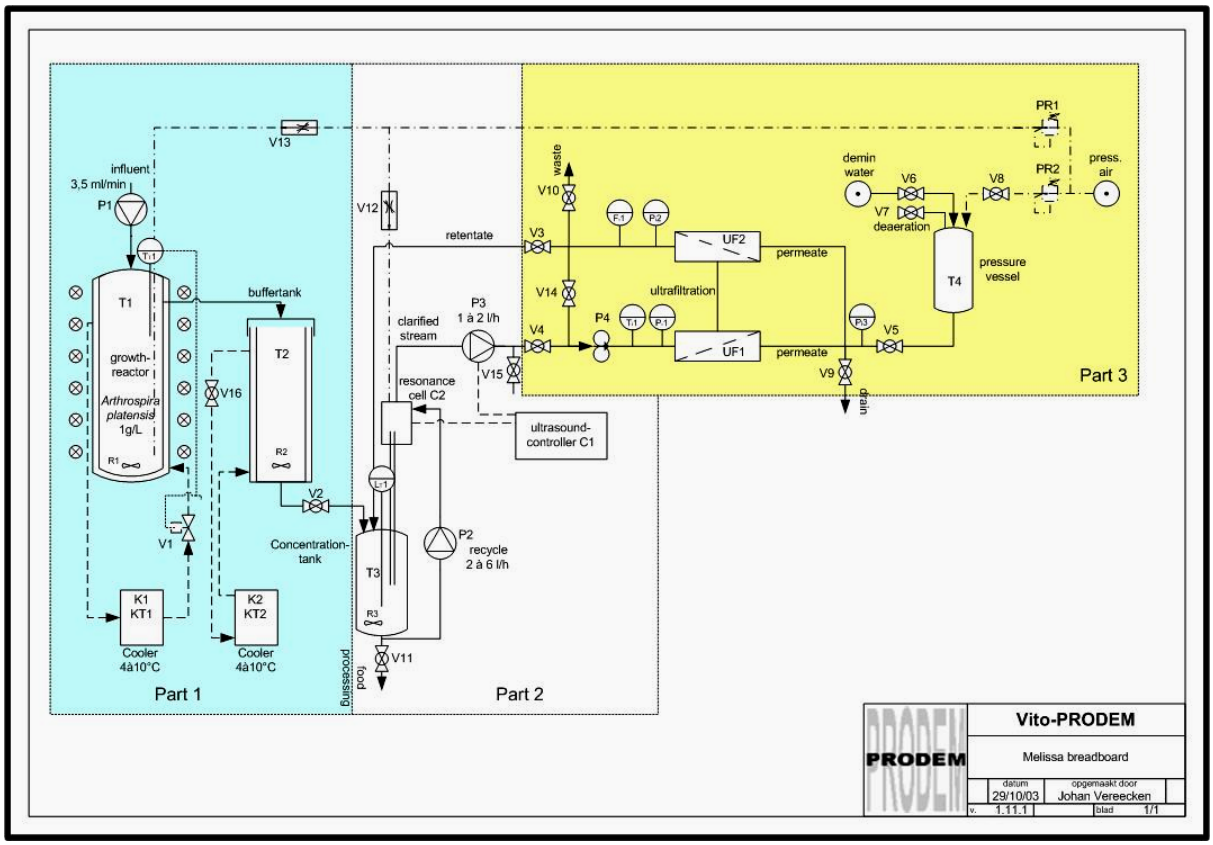

Figure 1. Overview scheme of the breadboard for *Arthrospira* harvesting

2. Evaluation of the functional test results

In view of the specifications mentioned previously, for the requirements of the harvesting system. It could be concluded that the tested breadboard has succeeded to fulfil the major requirements: (1) biomass concentration up to 10 folds, (2) no breakthrough of the cells during harvesting (100% separation efficiency), (3) very low or even no damage of the biomass during processing (7% of the escaped cells from the ultrasound unit was concentrated in the filtration unit and completely retained with however, low efficiency in maintaining biomass integrity), (4) complete water recovery after processing, and (5) recovery of salts in the filtrated stream.

Biomass recovery seems also to be an important criterion to be considered. According to the tests performed on the ultrafiltration unit, 10% to 16% of the cell suspension entering the ceramics membranes are sticking to the membranes and do not leave the membranes even after a back washing. Knowing that the liquid stream entering the ultrafiltration unit is rather low in cell suspension (around 7% of the total harvested biomass), from which 10% to 16% are sticking to the membranes, its influence on the whole harvesting system is not considerable, but accumulation may occur. Several rinsing steps are possible to avoid clogging of the membranes, however, this type of membranes (ceramics) are very robust and can be rinsed by heat to minimize water consumption for rinsing purposes.

The separation efficiency of the whole breadboard (including ultrasound unit and ultrafiltration unit) is shown in Figure 2. The separation efficiencies for each unit independently are reported in technical note 72.9.2.

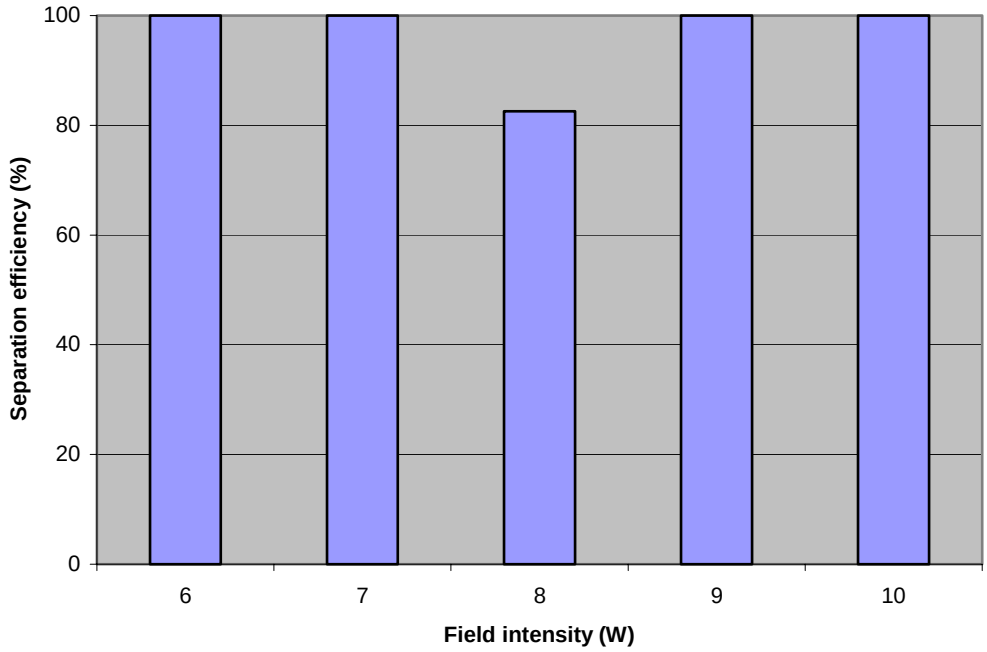

Figure 2. Effect of increasing field intensity on separator efficiencies of the whole breadboard. The recirculation flow was 4 L/h and the harvest flow 2 L/h.

3. Identification of problems

Some failures in the breadboard were noticed during the operation/testing period. Most of them were not expected during the hardware testing and could not be adapted before being tested with the algal suspension. The problems were related to the un-sufficient separation efficiencies of the ultrasound unit even at high field intensities (results discussed in technical note 72.9.2).

1. Low performances of the micro gear pump (P3) during operation of the recirculation gear pump (P4) of the ultrafiltration unit. P4 was applying a suction force on the filtrated stream from the ultrasound unit also during the “off” time of the ultrasound controller leading to a wash out of the agglomerates from the resonance chamber instead of settling back to the concentration tank.

2. Pump P3 was over-dimensioned in its initial concept. It was running at less than 10% of its capacity leading to some losses in its performances. As shown in Figure 3, the pressure delivered by the pump is rather low for low flow rates. As indicated in technical note 72.9.2, the harvesting flow rate of the alga was fixed at 2L/h (this is 33.3 ml/min). In this range, the pressure delivered by the pump is rather low (Figure 3). Therefore, it was decided to replace the pump by another with higher performances at lower flows.

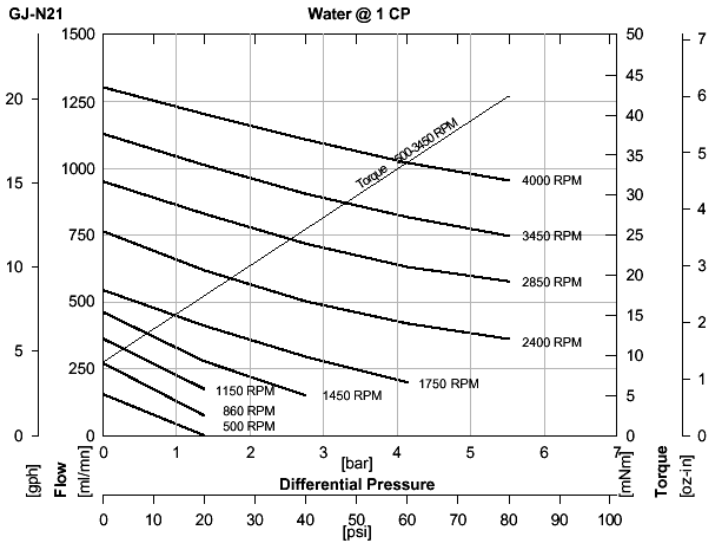

Figure 3. Performances of the Magnetic Drive Gear Pump P3

4. Solutions for the problems

For each failure in the breadboard, a solution was proposed and adaptations have been made. The breadboard was again tested after the changes have been made to investigate the possibility to increase the separation efficiencies of the ultrasound unit. The changes made on the breadboard are presented in Table 2.

Table 2. Origin of the problems and proposed solutions

Problem during *Arthrospira platensis* concentration	**Solutions**
Low performances of the micro gear pump (P3)	Initiation of a pressure build up (0.7 bar minimal) by placing a back pressure regulator at the outlet of the filtrate (after valve 10, Ref: Figure 1) to avoid that pump (P4) takes over the functions of P3 and therefore of the ultrasound controller
over-dimensioning of the micro gear pump (P3)	Replacement of the pump (P3) by another with higher performances at lower flows (same type)

5. Energy requirements of the breadboard

Table 3. Power consumption of the breadboard

Element	Effective used capacity	Number	Power (W)/unit	Effective Total Power (W)	Effective power used by the harvesting system (W)
Peristaltic pump (P1)	20%	1	207	41.4	NC
Peristaltic pump (P2)	20%	1	207	41.4	41.4
Micro gear pump (P3)	10%	1	253	25.3	25.3
Magnetic gear pump (P4)	10%	1	207	20.7	20.7
Cooling bath temperature control (KT1 and KT2)	70%	2	1550	2170	NC
Cooling bath (K1 and K2)	70%	2	2600	3640	NC
Ultrasound cell	100%	1	10	10	10
Ultrasound controller	100%	1	150	150	150
Magnetic stirrer (R1)	20%	1	25	5	NC
Stirrer (R2)	30%	1	17	5.1	5.1
Stirrer (R3)	30%	1	17	5.1	5.1
Lamp set	30%	56	35	588	NC
Total power of the system(Watt)					**257.6**

NC: Not considered since the use of not optimised commercial hardware.

The energy requirements of the harvesting system are about 258 watt during the running period of 8 hours per day (discontinuous operation mode). The growth of the alga however is a continuous operation mode and is not included in the energy requirements of the harvesting system since the use of commercially available material. This excludes indeed some elements, like the lighting system, the cooling baths, the influent pump and the stirrer R1 which have not been optimised for the purpose of this study and which consume quite a lot of energy. Thus the total energy consumed during the operation of the harvesting system is of about 2 kwh to process 5 litres of algal suspension. To harvest 1 m^3 of algal suspension, around 413 kWh/m^3 would be required. This corresponds more or less to the requirements for the selection of the LSSS. The best energy consumption would be in the range of 50 to 100 kWh/m^3. Since the harvesting system, mainly, the pumps were not selected because of their low energy consumption, it would be interesting in the future perspectives for the upgrading of the harvesting system and its space adaptation to study and optimise the energy consumption aspects of the hardware.

6. Mass of the breadboard

As for the energy consumption, the mass of the hardware was not optimised for this study. As already mentioned, the major aim was to test the breadboard for its efficiency to harvest and desalinate *A. platensis*. However, to have a global idea about the system, we presented in Table 4 an overview of the mass of the breadboard.

Table 4. Mass of the global hardware for *Arthrospira platensis* harvesting

Element	**Number**	**Weight (Kg/unit)**	**Total Weight (Kg)**
Peristaltic pump (P1)	1	4.1	4.1
Peristaltic pump (P2)	1	4.1	4.1
Micro gear pump (P3)	1	5	5
Magnetic gear pump (P4)	1	5	5
Cooling bath temperature control (KT1 and KT2)	2	30	60
Cooling bath (K1 and K2)	2	2.5	5
Ultrasound cell	1	1.5	1.5
Ultrasound controller	1	3.5	3.5
Magnetic stirrer (R1)	1	2.4	2.4
Stirrer (R2)	1	0.8	0.8
Stirrer (R3)	1	0.8	0.8
Photobioreactor (empty)	1	15	15
Buffer tank (empty)	1	17	17
Concentration tank (empty)	1	9	9
Washing tank (empty)	1	7	7
Lamp set with support	1	50	50
Electricity box (regulation halogen lamps)	1	70	70
Electricity box for (system alimentation)	1	50	50
Holding bench	2	20	40
Total weight			350

In the selection criteria reported in TN 72.6, it was decided, in the best conditions, to satisfy a 10 to 50 kg/m^3 occupied space. In our case, the system would fit in the category of 50 to 100 kg/m^3 since the volume occupied by the breadboard is about 4.5 m^3 . It is therefore important to study in the future the possibility to compact the system in order to fit in the best category for space adaptation.

7. Conclusions

The general evaluation of the breadboard for the harvesting of *Arthrospira platenis* was quite positive. Minor changes have been applied to the system to fulfil the major requirements. Separation efficiencies of 100% were obtained thanks to the combination of two liquid solid separation systems: the ultrasound unit completed with the ultrafiltration unit. Since the ultrasound unit was aimed to concentrate the alga up to high levels (90 to 95%), meaning that biomass concentration factor should be equivalent the volumetric concentration factor, the changes on the breadboard were made to reach this level of efficiencies. Indeed, the tests performed on the breadboard after changes have been made, were very promising. Separation efficiencies reaching 93% were obtained by the ultrasound unit. 100% separation efficiencies were obtained after the resting 7% of cell suspension had passed the ultrafiltration unit.

One of the desalination requirements was to study the option to desalinate the algal suspension down to very low salts contents (< 0.3 g/L) as suggested by GEPEA-Nantes University, mainly through several washing steps. However, as already observed in our tests and the tests performed by GEPEA-Nantes University, the option to re-suspend the alga in demineralised water was not the most promising since the cell integrity was almost lost, certainly after applying two successive washing steps. Therefore, it was though to wash the algal suspension with the filtrate generated by the system after treating it with electrodialysis to remove the salts, as was the option in the study of the breadboard reported in technical note 72.6.

Desalination efficiencies around 82% were obtained after only one single washing step. The conductivity of the suspended alga after washing was between 3.5 mS/cm and 4.5 mS/cm. This seems to be quite satisfying since the high salts content of the influent ($EC_{influent}$ was around 21 mS/cm) . It is doubtful that growth of *Arthrospira* on full strength Zarrouk medium will occur in the final MELiSSA concept. A reduction in the salinity of the feed to compartment IV will of course be beneficial in terms of chemical consumption and desalination efficiency which will give lower conductivity in the final re-suspended suspension but can only be applied when the growth pattern of *Arthrospira* is not disturbed.

Finally, the requirements related to the potential improvement of the breadboard for space as well as safety issues, energy requirements of the whole system when automated, mass, volume and the influence of its mass in microgravity conditions are discussed in technical note 72.10. However, more attention must be paid to the study of thermodynamics for the cooling system dedicated to maintain *A. platensis* in the buffer tank at 4°C before its processing. Here again, the required energy consumption should be balanced with the needs and depends on the surrounding temperature and the needed liquid temperature.