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# MELISSA

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## Pilot Plant Gas Loop Review

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# 1 INTRODUCTION

The advance of the MELISSA project as a tool for the study and development of Advanced Life Support Systems (ALS), requires to set up an integration loop, in a physical location, such as the MELISSA Pilot Plant. During previous phases, the MELISSA pilot plant has been devoted to the development of the individual compartments of the loop. To this purpose a systematic approach has been followed in a wide range of tasks. Those include the selection of strains, study of their growth kinetics at different conditions, design and set-up of the corresponding bioreactors and associated instrumentation, development of the corresponding mathematical models, characterisation of the continuous operation of the compartments and test of control laws. The research done has been mainly focused on compartments II, III and IV. As a main result, the interconnected operation of these compartments at two different sizes, bench scale and pilot scale, has been achieved for long periods of time ranging from weeks to months.

In order to complete the objectives envisaged since the elaboration of the project concept, and in order to demonstrate the validity of MELISSA as a model system for biological ALSs, the closure of the loop of compartments in the Pilot Plant has to be completed. This goal will be reached in a gradual way following a step by step approach during the following years.

Attainment of this goal is a very complex task that requires a careful design, combining all the information and conclusions generated during the previous years of research, including the different MELISSA brainstorming sessions and design meetings, together with a thorough preparation, scheduling and meticulous implementation. A preliminary review of the Pilot Plant integration loop has previously been done as a starting point (Godia *et al* 2001) and its description is going to be refined in this and future technical notes.

This technical note is devoted to the description of the preliminary engineering design of the gas loop to be installed in the MELISSA Pilot Plant laboratory and is complementary to technical notes 62.3 and 62.5 describing correspondingly the design of the liquid loop and the solid loop components of the MELISSA complete loop. Its purpose is to describe in a general way the different composing elements and their interconnections of key relevance in the treatment of the gas phase components of the MELISSA loop concept. This description will be the base line for its physical implementation in the upgraded MELISSA laboratory.

# 2 COMPARTMENT SET UP DESCRIPTION

## 2.1 General overview

Before a more detailed description of the gas loop corresponding to each one of the particular compartments, some general aspects regarding the design of the gas loop can be generalised for the complete MELISSA loop. These general aspects can be summarise as follow:

a) The major part of the reactors has to operate maintaining the axenicity of the cultures. To this purpose gas filtration units will be used.

b) An efficient pumping system in order to assure positive pressure in head of reactors and maintain a certain constant gas inflow-rate for the proper operation of the different reactors.

For this reason, the structure shown in figure 1 will be applied to all compartments. As can be observed in this figure, a pressure regulator is placed in the gas outflow of the compartment otherwise the suction of the compressor would produce a strong decrease in the head pressure of the reactor. In that way, this pressure regulator will assure a positive pressure in the head of the reactor. To improve the versatility of the compressor a pressure regulator is also used in the compressor discharge. To efficiently measure and/or control the gas flow-rate that is leaving the compartment a mass flow-meter is used.

There are two main possibilities to design the oxygen supply to aerobic compartments (nitrifying compartment and crew). Firstly, to use a pure oxygen gas stream to feed and regulate inflow oxygen concentration to aerobic compartments. The main drawback of this possibility is that to obtain a gas stream with a high content in oxygen is necessary to use physicochemical separation processes. On the contrary, the regulation of the oxygen composition leads to a very much stable and controlled process. Furthermore it allows to maintain independent the gas compositions of the producer compartments (higher plants and *Spirulina*) from the main consumer compartment that is the crew. The oxygen and carbon dioxide, separated using physicochemical methods are stored in oxygen and carbon dioxide buffer tanks. In the next sections this approach will be used because it allows to treat independently the gas environmental conditions of the compartments. Thus the crew compartment can be maintained at the optimal conditions for their health while the higher plant compartment can be operated at the best composition for their growth. The separation technology to use for oxygen and carbon dioxide will have to be defined in future studies.

Secondly, it is possible to use directly part of the gas produced in compartments IVa and IVb as oxygen supply for aerobic compartments. In that case, the gas composition in the outflow of compartments IVa and IVb and the gas composition in the inflow to compartments III and crew compartment is very similar to the air composition, but with a slightly higher content in oxygen in the case of oxygen producer compartments and with a slightly higher $CO_2$ content for oxygen consumer compartments. This configuration is not easy to maintain under control because a pure oxygen gas stream is not available to regulate oxygen concentration in the gas inflow to the aerobic compartments.

A general scheme of the overall gas loop is shown in figure 2, for a more detailed explanation about the gas loop design corresponding to each compartment see sections 2.2 to 2.6.

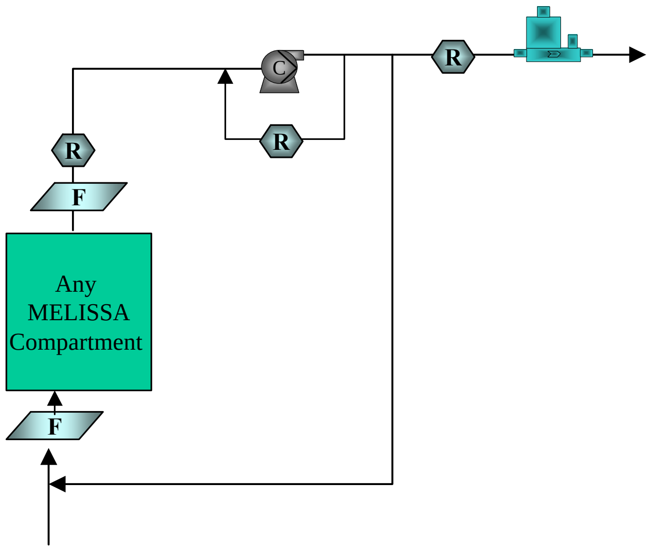


Figure 1.- General scheme of the gas loop for any of the MELISSA compartments. R: gas flow regulator. F: sterility filter. C: compressor.

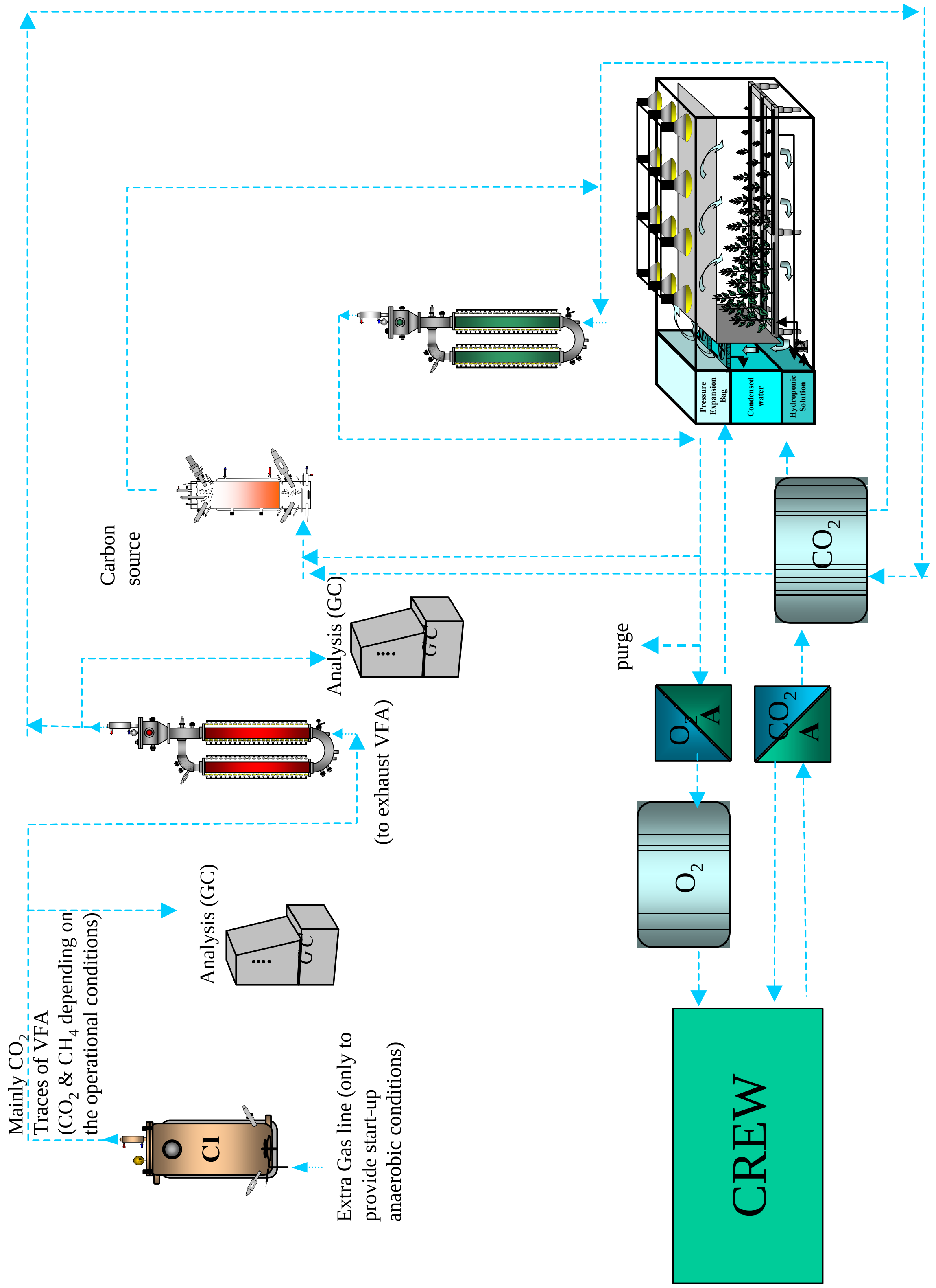


Figure 2.- General overview of the gas loop.

## 2.2 Compartment I

Despite the final design of the pilot reactor of the first compartment of the MELISSA loop is still under study by EPAS, a first approach to the gas loop configuration is presented in figure 3. The main structure of the gas loop is as it has already been discussed in previous section but with a main difference. Although the micro-organisms used in this compartment are anaerobic, an extra-gas line will be needed in order to provide start-up anaerobic conditions. The gas recirculation is used to improve the control of the head pressure for whatever operational conditions applied to the reactor (although in this compartment, is not strictly necessary) and also to keep a constant pressure for the analyser.

On the other hand, degradation will produce a gas flow. The composition of this stream is expected to be mainly $CO_2$ (but it will also contain volatile fatty acids (VFA) traces). Methane production will be inhibited in the operational conditions used. The gas outflow will be stored in a buffer tank, nevertheless this gas will be used to feed other compartments (compartment IV: the Higher Plant Compartment as well as the *Spirulina* compartment) and for this reason, it will be necessary to measure the gas composition (preliminary, a gas chromatograph is proposed to be used) and the VFA content have to be controlled (minimised). To remove the VFA content from the gas stream, two possibilities are proposed: to feed the complete stream to the second compartment to exhaust VFA traces and/or to remove it using the Biological Air Filter (BAF).

## 2.3 Compartment II

The structure of the gas loop corresponding to compartment II is presented in figure 4. The scheme has been developed tacking into account that the gas stream produced in compartment I (that will contain VFA traces) is the gas inflow to compartment II. Otherwise, if this possibility is not considered, only an extra gas line will be needed during start-up as gas inflow for this compartment.

The gas recirculation is again used to improve the head pressure control, as it has been discussed previously for compartment I. An on-line gas chromatograph is proposed to be used to measure the outflow gas composition. This outflow stream will be stored in a buffer tank and its composition is mainly $CO_2$. The buffer tank will feed compartments IVa (*Spirulina*) and IVb (Higher Plant Compartment).

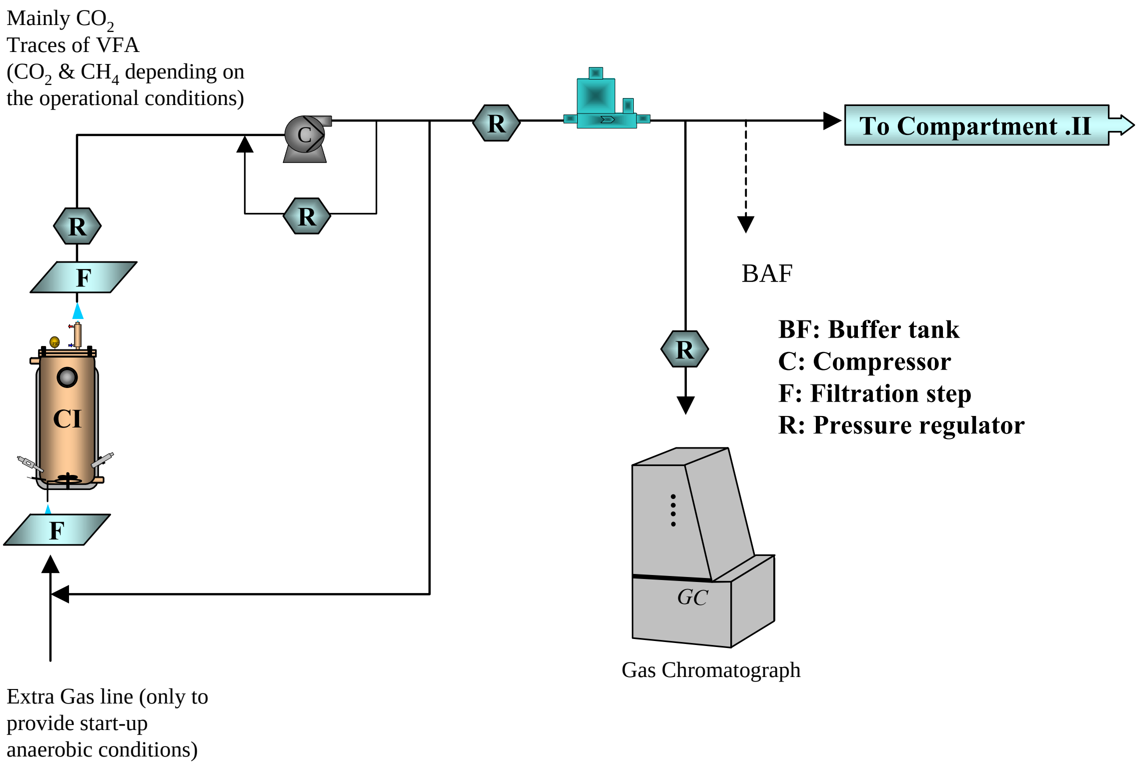


Figure 3.- Design of the gas loop in the first compartment of the MELISSA loop.

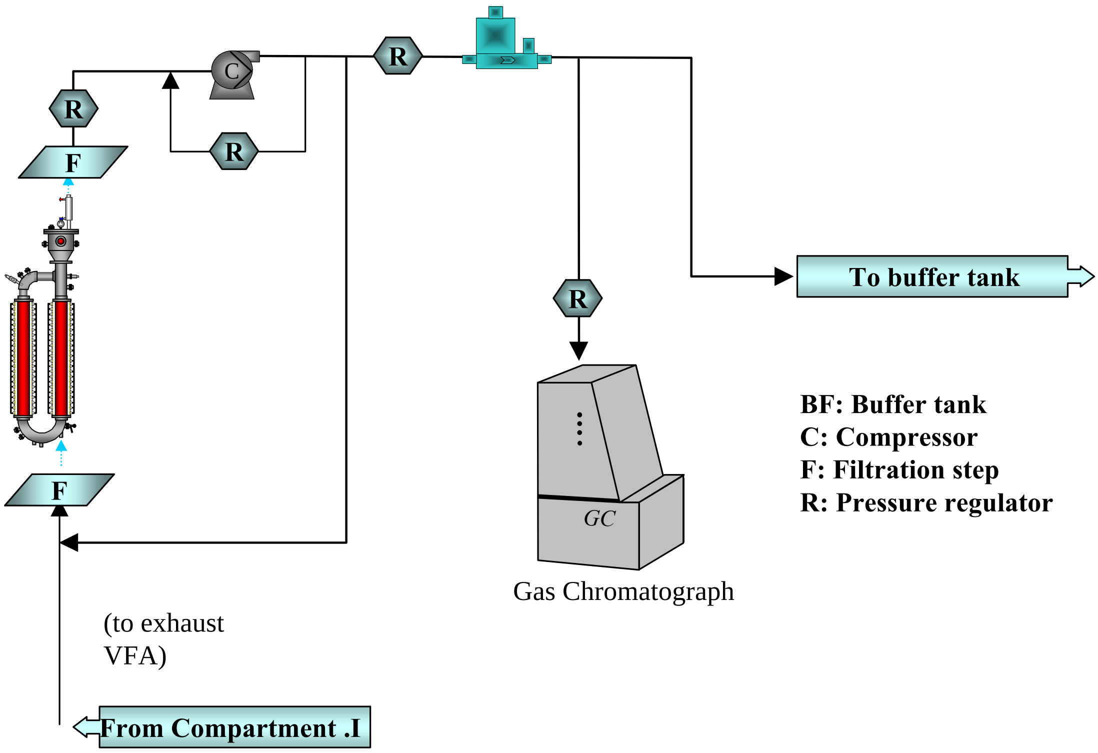

Figure 4.- Design of the gas loop in compartment II of the MELISSA loop.

## 2.4 Compartment III

The gas loop design for compartment III is presented in figure 5. As can be observed, the carbon source for this compartment will be supplied from the gas phase and the buffer tank containing mainly $CO_2$ is used to this purpose. To control $CO_2$ addition to the reactor a mass flow-meter is used.

The aeration is provided from the compartment IV, and the gas outflow is reused to feed *Spirulina* compartment. On the other hand if the nitrifying compartment eventually need an extra oxygen supply, then it can be provided from the oxygen buffer tank. The final configuration of the interconnection might depent on the availability of specific technology to separate $CO_2$, $O_2$ and $N_2$.

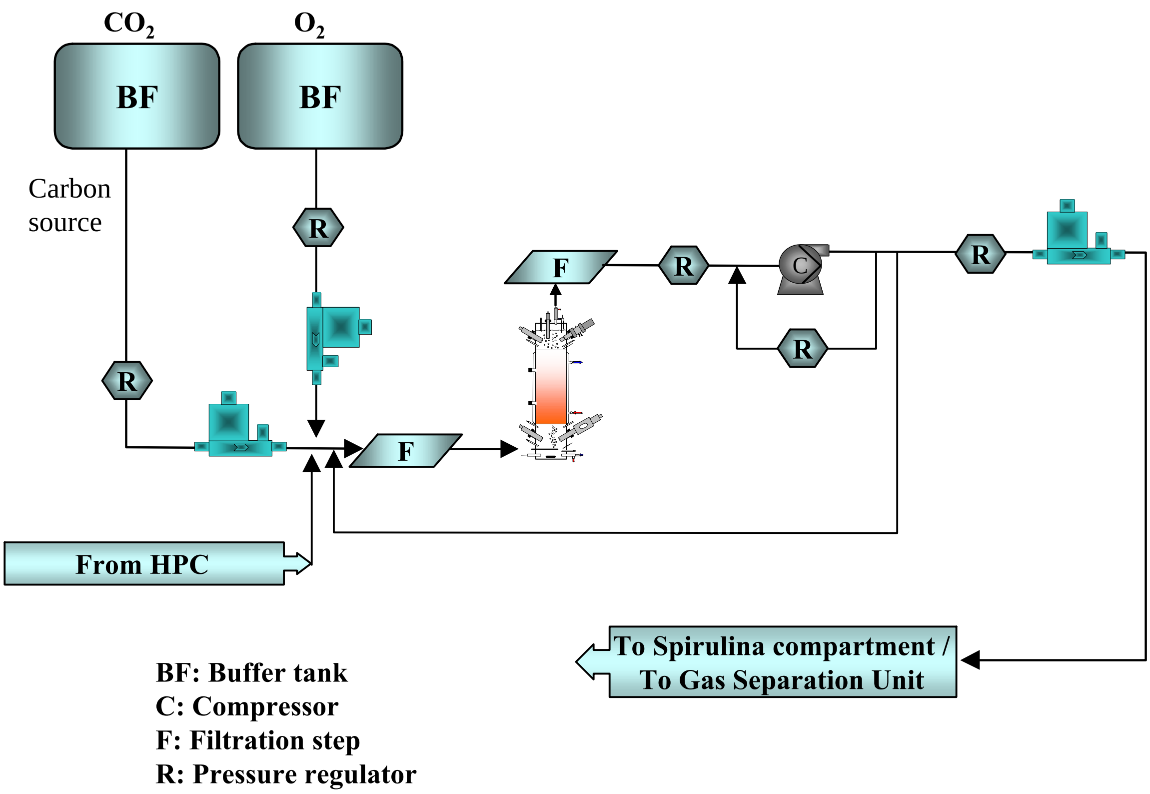


Figure 5.- Design of the gas loop in nitrifying compartment.

## 2.5 Compartment IVa and IVb

The design of the gas loop for the *Spirulina* compartment is shown in figure 6. $CO_2$ is provided from the buffer tank. The gas outflow from this compartment is treated together with the gas outflow from HPC (Higher Plant Compartment or compartment IVb) to separate the oxygen produced, as it has been already discussed in section 2.4.

In the case of the HPC (figure 7), the gas inflow is provided with the gas already treated to separate the oxygen, and $CO_2$ can be regulated by adding $CO_2$ from the buffer tank. The composition will be measured to assure suitable composition before entering to this compartment.

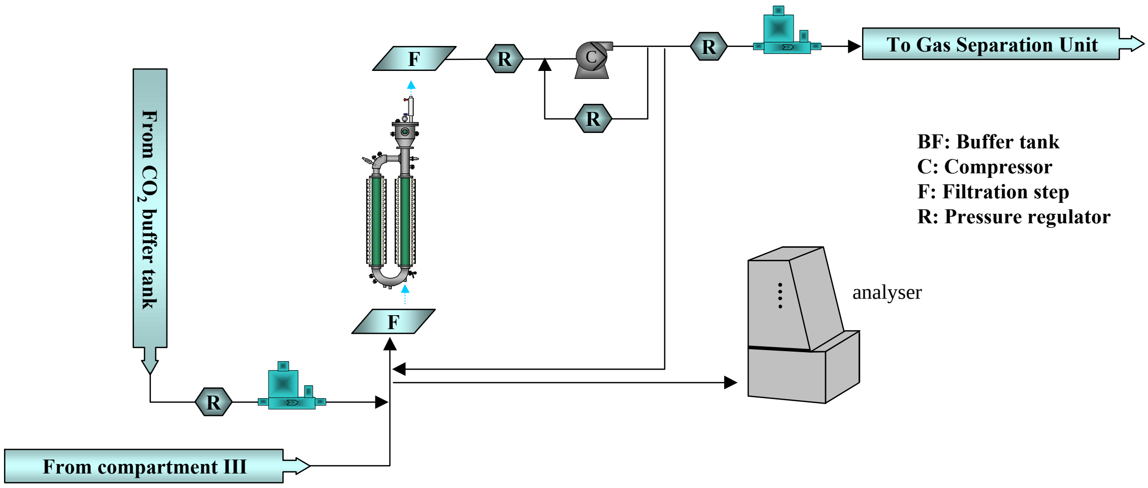


Figure 6.- Design of the gas loop in compartment IVa (*Spirulina*) of the MELISSA loop.

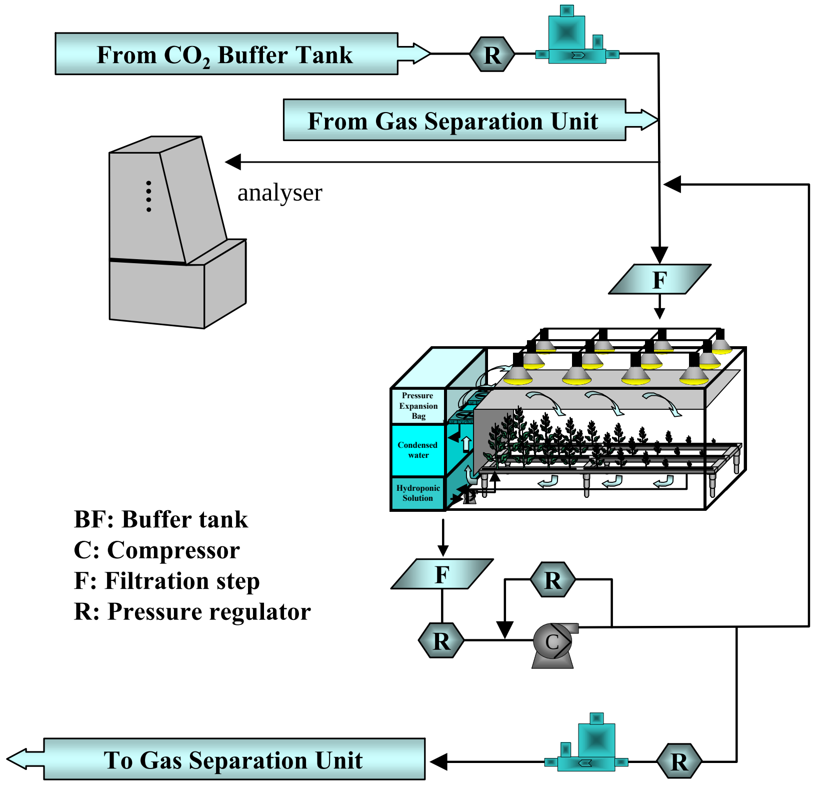


Figure 7.- Design of the gas loop in compartment IVb (Higher Plant Compartment) of the MELISSA loop.

## 2.6 Crew compartment

Crew compartment is one of the final consumers of the oxygen generated in compartments IVa and IVb. Nevertheless, the first scenario to study the MELISSA loop demonstration in the Pilot Plant will be based on rats as simulation for the crew. Eventually, the oxygen production is expected to be very much higher than consumption by crew compartment. For this reason in figure 8, where the scheme for the gas loop corresponding to this compartment is presented, a purge is introduced in the system. The oxygen buffer tank will provide a correct regulation of the inflow oxygen content for the crew compartment. The gas inflow to this compartment will be analysed to assure suitable composition.

The gas outflow will be treated to separate the $CO_2$ produced. After this separation process the air, $CO_2$ free, will be used again to feed the crew compartment, after to add the necessary oxygen proportion from the oxygen buffer tank.

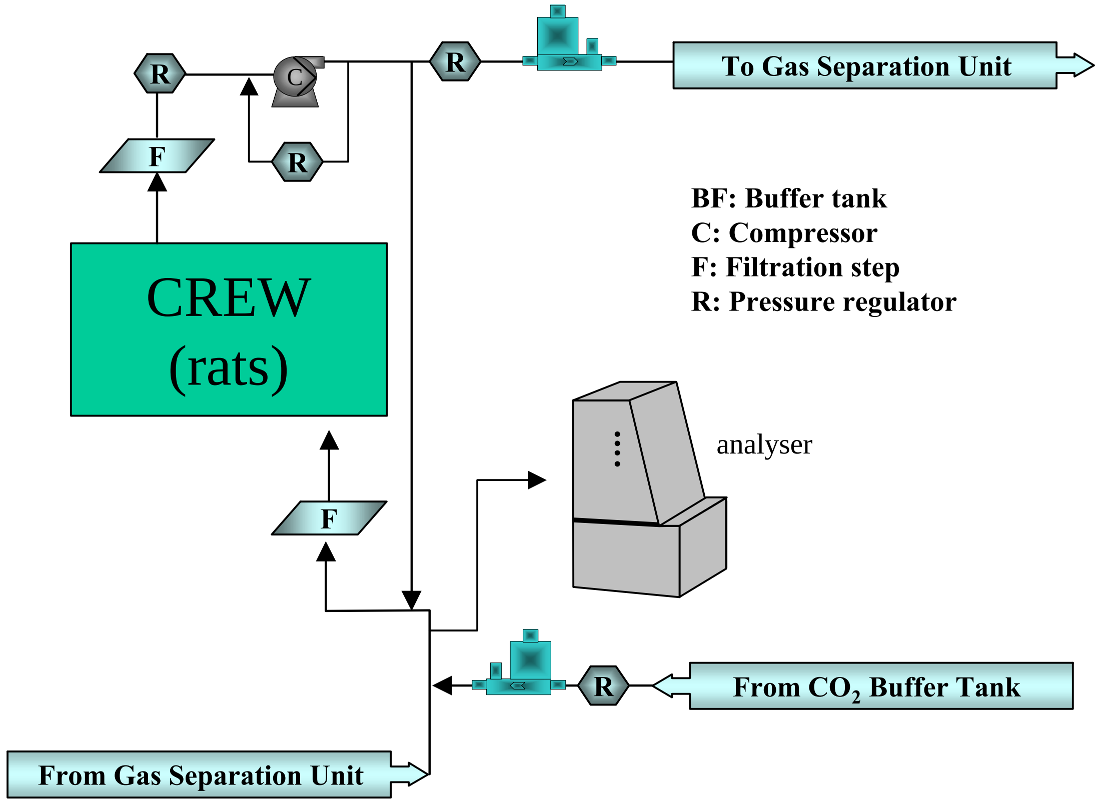


Figure 8.- Design of the gas loop in the crew compartment.

# 3 REFERENCES

**Gòdia, F.; Albiol, J.; Creus, N.; Pérez, J.** (2001) Preliminary Review of the Pilot Plant Integration Loop. Technical Note 47.3. ESTEC/CONTRACT13292/98/NL/MV.