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MELISSA

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Photoheterotrophic compartment set-up

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I. INTRODUCTION

The development of compartment II, and particularly the heterotrophic subcompartment, of the MELISSA loop is being performed at different levels. From the basic point of view, a number of experiments are carried out to characterise the growth of *Rhodospirillum rubrum* cells using different volatile fatty acids in their feed medium, and different illumination conditions. These data will be used to build the kinetic models that will be later applied to the control of this compartment. The first sets of these tests, performed as batch cultures in small volume reactors, have been reported in TNs 37.81 and 37.82. In addition to the completion of this task, a whole set of continuous experiments will have to be carried out in a photobiorreactor, in order to complete the kinetic study and to develop and test the control laws for this compartment, in a similar way as it was done previously for compartment IV. The reactor where these tests will be performed is the air-lift bioreactor that has been used up to this point for compartment IV (*Spirulina platensis* cultures). The exchange of cultures in this bioreactor is done simultaneously to the set-up of the new external loop air-lift bioreactor for compartment IV.

In the present technical note, the modifications performed in order to adapt the 7-litres air-lift bioreactor to the culture of *Rhodospirillum rubrum* cells are documented. Basically this adaptation consists in the following topics: modification of the control loops in order to incorporate new variables and remove those no longer used, the improvement in the liquid delivery system, the change in the gas loop in order to provide anaerobic conditions and the change of the pH control system to a acid-base addition system. A further improvement of this unit will be the acquisition of an on-line monitoring system for ammonium, that will be performed in the next phase of the project. The incorporation of a powerful technique for the on-line measurement of the volatile fatty acids concentration profile in the reactor, such as on-line gas chromatography, will be considered during the realisation of the continuous tests for this compartment, and could be incorporated to the equipment in a future up-grade of its performance.

II. GENERAL DESCRIPTION OF THE REACTOR AND AUXILIARY INSTRUMENTATION

The bioreactor is a 7 litres airlift, with a glass made cylindrical part (riser and downcomer sections) and a stainless-steel gas separation section. The introduction of a gas phase in the riser of the reactor causes a difference in medium density with respect to the downcomer, and provides the internal liquid mixing of the reactor. Also, the gas phase addition causes an overpressure in the reactor headspace.

For the culture of *Rhodospirillum rubrum*, anaerobic conditions are required, and for this reason the gas used in this case is an inert noble gas, such as He or Ar.

The reactor is illuminated around its cylindrical glass part, with halogen lamps. It is a set of 48 lamps (*SYLVANIA* Halogen –Professional de luxe–, 12V, 20 W, ∅ 50 mm). Six 15 V – 18 A power supplies provide the necessary electrical power. The lamps are distributed in six columns, of 8 lamps each, and equally spaced. The light supplied to the bioreactor is varied by the change of the voltage supplied to the lamps.

The pH control system has been changed to a more conventional one. The pH is controlled by an autonomous controller (CRISON *phrocon 18 pH/mV*) which regulates the pH by acid or base addition. Mainly a probe, the controller and two peristaltic pumps with their corresponding bottles of acid (HCl 0.5 M) and base (NaOH 0.5 M) constitute the new pH loop. The calibration of the pH probe is made before starting the experiment following a standard protocol.

Also, two gas analysers are connected to the gas loop, one for the CO_2 (MAIHAK) and the other for O_2 (SERVOMEX). Both can be calibrated during the experiments because they are installed in a line that can be independent of the main gas loop. The gas loop is made of polyamide tubes (LEGRIS, 8 x 10 mm). This material does not allow the flow of air through its wall due to its low gas permeability.

The pressure is controlled by means of a pressure transducer (PHOENIX CONTACT, MCR) that convert difference pressure signals in electrically standardised analogue signals (0-20 mA). The P-100 receives this signal and if the pressure is higher than a safety value an overpressure valve will be opened.

Temperature control is provided through a cooling system and a heater. The first uses an aqueous solution of ethylenglicol (20% v/v) as cooling fluid, the heater is a resistance and the temperature is measured by means of a Pt-100 probe. An external controller regulates both systems.

Finally, the cell concentration is measured on-line by means of a Monitek equipment. This optical system is based on the change of light transmission in the liquid medium due to the presence of cells.

III. CONTROL SYSTEM

III.1. General description

The control system of the MELISSA Pilot Plant has been modified as a consequence of the installation of a new bioreactor for compartment IV, equipped with a new type of controllers. The current structure is presented in Figure 1. Three kinds of stations are differentiated: system, control/command and GPS (general purpose station), which are connected through an Ethernet network, as the previous Arcnet network was replaced. The different stations are PCs, such as COMPAQ-386, COMPAQ-486 or Pentium, having MS-DOS as operating system and equipped with PC extension ports to allow the communication with the corresponding controller. These controllers are of type P-100 for compartments II and III, and ASCON-20 in the case of the new controllers installed in the reactor for compartment IV

III.1.1. System control/command station

This station supports two functions, system management and control/command. The system management function shall be installed in one station only to avoid problems associated to the use of many different configurations. This function allows the manager to customise the system.

Control/command is the active part for process control, that means a direct link exists between the station and the controllers in charge of the process. The station is connected to the P-100 controllers through a vertical communication controller (VCC). A specific CCU board installed in the PC extension port drive the VCC.

III.1.1.a. The P-100 controller

The P-100 controller is a fully autonomous programmable device able to manage up to four regulation loops. At present time the P-100 are configured such as to use two regulation loops because they have only two analogue outputs.

The P-100 has four interfaces with its environment:

- **A user interface** consists of a front face and a lateral dialogue keyboard. The front face allows user to have a global view of regulation loops. The loop states are thus monitored and displayed by means of light bar graphs, numeric values and luminous indicators. The lateral dialogue keyboard is used for configuration and utilisation of the P-100's capabilities; nevertheless a centralised system is more user friendly to manage more than one controller.

- **A lateral communication interface** allows to exchange data with other P-100 or extension modules when used. A maximum of 32 P-100 (62 regulation loops) may be interconnected by this way.

- **A vertical communication interface** to allow the connection with a supervising computer. This connection is made via a VCC-100 that is able to drive up to four controllers. The serial link is a RS-485 half duplex, asynchronous link with a rate of 315.5 kBauds.

- **A process interface** with analogue and digital input/output.

Type	Quantity	Description
Analogue Inputs (AI)	4	Voltage input 0-5 V and 1-5 V Current loop 0-20 mA and 4-20 mA Analogue/Digital conversion 12 bits
Analogue Outputs (AO)	2	Current loop 0-20 mA and 4-20 mA Analogue/Digital conversion 12 bits
Digital Inputs (DI)	4	This inputs may be activated by a relay contact or by an open collector connected to ground.
Digital Outputs (DO)	2	This outputs provide when activated a 125 mA output current under 24 V through an unprotected open collector.

The structure designed for MELISSA compartment II includes one VCC-100 with four P-100's and a logic extension set (24 inputs, 16 outputs) were affected for each compartment in order to have specific electronic control as close as possible to the process. The analogue links are all made using current loops 4-20 mA, but for a low number of links the 0-20 mA current loops is preferred.

The P-100 also drive two regulation loops. A regulation loop program is a set of 20 lines of code, each line containing one of the P-100 internal functions. The set of lines is scanned at an adjustable rate from the first line to the last one. This constitutes the so called internal loop.

There are various internal functions to be used in a loop in order to define a control strategy such as:

- Input an output functions
- Regulation functions
- Mathematical functions
- Sequence control functions
- Logical and jump functions

III.1.2. User station

This station has only the control/command possibilities with, eventually limited access limitations to data, and without any configuration capabilities. It exists however a storage function independent from other stations.

III.1.3. – GPS – General Purpose Station

This station communicates with the control/command station connected to the process, using a set of predefined procedures (GPS programming interface) to read or write data relative to the controlled process.

It can access two types of data:

- TAG read only
- COMMAND read and writes

The system configuration software configures the permission to access/modify data. These are gathered by groups composed of 40 variables each with only one active at a time. This station is intended to support user specific software such as control model and allow a global view of many processes.

This station allows the implementation of a global control strategy using more elaborated knowledge models than it is possible do using the P-100 alone.

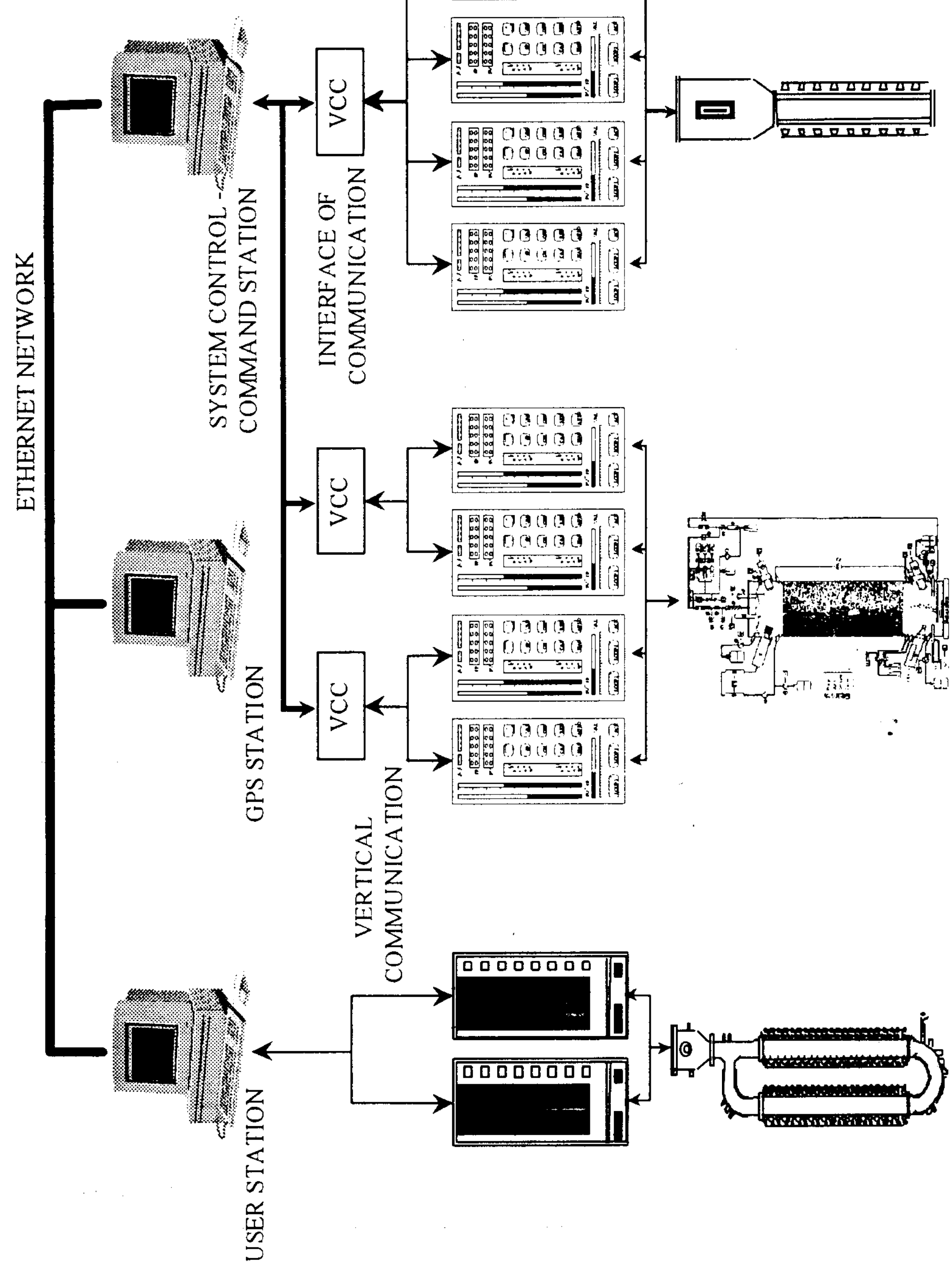


Figure 1: Hardware structure of the Melissa control system

IV. REGULATION LOOPS IN THE PHOTOHETEROTROPHIC COMPARTMENT OF MELISSA

The regulation loops of this compartment were first defined for compartment IV and have recently been adapted to the culture of *R. rubrum* cells in compartment II. This implies also the change of a number of loops. That is the case of the pressure regulation loop, which has to be fitted to the new working conditions such as anaerobic atmosphere. Also, the pH regulation loop has to be modified using HCl to decrease the pH value instead of CO_2, and NaOH to compensate for a hypotethical pH decrease.

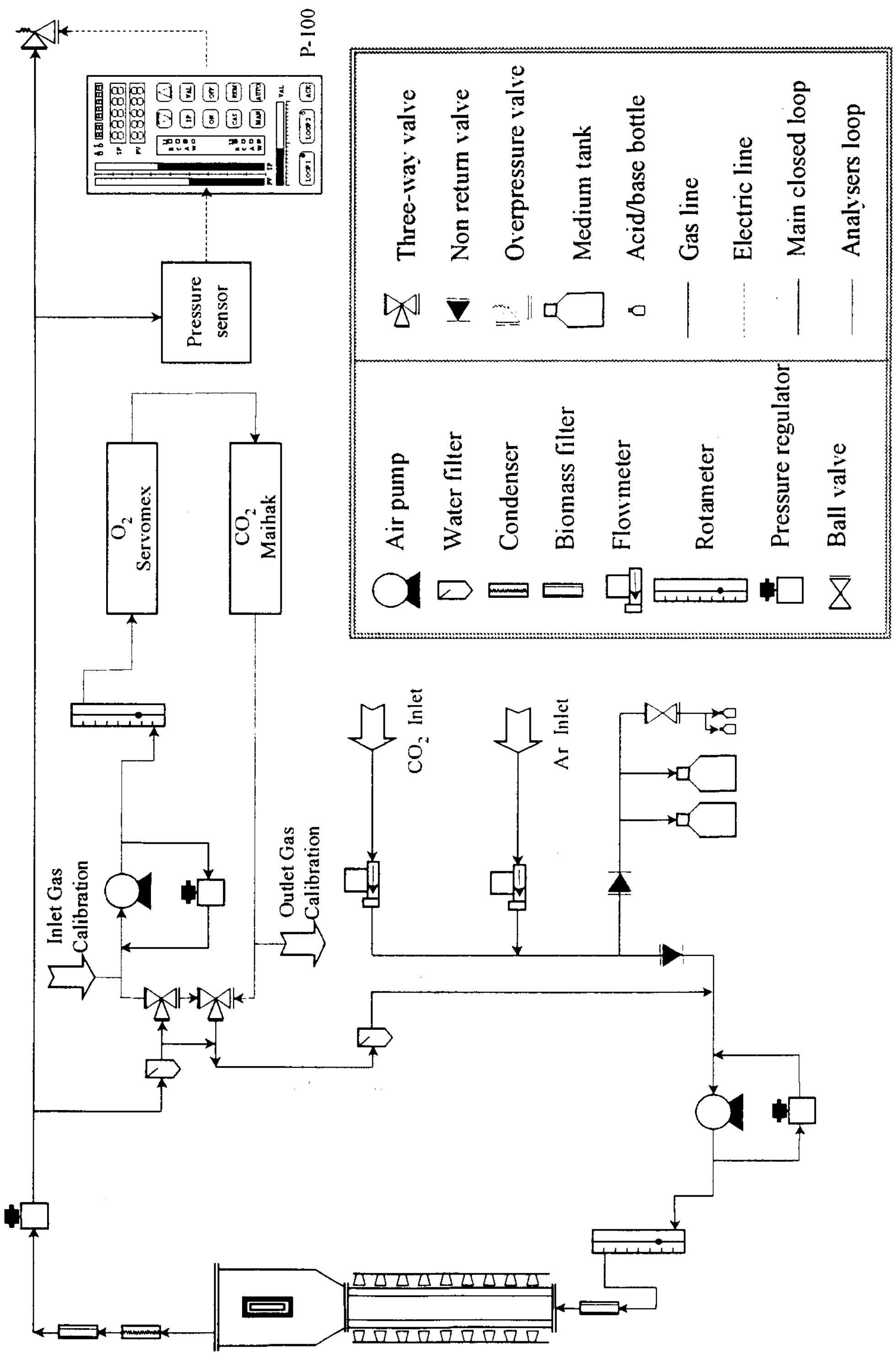
In the next paragraphs, the different control loops for the second compartment of MELISSA are defined. For every loop a synoptic describes the principle and two tables list the operations done for the control, and the TAG and COMMAND variables associated to the controlled loop.

Loop 1 – Alarms and general management

LOOP	Alarms and general management
GOAL	Provide a central management of alarms at controller level, counters resetting and transfer of intermediate results of control into memory location codes (LOC)
MEASUREMENTS	
ACTIONS	The P-100 checks all the loops of the MICON 1 and set-up a general alarm TAG if an alarm occurs on one loop. The alarms are enabled/disabled at controller level and at MICON level by user operation. A general alarm vector is provided in order to allow a quick identification of faults by the user control software. The loop manages also the daily resetting of the totalisers using an external clock.
ALARMS	
INFORMATION	

	NAME	DESCRIPTION
ANALOGUE VALUES	LOC-0122	Main alarm, active=1
	LOC-0121	Alarm vector for Micon 1, sum of the following values if an alarm is set on the controller. Zero if none. 1 → controller 1 2 → controller 2 4 → controller 3 8 → controller 4
DIGITAL VALUES	DO-0101	Electric valve command for pressure regulation
ALARMS		

Loop 2 – Pressure regulation loop



The main characteristic of the pressure loop is the use of a noble gas (Helium or Argon) with the purpose to maintain the mixing of the bioreactor. Air has to be discarded because an anaerobic atmosphere has to exist. Nitrogen cannot be used either, as there would be the possibility of assimilation by *R. rubrum*, at least in certain conditions such as nitrogen limitation.

The gas loop is closed, thus the outlet gas is recirculated to the inlet by means of a compressor. The outlet gas can be mixed with CO_2 and the noble gas if desired just before to be fed again to the reactor. CO_2 allows the bacteria to start quickly to grow up at the beginning of the fermentation, reducing the lag phase. It is also necessary when using long chain fatty acids as a carbon source. The system needs a continuous inlet of Ar to compensate the small leaks. The consumption of Ar is small although is not continuously measured.

The reactor is provided also with an analyser loop, which is connected to the main gas loop by means of two three-way valves. These valves allow to disconnect the analysers from the main loop when they have to be recalibrated, making both loops independent. The analyser loop is composed mainly of an O_2 Servomex analyser an a CO_2 Maihak analyser.

There is a system for flow rate regulation at the beginning of the analyser loops, because the gas flow rate in the analysers have to be constant and to be inside an specific interval of flow (0-1.67 $l \cdot min^{-1}$) and constant pressure. This regulation is achieved by an air pump, a pressure regulator and a rotameter, all connected in series and in this order. So, at the gas outlet of the reactor, after passing the condenser and the filters, the gas flow is divided in two streams of approximately the same value. One part is passing through the analysers and the other one is bypassing the analyser loop.

It is important to remark that all, including the bottles of acid and base of the pH regulation loop and the different tanks are all connected to the Ar line, with the purpose of avoiding the entry of O_2 inside the reactor.

One possible drawback in the operation of this loop is that the pressure sensor is connected after the condenser and the filter, so it does not have a direct measure of pressure at the top of the reactor. So, the pressure value that is reading the Micon is the pressure after the filter, which is different of the reactor pressure and could vary independently.

LOOP	Pressure
GOAL	Maintain the pressure of the gaseous phase under a set point.
MEASUREindependentlyMENTS	Pressure sensor connected to the air lift. Characteristics: • Range 0 to 1000 mbar • Continuous measure • Calibration none • Direct value
ACTIONS	The P-100 controls aperture of the valve during a fixed bed time when the pressure is upper the set point.
ALARMS	
INFORMATION	

	NAME	DESCRIPTION
ANALOGUE VALUES	AI-0101	CO_2 analyser Maihak output
	AI-0102	O_2 Servomex output
	AI-0103	Gaseous pressure in air lift
	LOC-0102	Pressure regulation loop
	LOC-0114	Counter of the valve command actions
	LOC-0115	Totalisation of the pressure regulation command
DIGITAL VALUES	DI-0121	Range switch CO_2 analyser
	DO-0121	Electric valve command for pressure regulation
ALARMS		

Loop 3 – Ammonium measurement loop

This loop has been left free for the future configuration of the loop for ammonium measurement.

Loop 4 – pH regulation loop

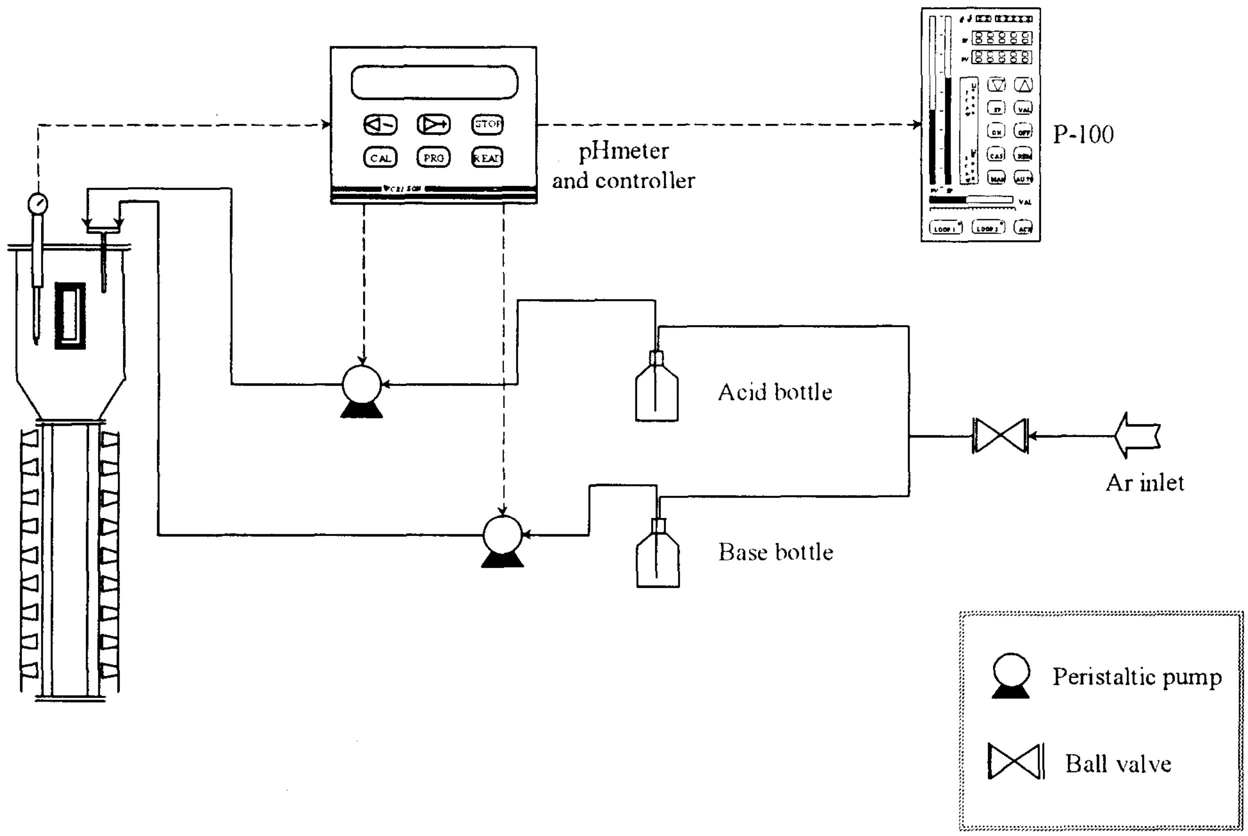


Figure 3: pH regulation loop

The P-100 is reading the pH value by means of a 4 – 20 mA current which is an analogue output of the controller.

It is important to realise either the acid and the base bottles are connected to the Ar line, thus an inert atmosphere in both bottles is maintained. There is a valve in the noble gas inlet in order to reduce the pressure of the line.

LOOP	pH
GOAL	Maintain the pH in culture medium around a fixed value to compensate the pH increase due to *R. rubrum* growth.
MEASUREMENTS	The pH is measured with a pH probe in the bioreactor liquid phase.
ACTIONS	The pH controller (*CRISON pHrocon*) controls the addition of acid and base to the bioreactor.
ALARMS	
INFORMATION	

	NAME	DESCRIPTION
ANALOGUE VALUES	AI-0101	CO_2 measurement
	AI-0102	O_2 measurement
	AI-0105	pH measurement
	AI-0113	pO_2 measurement
	AO-0104	pH regulation command
	LOC-0104	pH regulation loop
	LOC-0113	Totalisation of pH regulation action
	LOC-0117	CO_2 computed value
	LOC-0112	Regulation action
DIGITAL VALUES	DI-0121	CO_2 range
	DO-0126	Alarm switch of thermostatic bath for air-lift condenser
	DO-0124	Enable power supply of mixing pump
ALARMS		

Loop 5 – Light regulation loop

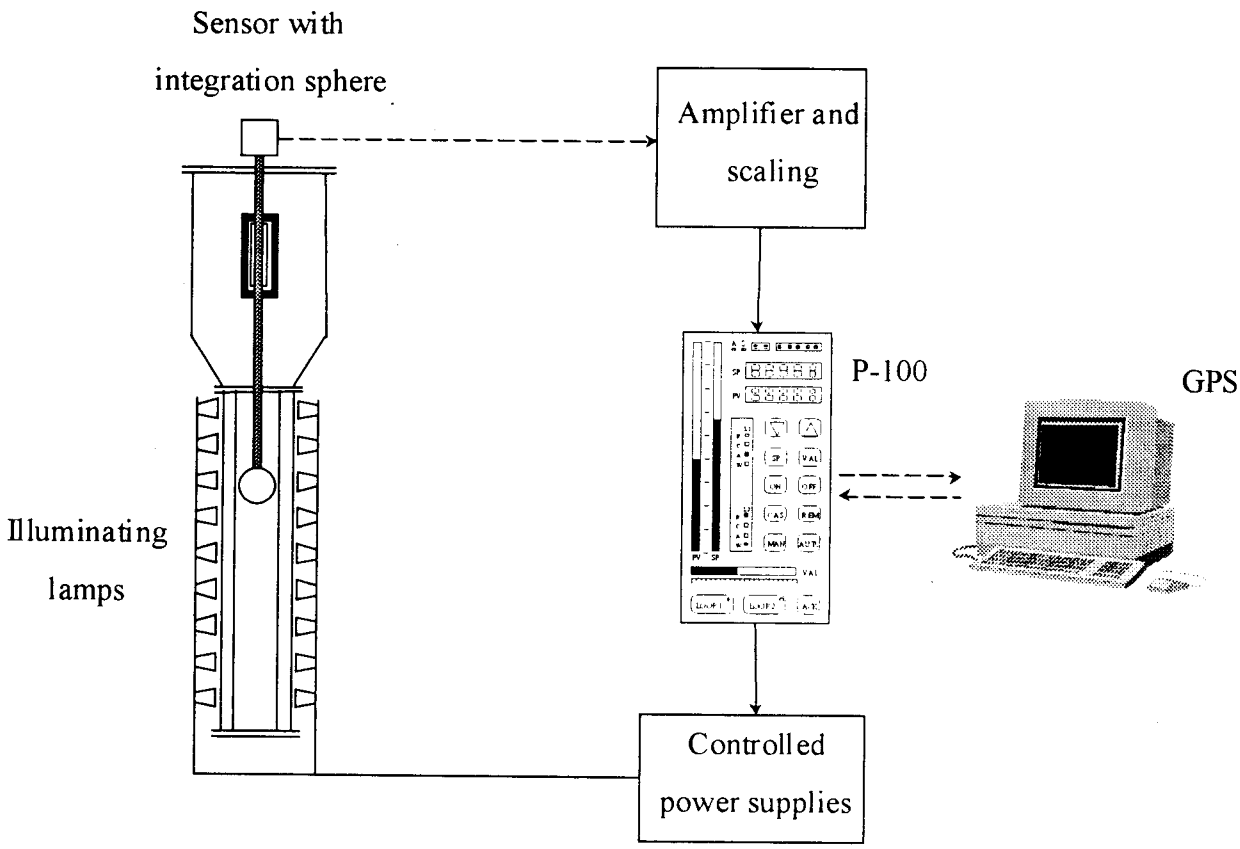


Figure 4: light regulation loop

The light regulation loop has suffered no modification with respect to the previous configuration. The light calibration has been made as explained by Vernerey in the Technical Note 37.110. (Vernerey *et.al.* 1997). The calibration relationship between the radiation energy at bioreactor surface (Fr) and the controller output value is included in the GPS station. In this way, it is able to modify the light intensity value. It is possible to use the knowledge model in order to know the average radiation intensity at every point of the bioreactor.

Nowadays, the spherical light sensor is not used for control purposes. The reason being that at certain values of biomass concentration and illumination conditions, the Fr value calculated from its measure differs significately from the Fr obtained by the calibration relationship between the radiation intensity and the P-100 output.

LOOP	Light intensity regulation
GOAL	Maintain the light intensity inside the bioreactor around a set point.
MEASUREMENTS	The light is collected by an integration sphere in the middle of the bioreactor and lead to the sensor by an optical fibre. Characteristics: – Eb range 0 to 5000 $W \cdot m^{-2}$ by use of four scales (Fr: 0-500 $W \cdot m^{-2}$). – Continuous measure – Calibration done before starting the culture
ACTIONS	The P-100 controls the power supplies to have the desired intensity inside the bioreactor.
ALARMS	
INFORMATION	

	NAME	DESCRIPTION
ANALOGUE VALUES	AI-0112	Light measurement, raw value
	AO-0105	Power supplies control
	LOC-0105	Light regulation loop
	LOC-0119	Light measurements, computed value
	LOC-0110	Totalisation of the light regulation action
DIGITAL VALUES	DI-0129	Light range 0 to 5000 $W \cdot m^{-2}$
	DI-0130	Light range 0 to 500 $W \cdot m^{-2}$
	DI-0131	Light range 0 to 50 $W \cdot m^{-2}$
	DI-0132	Light range 0 to 5 $W \cdot m^{-2}$
ALARMS		

Loop 6 – Temperature regulation loop

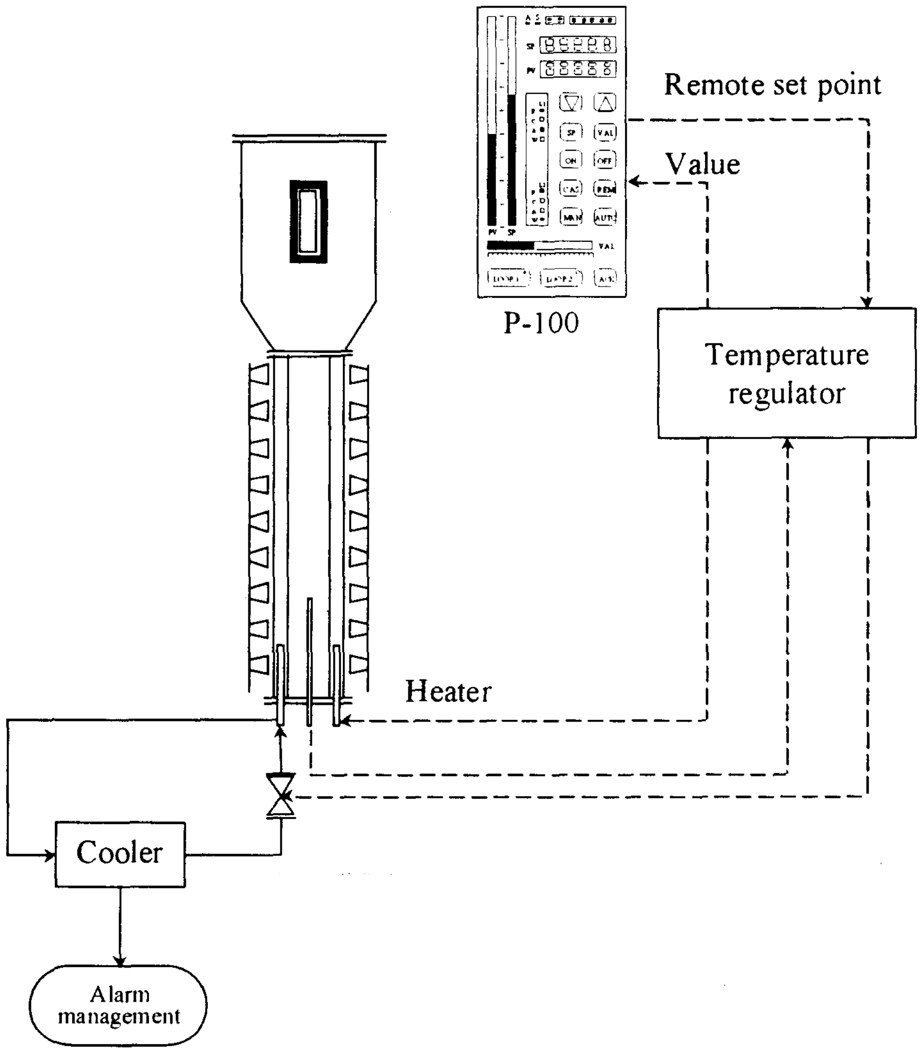


Figure 5: temperature regulation loop

The temperature regulation loop has not suffered any modification, although it has difficulties to maintain the temperature around a set point when the intensity of the light is varied.

Basically the loop consists of a cooler and a heater. Both are controlled by a temperature regulator, which sends a 4-20 mA analogue output to the P-100 and receives the remote set point from it.

LOOP	Temperature
GOAL	Maintain the temperature of the culture around a set point.
MEASUREMENTS	A probe measure the temperature of the medium, the temperature controller provide the value to the P-100. Characteristics: – Range 0 to 150 °C – Continuous measure – No calibration necessary
ACTIONS	All the regulation actions are performed by the temperature regulator. The P-100 can only modify the value of the set point.
ALARMS	In case of failure of the cooler, the light set point is reduced in order to limit the radiation energy coming from the lamps.
INFORMATION	

	NAME	DESCRIPTION
ANALOGUE VALUES	AI-0110	Temperature measurement
	AO-0106	Set point output for temperature
DIGITAL VALUES	DI-0127	Alarms switch of the thermostatic bath for the temperature regulation
ALARMS		

Loop 7 – Biomass regulation loop

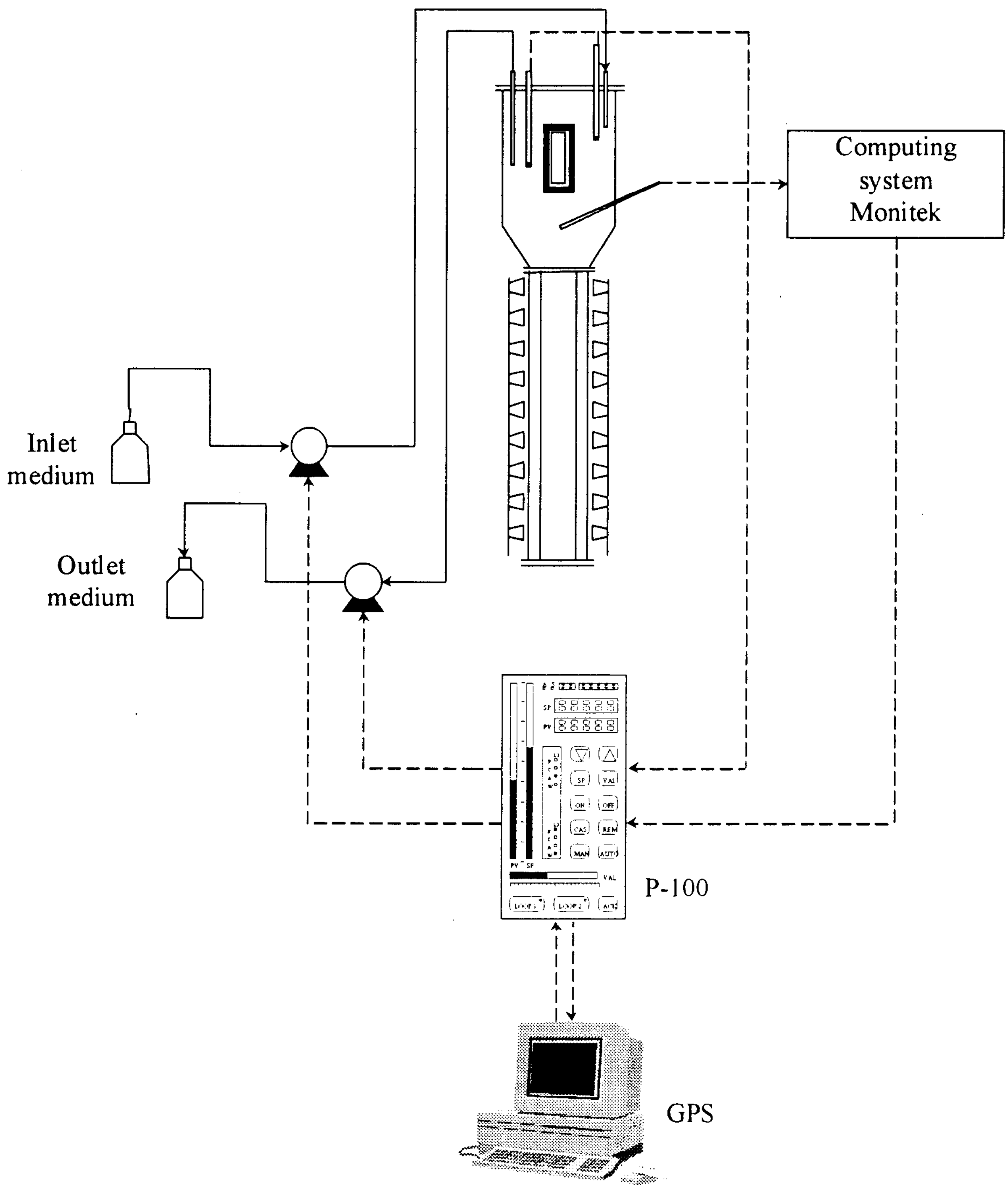


Figure 6: biomass regulation loop

The biomass is regulated by the inlet medium pump (membrane pump), which is commanded by the P-100 and in the last term, the GPS.

The GPS decides the value of the inlet medium flow rate and sends to the P-100 the output controller value, by means of a linear regression.

The bioreactor has a biomass probe which provides a 4-20 mA to the P-100.

LOOP	Biomass
GOAL	Maintain the biomass concentration in culture medium around a set point to compensate the *R. rubrum* growth.
MEASUREMENTS	A biomass probe measures attenuation of a light beam through the culture, then a correction law is used by the controller to calculate the biomass concentration in the reactor. Characteristics: – Range 0 to 2 absorbance – Continuous measure with two different damping factors, one for low variations and one for high variations. – Calibration before starting the culture for zero value. During the culture, measurements on samples may be use to check and correct the biomass measurement.
ACTIONS	The P-100 controls input of medium. The extraction of medium is managed by the liquid level regulation loop.
ALARMS	
INFORMATION	Totalisation of action allows volumetric growth speed calculation.

	NAME	DESCRIPTION
ANALOGUE VALUES	AI-0114	Monitek attenuation (0-2)
	AO-0107	Biomass harvesting pump command
	LOC-0107	Biomass regulation loop
	LOC-0118	Monitek attenuation
	LOC-0120	Computed value of biomass concentration
	LOC-0111	Totalisation of biomass regulation action
	LOC-0123	% action regulation
DIGITAL VALUES		
ALARMS		

Loop 8 – Liquid level regulation loop

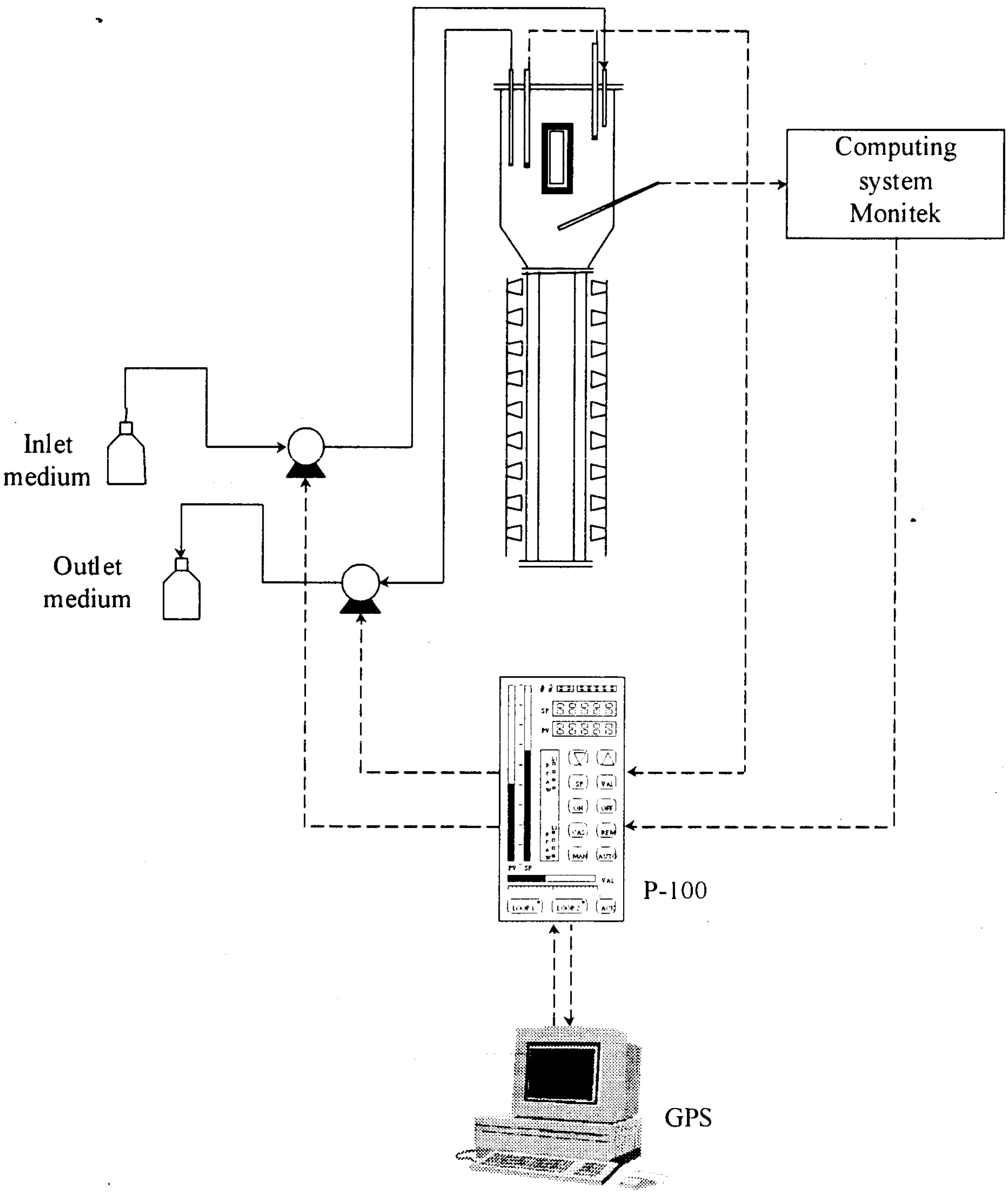


Figure 7: biomass regulation loop

The liquid level is regulated by the outlet medium pump (peristaltic pump), which is commanded by the P-100. It controls the level between a maximum and a minimum value by means of two sensors.

In order to regulate the output flow rate the P-100 increases o decreases a 25% the frequency of the peristaltic output pump.

LOOP	Liquid level
GOAL	Maintain the liquid level in the reactor within a range determined by two level detectors, one for the high level and the other for the low level. This regulation loop was implemented to avoid an unbalanced emptying or filling of the reactor.
MEASUREMENTS	Two level detectors signals the different culture liquid level. Therefore two digital information are available. Only one level measurement system is available, a relay was added to commute the input of this system either on the high level sensor or on the low level sensor.
ACTIONS	Three cases exists: – The liquid level is below the low level, the control signal of the injection pump is 25% more than the speed of the extraction pump. – The liquid level is between the low and high level, the control signal of the injection pump is the same than the speed of the extraction pump. – The liquid level is above the high level, the control signal of the injection pump is 25% less than the speed of the extraction pump.
ALARMS	
INFORMATION	

	NAME	DESCRIPTION
ANALOGUE VALUES	AO-0108	Medium injection pump command
DIGITAL VALUES	DI-0136	Switch output of the liquid level detector system
	DO-0127	Relay command for the selection of the level detector.
ALARMS		

V. APPENDIX

a. Micon 1

NO.	POL	TAG NAME	DESCRIPTION
1 2	+ -	AI-0101	CO_2 analyser Maihak
3 4	+ -	AI-0102	O_2 Servomex
5 6	+ -	AI-0103	Gaseous pressure air-lift
7 8	+ -	AI-0104	
9 10	+ -	AO-0101	
11 12	+ -	AO-0102	
13 14	+ -	DI-0121	Range switch CO_2
15 16	+ -	DI-0122	RAZ by main clock
17 18	+ -	DI-0123	
19 20	+ -	DI-0124	
21 22	+ -	DO-0121	Pressure valve air-lift
23 24	+ -	DO-0122	Main alarm output, red blinking light (220 V)
26 27 28	D GND D/	Lateral communication	
30 31 32	D GND D/	Vertical communication	
33 34	+ -	24 V power supply	

b. Micon 2

NO.	POL	TAG NAME	DESCRIPTION
1 2	+ -	AI-0105	pH air-lift
3 4	+ -	AI-0106	
5 6	+ -	AI-0107	
7 8	+ -	AI-0108	
9 10	+ -	AO-0103	
11 12	+ -	AO-0104	Flowmeter for CO_2 addition
13 14	+ -	DI-0125	
15 16	+ -	DI-0126	Alarm switch thermostatic bath for air-lift condenser
17 18	+ -	DI-0127	Alarm switch thermostatic bath for temperature regulation
19 20	+ -	DI-0128	
21 22	+ -	DO-0123	
23 24	+ -	DO-0124	Enable power supply of compressor
26 27 28	D GND D/	Lateral communication	
30 31 32	D GND D/	Vertical communication	
33 34	+ -	24 V power supply	

c. Micon 3

NO.	POL	TAG NAME	DESCRIPTION
1 2	+ -	AI-0109	
3 4	+ -	AI-0110	Temperature measurement
5 6	+ -	AI-0111	
7 8	+ -	AI-0112	Light measurement
9 10	+ -	AO-0105	Light regulation, power supplies control
11 12	+ -	AO-0106	Temperature set point
13 14	+ -	DI-0129	Light range switch (lower)
15 16	+ -	DI-0130	Light range switch
17 18	+ -	DI-0131	Light range switch
19 20	+ -	DI-0132	Light range switch (higher)
21 22	+ -	DO-0125	
23 24	+ -	DO-0126	
26 27 28	D GND D/	Lateral communication	
30 31 32	D GND D/	Vertical communication	
33 34	+ -	24 V power supply	

d. Micon 4

NO.	POL	TAG NAME	DESCRIPTION
1 2	+ -	AI-0113	pO_2 air-lift
3 4	+ -	AI-0114	Monitek measurement, biomass concentration
5 6	+ -	AI-0115	
7 8	+ -	AI-0116	
9 10	+ -	AO-0107	Biomass extraction pump
11 12	+ -	AO-0108	Medium injection pump
13 14	+ -	DI-0133	
15 16	+ -	DI-0134	
17 18	+ -	DI-0135	
19 20	+ -	DI-0136	Liquid level detector switch
21 22	+ -	DO-0127	Relay for selection of level detector
23 24	+ -	DO-0128	
26 27 28	D GND D/	Lateral communication	
30 31 32	D GND D/	Vertical communication	
33 34	+ -	24 V power supply	

e. Bay connector

No.	Signal Name	Voltage/Current	From	To
1 2 3	D GND D/	Lateral communication		
4 5 6	D GND D/	Vertical communication (VCC-1)	Micon 1 Controller 4	Micon 3 Controller 6
7 8 9	D GND D/	Vertical communication (VCC-2)		
10	N/A			
11 12	+ CO_2 - CO_2	4-20 mA	CO_2 analyser	AI-0101
13 14	CO_2 range	Switch	CO_2 analyser	AI-0121
15 16	+ O_2 - O_2	0-1 V	O_2 analyser	Converter 4-20 mA (AI-0102)
17 18	+ Biomass - Biomass	4-20 mA	Monitek CT4 turbidimeter	AI-0114
19 20	+ pH - pH	4-20 mA 0-14 pH	pH indicator and controller	AI-0105
21 22	+ set point temperature - set point temperature	0-20 mA to 4-20 mA isolated	AO-0106	Temperature controller
23 24	+ temperature - temperature	4-20 mA	Temperature Controller	AI-0110
25 26	+ pO_2 - pO_2	4-20 mA	pO_2 indicator	AI-0113
27 28	+ NH_4^+ - NH_4^+	4-20 mA		AI-0107
29 30	Calibration switch NH_4^+			DI-0125
31 32	N/A N/A			
33 34	N/A N/A			
35 36 37 38	+ Pressure - Pressure - 24 V - 0 V	4-20 mA 0-20 mA sensor supply	pressure sensor gaseous phase BAY 24 V power supply	AI-0103 pressure sensor

39 40 41 42 43	+ pH control - pH control + 15 V 0 V - 15 V	0-20 mA Flow controller Supply	AO-0104 BAY±15 V power supply	CO_2 injection flow controller
44	N/A			
45 46	+ Biomass control - Biomass control	4-20 mA	AO-0107	Peristaltic pump biomass output
47 48	+ alarm cooler condensation - alarm cooler condensation	+ 12 V	thermostatic bath	relay 12 V to DI-0126
49 50	+ alarm cooler temperature - alarm cooler temperature	- 12 V	thermostatic bath	relay 12 V to DI-0126
51 52	liquid level relay	+ 24 V	DO-0127	relay for selection of level detector
53 54	liquid level detector switch	switch	level detector	DI-0136
55 56	+ medium inlet pump - medium inlet pump	4-20 mA	AO-0102	inlet pump
57 58	+ pressure control - pressure control	0-20 mA	AO-0102	pressure regulation flowmeter
59 60 61 62	N/A N/A N/A N/A			
63 64	+ gas analysers pump - gas analysers pump		BAY 24 V power supply	analysers pump
65 66 67 68 69 70 71 72	N/A N/A N/A N/A N/A N/A N/A N/A			
73 74	mixing compressor	220 V	DO-0124 via relay	compressor power supply
75 76	N/A N/A			
77 78	Main alarm red blinking light	220 V	DO-0122 via relay	light
79 80	pressure valve	220 V	DO-0121 via relay	valve

f. Complementary instrumentation rack

No.	Signal Name	Voltage/Current	From	To
1 2 3 4	+ IN - IN + OUT - OUT	N/A	Converter 10	Converter 10
5 6 7 8	+ IN - IN + OUT - OUT	N/A	Converter 9	Converter 9
9 10 11 12	+ IN - IN + OUT - OUT	N/A	Converter 8	Converter 8
13 14 15 16	+ IN - IN + OUT - OUT	N/A	Converter 7	Converter 7
17 18 19 20	+ IN - IN + OUT - OUT	N/A	Converter 6	Converter 6
21 22 23 24	+ IN - IN + OUT - OUT	N/A	Converter 5	Converter 5
25 26 27 28	+ IN - IN + OUT - OUT	N/A	Converter 4	Converter 4
29 30 31 32	+ IN - IN + OUT - OUT	N/A	Converter 3	Converter 3
33 34 35 36	+ IN - IN + OUT - OUT	N/A	Converter 2	Converter 2
37 38 39 40	+ O_2 - O_2 + out converter - out converter	4-20 mA	O_2 analyser Converter 2	Converter 1 AI-0102

41 42 43 44	Light regulation, power supplies control voltage	0-5 V 0-5 V	power supplies remote control box	power supply 4 remote control power supply 5 remote control
45 46 47 48	Light regulation, power supplies control voltage	0-5 V 0-5 V	power supplies remote control box	power supply 4 remote control power supply 3 remote control
49 50 51 52	Light regulation, power supplies control voltage	0-5 V 0-5 V	power supplies remote control box	power supply 2 remote control power supply 1 remote control
53 54	Light regulation, power supplies control	0-20 mA	AO-0105	power supplies remote control box
55	Range 4	switch	light amplifier	DI-0132
56	Range 3	switch		DI-0131
57	Range 2	switch		DI-0130
58	Range 1	switch		DI-0129
59	Common	0-10 V		
60				
61	- Light		light amplifier	Converter 1
62	+ Light	4-20 mA	converter 1	AI-0112