BPC INSTRUMENTS

BRS

BioReactor Simulator

Operation and Maintenance Manual

BRS

BioReactor Simulator

Release History

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1 PREFACE

BPC Instruments AB

BPC Instruments AB (BPC) is a technology and market leader in the area of advanced instrumentation & control technologies for research and commercial applications in the biogas industry. The company was founded in 2006, and today brings to market more than 15 years of industry leading research in the area of instrumentation, control and automation of anaerobic digestion processes.

In 2009, BPC launched the Automatic Methane Potential Test System (AMPTS), a revolutionary product in the area of on-site lab equipment for methane potential analysis. Today, the second generation of the AMPTS (AMPTS II) is used by biogas researchers, commercial operators and other industry actors in over 30 countries within the Americas, EMEA, Africa and Asia Pacific regions.

In 2012, BPC launched the BioReactor Simulator (BRS), an analytical device for the control and monitoring of anaerobic fermentation processes in a continuous mode of operation. The BRS is an ideal instrument and platform for gaining knowledge and experience of the continuous operation of biogas production processes, as well as serves as the complementary tool to AMPTS II, which is used for feedstock characterisation and optimisation. The system is controlled by a web-based software running on an efficient cloud computing solution accessible from any computer or mobile device with an internet connection.

Taking into consideration the high number of the AMPTS units in use today around the world, it is expected that BRS will have a similar impact on the biogas industry, becoming the technology of choice for universities, private labs and biogas operators interested in the laboratory scale simulation of continuously operated full-scale biogas digesters.

2 GENERAL INFORMATION

The process of anaerobic degradation is highly complex and dynamic, where microbiological, bio-chemical and physico-chemical aspects are closely interrelated. For optimisation purposes, fermentation tests at laboratory scale are used to determine feedstock characteristics and to simulate continuous operations of biogas reactors. In general, for broadly designed test programs, the combination of batch and continuous methodologies should be used. A large number of batch tests running in parallel deliver results on feedstock characteristics, whereas a continuous test simulates long-process conditions spanning a large time frame.

2.1 CONVENTIONAL CONTINUOUS FERMENTATION TEST

In a conventional continuous fermentation test, the organic matter is added either in stages or continuously to the reactor. The end products are periodically or continuously removed, resulting in a constant and predictable production of biogas. A single digester or multiple digesters in sequence may be used such as: continuous stirred-tank reactors (CSTR), upflow anaerobic sludge blankets (UASB), expanded granular sludge beds (EGSB), internal circulation (IC) reactors, etc.

The objective of the fermentation tests in the defined continuous procedure is to obtain reliable long-term base data about the gas yield and its composition, and to build up a comprehensive picture regarding the degradation of the organic material, the course of fermentation, and any problems in the degradation process which may occur. In fact, results from continuous lab-scale fermentation tests have on several occasions been shown to provide a good representation of the full-scale operation. With the help of continuous fermentation tests, it should also be possible to determine how the properties of substrates affect the fermentation process and what process conditions must be put in place in order to achieve an optimal degradation and maximisation of gas yield. Continuous fermentation tests thus deliver the first useful information about the capabilities and loading limits of a process, which is essential for designing and operating a biogas plant as well as for creating models concerning the economical feasibility of a project.

Conventional continuous fermentation tests are laboratory-scale methods subject to large variations, not only due to the heterogeneous nature of bio-wastes and bacteria culture used, but also due to differences in experiment setup and non-unified test protocols. For example, reactor configuration, instrumentation and operational modes can all differ from one laboratory to another. In addition, the presentation of the results is not standardised either, which makes comparability between two tests very difficult. Furthermore, the execution of a fermentation test in continuous mode is often a complex and very labour-intensive and time-consuming procedure, spanning a considerable period of time.

The BRS has been developed by BPC for the on-line monitoring and control of anaerobic fermentation tests in a continuous mode with modern instrumentation and IT technologies. The

gas flow rate measurements and data logging of the BRS are fully automated during the incubation period. The high precision of gas flow monitoring is based on a patented flow meter array using the principle of liquid displacement and buoyancy. The organic loading rate (OLR), hydraulic retention time (HRT), and specific gas production (SGP) are calculated and displayed in real time.

Any type of reactor can be connected to the BRS through a gas inlet port. However, designing a gas tight reactor that allows for a high liquid and gas mass transfer, as well as continuous mixing and heating, is a difficult task and many systems are considered to be unreliable. Therefore, the BRS is available with a verified set of reactors and with several different configurations, such as CSTR (standard), UASB, EGSB, IC, Biofilm, etc (optional).

From a biogas producers' point of view, increasing the knowledge and experience of a digestion process, improving the method of selecting optimal substrate feeds, developing open and closed-loop control strategies, identifying stress factors in the degradation process and implementing adjusted reactor designs, have a significant impact on the initial design as well as operational and economic details of a biogas plant.

2.2 Advantages of BRS over Conventional Fermentation Tests

The BRS provides several unique functionalities that are important for anaerobic fermentation tests in a continuous mode of operation:

- User friendly interface both for experiment setup and follow-up
- Real-time data logging of gas flow rate
- Real-time pressure and temperature compensation of gas flow rate measurements
- Real-time gas flow rate normalisation
- Real-time calculation and visualisation of key parameters such as OLR, HRT, SGP
- Interactive feeding and discharging support
- Possibility of running feeding and discharging in manual or automatic modes
- Generation of a standardised report with all recorded and interpreted data
- Remote monitoring of experiments
- High capacity for data logging and handling
- One of the most cost competitive solutions on the market today

3 DELIVERY CHECKS

Upon delivery, unpack and check that the contents match with what is listed below in the Section "Box Content".

If the packaging or equipment is broken or damaged at delivery, please:

a) Document and take photos of the parts and packaging
b) Inform the transport company at the time of delivery
c) Make sure that the transport company documents the incident
d) Inform the seller of the incident

BOX CONTENT

See also Chapter 7. Equipment Description (Design/Function) for pictures of the included parts.

UNIT BRS-A

6 glass bottles with 3 ports (2 l reactors)
6 plastic caps with agitators/motors, including 5 short motor cables
1 long motor cable (from Motor Controller to first motor unit)
1 Motor Controller
1 signal cable
6 rubber stoppers with 2 metal tubes, 1 plastic tube and rotating shaft for mixing
1 thermostatic water bath (18 l)
1 plastic glass lid, for the water bath, with 6 circular openings for the reactors
6 helical couplings + tool
6 funnel shaped feeding units with 6 silicone stoppers
6 bent glass discharging tubes
18 plastic screw caps (12 with and 6 without holes)
12 silicone sealing rings
6 plastic tubing clamps

UNIT BRS-B

1 water bath package (including water tank, flow cell holder, injection moulded flow cells containing magnetic metal pieces, base and protection plate)
1 plastic glass lid for the water tank (including straight connector)
1 manual plastic water pump
1 power adapter (input 100 - 240 V ~ 50 / 60 Hz, output 12 V DC / 5 A)

OTHER COMPONENTS

1 shielded Ethernet cord
1 box of 15 m flexible Tygon® tubing
1 number markers kit for tubes
6 plastic lids (blue)
1 manual

OPTIONAL EQUIPMENT

Glass reactors, 5 l
Stainless steel reactors, 5 and 10 l

Gas sampling units

Plastic screw caps with hole

Glass bottles, 0.5 or 1 l

Rubber stoppers with 2 metal tubes

4 PRE-COMMISSIONING

The following items are not included in the delivered BRS, however they will/may be required to operate the BRS:

- Silicone spray or other similar lubricant
- Silicone tubing, two-way valves and clamps
- Additional wall socket adapters (plugs/contacts) (the ones supplied are according to European, US or UK standards, depending on original purchase order)
- If a customer has a gas chromatograph and is interested in off-line biogas composition analysis, gas sampling units can be ordered separately from BPC
- N_2 or a mixture of N_2/CO_2 to obtain anaerobic conditions during the start up phase of the experiment (BPC recommends a mixture of N_2 (60%) and CO_2 (40%) to be used)
- NaOH (reagent grade 97%, pellets, e.g., Sigma-Aldrich 221465 or equivalent quality), a pH indicator such as thymolphthalein (2',2"-Dimethyl-5,5"-di-iso-propyl phenol phthalein, $C_{28}H_{30}O_4$, CAS 125-20-2, ACS reagent, dye content 95%, e.g., Sigma-Aldrich 114553 or equivalent quality) and ethanol (ACS reagent 99.5%, e.g., Sigma-Aldrich 459844, or equivalent quality) for the preparation of the alkaline solution for CO_2 fixation, if the user is interested in measuring bio-methane.

5 QUALITY RULES AND RECOMMENDATIONS

- The product guarantee provided corresponds to the guarantee stipulated on the confirmed product order form and shipping documentation. The removal of the metal bottom plate on the Unit BRS-B is considered a breach of guarantee.
- For guarantee claims relating to the thermostatic water bath, contact the manufacturer directly (see separate handbooks) and inform BPC.
- When 2000 ml bottles are used as reactors, the recommended headspace in the bottles during the methane potential test analysis is approximately 300 ml.
- For a high accuracy analysis, the BRS should not be exposed to mechanical vibrations and/or high frequency radio transmissions, and should be placed on a level and stable surface.
- In order to guarantee the quality and performance of the product, only the parts delivered with the product should be used.
- The product contains alkaline AA batteries that need to be handled accordingly.
- BPC reserves the right to correct any possible text and image errors as well as changes to technical data in this manual.

BEFORE GETTING STARTED

- Read this manual and additional separate manuals for the individual instruments before installing and using the equipment.
- Keep the instruction manual for future reference and make sure it is easily available for people who regularly use the BRS.
- Read the Bioreactor Agitation Systems instruction manual before using the equipment.

6 SAFETY CONSIDERATIONS

Using the BRS should always be done in an environment with good ventilation, preferably in a laboratory fume hood. When handling NaOH, always use safety glasses, a lab coat and plastic gloves.

See the safety data sheet for your chemicals for further information. Always be cautious when handling electrical devices close to water.

The Agitation System contains rotating parts. Make sure to tie back any loose hanging objects like clothing or hair when using the instrument.

The power adapter for the multifunction brushless DC Agitation System must never be used in the BRS detection unit.

7 EQUIPMENT DESCRIPTION (DESIGN/FUNCTION)

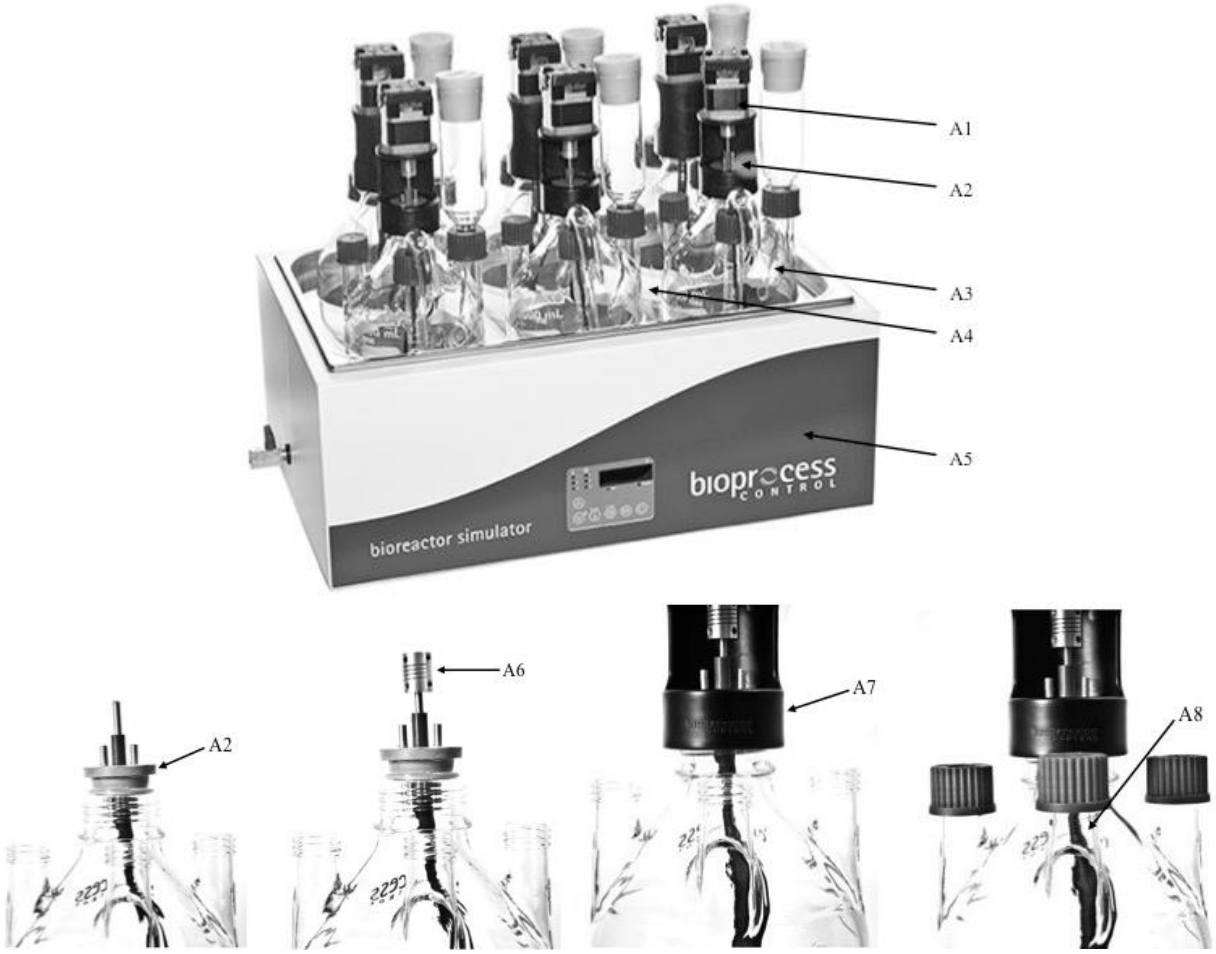
With the BRS, data recording and analysis are fully automated during the long fermentation period, which significantly reduces time- and labor-demands. High quality data regarding key process parameters, e.g. gas flow rate, gas yield, organic loading rate (OLR), hydraulic retention time (HRT), specific gas production (SGP), etc, can be used to extract information regarding the degradation process. This will in turn allow for a much better understanding of a specific biomass substrate, further leading to an improved process operation.

The BRS can be divided into two units: BRS-A, and BRS-B (please refer to the photos included).

With BRS-A (*sample incubation unit*), up to 6 reactors containing mixtures of a sample with anaerobic inoculum are incubated at a desired temperature. The reactors are equipped with three ports: a port for feeding the substrate (i.e., feedstock), a port for discharging the digested sludge, and a port for the continuous measurement of pH or temperature during the fermentation process (or insertion of other suitable probes). The media in each reactor is mixed by means of a slowly rotating agitator. Biogas is then continuously produced and registered by the system. With the BRS, both the OLR and HRT are calculated and presented in real-time together with normalised gas flow. For feeding high-suspended solids, a funnel shaped feeding device is recommended, which can be ordered separately from BPC.

With unit BRS-B (*gas volume measuring device)*, the volume of gas released is measured using a wet gas flow-measuring device with a multi-flow cell arrangement. This measurement device works according to the principle of liquid displacement & buoyancy and can monitor low gas flows; a digital pulse is generated when a defined volume of gas flows through the device. An integrated embedded data acquisition system is used to record, display and analyse the results.

7.1. Sample Incubation Unit



Unit BRS-A

A1 Multifunction Brushless DC motor
A2 Rubber stopper with 2 metal tubes, 1 plastic tube and rotating shaft for mixing
A3 2 liter glass bottle reactor with 3 ports
A4 Plastic lid for thermostatic water bath with circular openings for reactors
A5 Thermostatic water bath
A6 Helical coupling
A7 Plastic screw thread cap/motor holder
A8 Bent stirring rod/rotating shaft

7.2. Gas Volume Measuring Device

Unit BRS-B

B1 Water bath package (including water tank, flow cell holder, protection plate and electronics)
B2 Injection moulded flow cell
B3 Manual plastic water pump
B4 Connection block
B5 Motor signal connection socket for the Motor Controller: 12 V DC / 3 A
B6 Power connection socket for the motor module: 12 V DC / 5 A
B7 Shielded Ethernet socket
B8 Power adapter: 12 V DC/ 5 A

7.3 Bioreactor Agitation System

Two different bioreactor agitation systems are available from Bioprocess Control: i) an initial configuration (in left picture) based on standard brush DC motors with a gearbox and ii) a multifunction version (in right picture) based on a unique design of brushless DC stepper motors. (The motors are shown on a glass bottle different from the type and size used in the BRS.) For a full description of each system, please refer to the Bioreactor Agitation Systems manual.

The reasons for introducing a new agitation system are:

- To increase the life span of the system by changing to a brushless stepper DC motor based system for direct drive.
- To offer improved and more flexible mixing properties by adding new features:
    - Reversal of motor direction (clockwise [CW]/counter-clockwise [CCW])
    - Timer function to set time periods for the motor reversal
    - Remote speed control on a broad range (i.e. 5-100%)

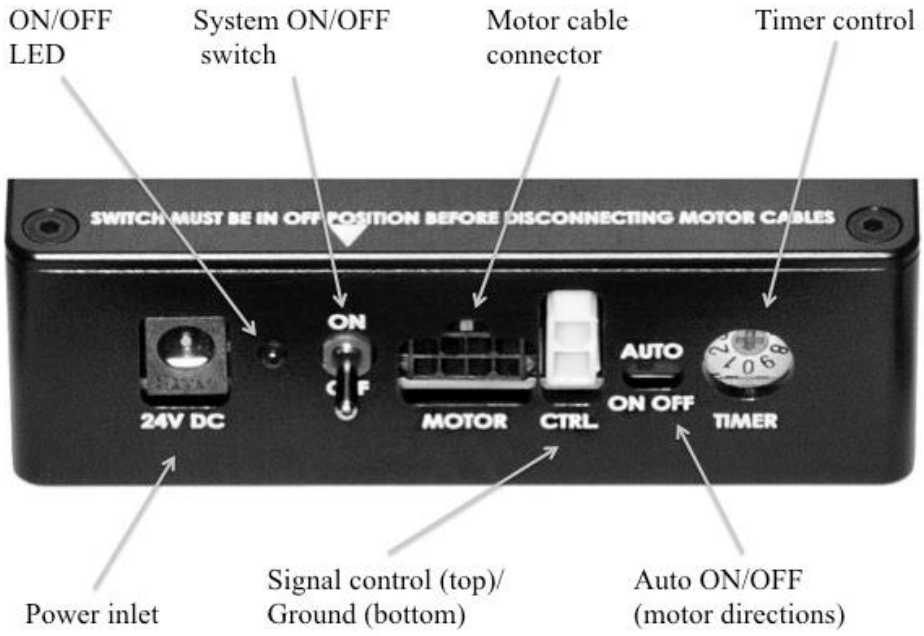
A photo of the multifunction configuration of the motor, the brushless DC stepper motor, is presented below. The complete agitation system consists of the following components: Motor Controller, 24 V power adapter for the Motor Controller, brushless steppers DC motor units with plastic caps, helical couplings, short motor cables (0.2 m), long motor cable (1.5 m), signal cable and a hex tool.

MOTOR CONTROLLER

The Motor Controller provides power to the motors via the motor cables, and **it is very important that the Motor Controller always is turned off and is unplugged from the power source when any cables are connected or disconnected from the motors.** Turning the switch off is not enough.

The Motor Controller is the hub of the agitation system. It interprets the speed signal sent from the Unit C of the AMPTS II and controls the direction of the motors. All the mixers receive the same information from the Motor Controller.

The picture below shows the control panel on the front side of the Motor Controller.



The **ON/OFF switch** (shown in the picture above) turns the power of the Motor Controller on and off. When the switch is ON (in the upper position), the red LED will be lit up to indicate that the system is active. It is recommended to set the switch to OFF before connecting / disconnecting the Motor Controller to / from the power mains.

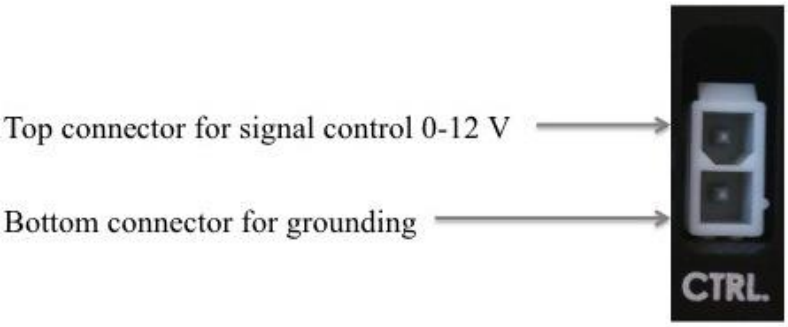
When the **AUTO switch** on Motor Controller is set to OFF, the mixers will be operated in continuous rotation mode, i.e. the mixers will always rotate in the same direction. Setting the switch to ON will activate the AUTO reversing mode, which will make the Motor Controller change the mixer directions at regular intervals.

For the Auto reversing mode to work as intended, the DIRECTION switch on each motor needs to be in the AUTO (middle) position as well. If the switch is in either CW or CCW position, the mixer will start and stop but never change direction. See section Direction Switch for further explanation of the different combinations of settings on the Motor Controller and the motor units.

SIGNAL CABLE

The Motor Controller receives signals from the test system through an analogue signal cable (pictured below).

WARNING: The position of the signal and grounding terminals of the connectors are reversed on the Motor Controller compared to the AMPTS II system. On the Motor Controller, the ground is at the bottom terminal (see the picture below). **Always make sure the proper cable is used and that it is inserted the correct way, or the system could be permanently damaged!**



Motor Cables

The signals from the Motor Controller are distributed to each motor unit through the motor cables (see picture below). They should be connected serially, and are fastened to the motor units with the help of latches. The 1.5 m cable is used only to connect the "MOTOR" output on the Motor Controller to the first motor.

Mixing Intensity

The motors can be operated at different speeds ranging from 10-200 RPM. The speed is adjusted linearly between 10 and 200 RPM, referred to as per cent (5 – 100%) in the AMPTS II software. At a DC-signal of 0 (zero) V, the motor is out of function, and at 12 V it is rotating at top speed (200 RPM). An acceleration /deceleration ramp is built into the system to provide a smooth transition between different speeds.

Timer to Control Intervals of Motor Reversal

The rotary Timer switch can be used to set the time that should elapse before the direction is changed. 10 positions are available ranging between 5 s to 1 h.

Timer Switch Position	Time
0	5 s
1	15 s
2	30 s
3	45 s
4	60 s (1 min)
5	120 s (2 min)
6	300 s (5 min)
7	600 s (10 min)
8	1800 s (30 min)
9	3600 s (60 min)

FUSE

To protect the Motor Controller, the Printed Circuit Board (PCB) is fitted with a slow-blow 2 A fuse (522.520). If none of the mixers are working even though the power supply is connected, this fuse should be replaced. The fuse is located inside the Motor Controller, which can be opened by removing the four screws placed in each corner of the top cover. (See picture below).

MOTOR UNIT

Each motor unit has its own driver board, which controls the power distribution to the actual motor. The switches are explained below.

Motor Unit ON/OFF Switch

The ON/OFF switch is located on the side of the motor, and marked on the very top of the motor unit, just above where the actual switch is located. When a mixer is active and power is supplied, an LED next to the ON/OFF switch will be green. If not all mixers will be used, setting the ON/OFF switch to OFF can turn each motor off individually. The motor unit will make a sound to indicate when this is done.

It is recommended to set the switch on each Motor Unit to the OFF position before connecting or disconnecting the Motor Controller or any of the motor cables.

When the system has been turned off, and then switched back on, it can take up to 8 seconds for it to start up again.

Direction Switch

The DIRECTION switch is located on the side of the motor, and marked on the very top of the motor unit, just above where the actual switch is located. It is used to set the motor to rotate in a CW or a CCW direction. Setting the switch to AUTO gives the Motor Controller automatic control over the reversal of the direction. Below is a table that will show the output of the different combinations of switch settings on the Motor Controller and the motor unit.

Settings		**Mixer output**	
Motor Controller AUTO switch	**Motor unit switch**	**Intervals**	**Rotation**
ON	CW	Starting and stopping according to Motor Controller intervals	Constantly CW
ON	AUTO	Starting and stopping according to Motor Controller intervals	Reversing directions
ON	CCW	Starting and stopping according to Motor Controller intervals	Constantly CCW
OFF	CW	N/A	Constantly CW
OFF	AUTO	N/A	The latest direction used before the Motor Controller AUTO switch was set to off
OFF	CCW	N/A	Constantly CCW

RESET BUTTON

If an error is encountered somewhere on the driver board in the motor unit, a red LED will light up on the side of the motor unit, opposite to where the switches are located. A marking on the top of the motor unit shows where to find it (see picture below).

The problems could be e.g. high temperature, a disconnected motor cable, or power loss. If this happens, the mixer can be reset with a quick press on the RESET button. The RESET button is marked on the very top of the motor unit, just above the actual button. It can be reached by using a pen or other pointy object. If the mixer was reset successfully, the red LED will turn off.

POWER

The Motor Controller is powered by a 24 V / DC 2.71 A power supply adapter. The power supply is then distributed serially from the Motor Controller, through the 8-pin signal cables, to each motor unit.

WARNING: The power supply always has to be disconnected from the Motor Controller before removing or connecting any of the cables from the motors.

7.4. Technical Characteristics

General

Usage: indoor
Power supply: 100 or 240 V ~ 50/60 Hz (thermostatic water bath and power adapter)
Tubing material: Tygon® (ID 3.2 mm, OD 4.8 mm)
Weight: approx. 25 kg

Sample Incubation Unit

Maximum number of reactors per system: 6
Reactor material: glass (standard) or stainless steel
Reactor volume: 2 (standard), 5 and 10 l
Power consumption: 1300 W (maximum)
Dimension: 53×33×24 cm
Temperature control: up to 95 °C (precision 0.2 °C)
Mixing in the reactor: mechanical (adjustable interval and speed), maximum speed 140 rpm

Gas Volume Measuring Device

Working principle: liquid displacement & buoyancy
Built-in sensors: pressure and temperature
Data acquisition: integrated system
Measuring range: 10 to 4000 ml per hour
Measuring range for instant gas flow rate: 10 to 120 ml per minute
Measuring resolution: 10 ± 0.1 ml
Power consumption: 15 W (average), 28 W (maximum)
Dimension: 51×44×18 cm
Accuracy: 5% (RE) & Precision: 1% (CV)

Motor Module

Dimensions: 5.5×3×2.5 cm
Weight: approximately 50 g

Software

Web based software running on cloud solution
Accessibility from any location with an internet connection via industry-strength encryption
Support both for running feeding and discharging in manual or automatic mode
Possibility for running experiments with high quantity of data generation
Possibility for measuring both produced biogas and biomethane
Real-time gas flow rate, HRT and OLR display
Assisted SGP calculation
Real-time gas flow and volume normalisation
Possibility for multiplexing, allowing for simultaneous analysis initiation of parallel experiments at different startup times
Standardised report generation in Microsoft Excel format for easy usage
On-line system logger for operational diagnosis

8 OPERATION

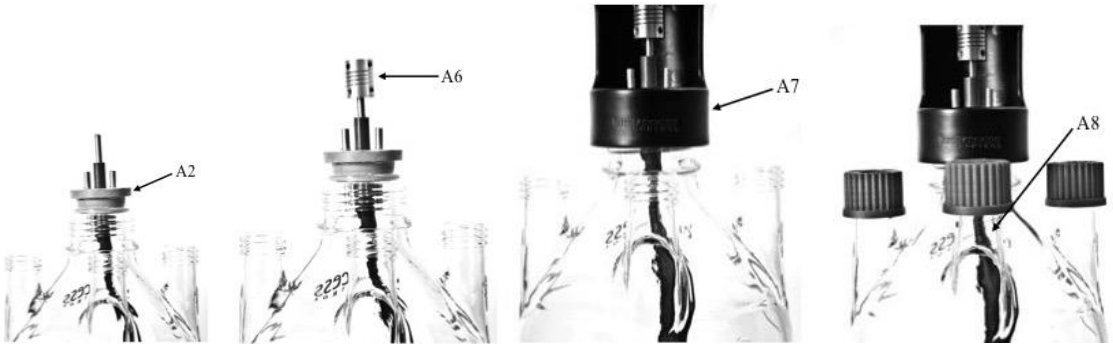
In this section, references are given to pictures in the Chapter 7. Equipment Description (Design/Function) in the form of a letter and number within parenthesis, e.g., (A1).

Please also refer user manual for the thermostatic water bath before installation and use.

8.1 BEFORE START UP

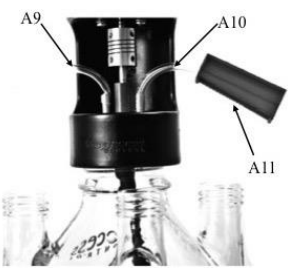
REACTORS

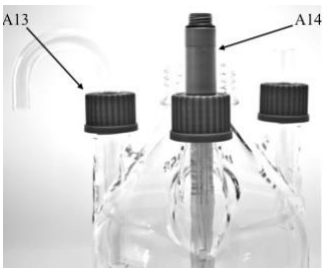
a) Perform a simple leakage test for each reactor by creating some overpressure by blocking one of the metal tube ports and injecting air from the remaining metal tube port, then immerse the reactor in water to check if there are air bubbles escaping from the reactor. Make sure that all tubes are properly connected and there is no potential leakage anywhere.
b) Add the sample (e.g., 2000 g of inoculum) into the reactors. Use at least duplicates for statistical significance (see Appendix A for more details).



c) Lubricate rubber stoppers (A2) on the side that is in contact with the glass bottle, preferably with silicone spray or silicone stick.
d) Place the rubber stopper (A2) (with two metal tubes and the bent stir rod (A8) connected) in the opening of each bottle (A3) and press the rubber part in order to close the bottle. Avoid pressing the metallic rod as this will lead to separation of the white plastic cap from the bottom of the stirring rod and allow gas or liquid leakage from the reactor. Then pull out the metallic rod from the bent stirrer into the helical coupling (A6), and attached it before placing the plastic screw thread cap/motor support (A7). Screw until the thread on the bottle is no longer visible and the lid is properly sealed.
e) Connect the bent stir rod (A8) to the motor by carefully tightening the two screws on the helical coupling. Care should be taken so that the helical coupling is not touching the plastic motor support or the metallic screws holding the motor in place, to avoid friction from the movement of the helical coupling.

f) Cut 6 pieces of Tygon® tubing (A9) of sufficient length to connect one of the small metal tubes on top of the rubber lids (A2) of each reactor to the corresponding tubing connector on the connection block (B4) located on the back of the detection unit.
g) Cut 6 pieces of Tygon® tubing (A10) at lengths of about 10 cm and connect them to each of the free small metal tubes on top of the rubber lids (A2) of the reactors. Close the tubing pieces with the help of plastic tubing clamps (A11).





h) Equip the reactors with the inlet (i.e., funnels or glass tubes, (A15)) and outlet ports (bent glass tubes (A16)) by inserting the glass tubes through the screw connector caps (A13) adapted with the silicone sealing caps (A12). If the third port is not used for pH measurements (A14), it should be closed with a screw connector cap without a hole.
i) For creating an anaerobic environment, the inlet and outlet ports should be closed with the help of tubing clamps or two-way valves attached to the system through silicone tubing. The clamps, two-way valves and the silicone tubing are not delivered together with the system.

MOTOR CONNECTIONS

a) Make sure that the power adapter for the Motor Controller is disconnected from the power supply.
b) The motor modules should all have the ON/OFF switch set to the OFF mode.
c) Connect one short motor cable to each motor (excluding the last motor in the chain) and then connect the free end of the cable from motor 1 to the free port on motor 2 and so on until motor 6.
d) The Motor Controller should have the System ON/OFF switch in the OFF mode.
e) Connect the long motor cable from motor 1 to the Motor Controller.
f) Connect the signal cable from the Motor Controller to the motor signal port on BRS-Unit B.

   WARNING: The position of the signal and grounding terminals of the connectors are reversed on the Motor Controller compared to the AMPTS II system. On the Motor Controller, the ground is at the bottom terminal (see the picture below). **Always make sure the proper cable is used and that it is inserted the correct way, or the system could be permanently damaged!**

THERMOSTATIC WATER BATH

Do not install or use the equipment before reading the separate instructions for the thermostatic water bath (see above).

a) After inserting all the reactors into the thermostatic water bath (A5), fill it up with enough water to completely cover the equivalent height of the content in the reactors (approx. 8 liters). If normal tap water is used, calcareous deposits may appear in the bath and on the heating element. It is therefore recommended to use deionised or distilled water.
b) Place the plastic glass lid with 6 circular openings (A4) on top of the water bath, in order to minimise the evaporation of water during the experiment.
c) It is recommended to place a thermometer through one of the holes in the lid, inside the water bath, in order to keep track of the real temperature of the reactors during the incubation period.

GAS VOLUME MEASURING DEVICE

a) Install Unit BRS-B on a flat and stable surface. Use appropriate instrumentation (i.e., bubble level device) to verify the horizontality of the surface and to adjust the level of the system placed on the surface.
b) Fill up the water bath (B1) with deionised or distilled water. The water level should be within the limits of the marking on the water bath.
c) Make sure to remove the protective film from the transparent lid of the water tank.

NETWORK AND POWER CABLES

a) Connect one end of the Ethernet cord to the gas volume measuring device, BRS-Unit B.
b) Connect the other end of the Ethernet cord to an internal network or suitable network equipment. For its operation, the BRS system needs to have access to an internet connection.
c) Make sure that the network cable is connected to the network prior to connecting the power supply.

ALKALINE SOLUTION (OPTIONAL)

If CO_2 elimination from the biogas is foreseen, optional 500 ml bottles with rubber cap and 2 metal tubes can be purchased from BPC in this scope. The biogas produced in each reactor will pass through individual bottles containing alkaline solution. For the preparation of NaOH solution for CO_2-fixation, necessary protection should be used. All work should be carried out inside a fume hood while wearing protective equipment (see Chapter 6. Safety Considerations).

a) Prepare a 3 M NaOH solution; take into account that the 500 ml bottles should be filled with approximately 400 ml each. Be careful and follow safety precautions as this is a highly alkaline solution. After weighing the necessary amount of NaOH, mix it with approximately ¾ of the required total volume of distilled water (e.g., 120 g NaOH in ¾ of

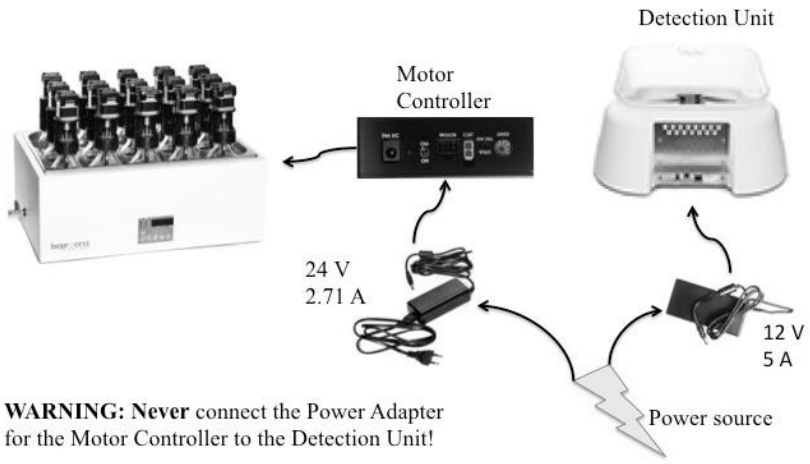
1 liter of water). The heat generation following dissolution of NaOH in water is high, so that adding small amounts of supplementary water followed by mixing is recommended. When the NaOH is completely dissolved, add the entire amount of remaining water and mix well.

b) Prepare a 0.4 % Thymolphthalein pH-indicator solution (40 mg in 9 ml ethanol 99.5% followed by the addition of 1 ml of water). Thymolphthalein is insoluble in water, but it is freely soluble in ethanol.
c) Prepare the NaOH solution containing the pH indicator by mixing 5 ml of the 0.4 % Thymolphthalein solution per 1 liter of 3M NaOH solution. If all 6 reactors are used, preparation of as much as 3 liters of NaOH and 15 ml of Thymolphthalein is recommended (the additional solution may be necessary for quickly changing the fixation liquid if the solution becomes impaired (the color changes from blue to colorless due to the pH-indicator Thymolphthalein).
d) Add approximately 400 ml of the mixture containing NaOH solution and Thymolphthalein pH indicator into each glass bottle (500 ml).
e) Lubricate rubber stoppers on the side that is in contact with the glass bottle, preferably with silicone spray or silicone stick.
f) Place a rubber stopper (with two metal tubes connected) in the opening of each bottle, seal by placing the plastic lid on the top, and screw until the thread on the bottle is no longer visible and the lid is properly sealed.

8.2 START UP

MOTOR AND POWER CABLES

a) Check that all motor cables are connected to each other, and that the long motor cable is connected between the first motor and the Motor Controller.
b) Check that the analogue signal cable is connected between the Motor Controller and BRS-Unit B.
c) Connect the **12 V** power adapter to the detection unit, BRS-Unit B (C6), and to a 100-240 V 50/60 Hz standard power socket. After this, connect the **24 V** power adapter to the Motor Controller and to a 100-240 V 50/60 Hz standard power socket. **IMPORTANT: Always connect power to the units in this order to minimize the risk of damage to the system. Always make sure that the correct power supply is connected to the different units. Failing to do so will result in damage. (See schematic picture below.)**



THERMOSTATIC WATER BATH

a) Start up the thermostatic water bath using the main switch.
b) Set the operating temperature.

GAS VOLUME MEASURING DEVICE

a) If an anaerobic condition needs to be established during the experimental setup, the reactor headspace shall be flushed with N_2 or a mixture of N_2/CO_2 gases. Before flushing the system with gas to create anaerobic conditions, disconnect the Tygon® tube from the connection block on the Unit BCR-B (B4). Failing to do so might damage the equipment.
b) Connect the gas source to the Tygon® tubing with the red tube clamp.
c) Open the red tube clamp.
d) Flush the system with a low gas flow (i.e., 2.5 to 10 l/min) gently for 60 - 120 seconds.
e) Stop the flush gas and close the red tube clamp.
f) Disconnect the flush gas source.
g) Re-connect the Tygon® tubing to the Unit BCR-B (B4).

Repeat the procedure for all the reactors used in the test.

Important! Before flushing the system, disconnect the Tygon® tube from Unit BRS-B in order to eliminate the risk of damaging built-in check valves in Unit BRS-B by the high pressure gas flow.
After flushing the system and before starting the data logging, manually open all the flow cells in the gas measuring device in order to release any remaining flush gas trapped in the flow cell chambers.

Software

a) Make sure that the shielded Ethernet cord is connected to the gas volume measuring device, Unit BRS-B, and a local internal network or other suitable network equipment. Make sure that the network cable is connected prior to connecting the power supply.
b) Follow the instructions presented in Chapter 9. BRS Software step by step for accessing the software interface through an Internet browser, such as Google Chrome or the latest version of Internet Explorer. Using Google Chrome is always recommended.
c) When software and experiment configuration have been completed, start the data logging function of the BRS software. In the Control menu, activate all the cells for data registration. Open each cell in the gas volume measuring device manually several times and follow the corresponding result of each opening on the plots in the Graph menu of the software to make sure that both the detection system and data acquisition system function properly.
d) Check the files obtained when generating a report in the Download report menu. Download these files and open them using Microsoft Excel 2007 (or a later version).
e) Re-start the BRS data acquisition by pressing the “End experiment” and “Start experiment” buttons for each individual cell.

8.3 Monitoring

Reactors

a) If possible, perform a GC analysis to determine the fraction of methane in the raw biogas samples or simply estimate the methane content based on literature studies or previous experiment results for a similar substrate sample.
b) Periodically check that the mixing works properly.

Thermostatic Water Bath

a) Periodically check the water level in the thermostatic water bath.
b) Fill up with additional deionised or distilled water when necessary.

Gas volume Measuring Device

a) Check that the water level in the water bath for the gas flow measuring device is within the recommended range.
b) Fill up with additional deionised or distilled water to the recommended water level when necessary.
c) Make sure that data is registering properly.

Removing CO_2 (If Necessary)

a) The pH indicator Thymolphthalein will turn from blue to colourless when the CO_2 binding capacity of the NaOH solution decreases below optimal. At this point, replacement of the bottle with NaOH solution is recommended, for avoiding the CO_2 gas to pass to the detection unit. At 22 °C, about 20-25 l CO_2 can theoretically be captured in each bottle with 400 ml solution before it needs to be changed.
b) To change a NaOH solution bottle, place the tubing clamps on the tubing on each side of the bottle and then disconnect the bottle by gently pulling the Tygon® tubing. Replace the old NaOH solution with a fresh one and open/remove the clamps.

Software

See the Chapter 9. BRS Software for information regarding software function and operation.

8.4 End of Operation

a) Note the total running time if this is of interest. In the saved data files, the last data collected will be from the last opening of a cell.
b) Generate a report in the Reports menu. Download the report and open it to make sure that the report has been generated properly and that no errors occurred while downloading the file.
c) Stop the logging by pressing the pause button and then the stop button. Note: When pressing the stop button, the experiment associated with that particular cell can no longer be continued.
d) Turn off the thermostatic water bath.
e) Set the ON/OFF switch on each motor unit to OFF.
f) Set the System switch on the Motor Controller to OFF.
g) Unplug the power adapters (for the Motor Controller and the detection unit) from the power source.
h) Disconnect all tubing connections between the reactors and the gas volume measuring device. (If CO_2-elimination solution bottles have been used, disconnect all tubing between the NaOH bottles and the reactors and detection unit (BRS-Unit B)).
i) Empty the water from the water bath by using the manual plastic water pump only. Do not pour out water from water bath in any other way. Directly pouring out the water without using the water pump might allow water to flow into the space between the water tank and the stand, as well as flow into the stand. There is a potential risk of electronic

damage even if only very limited amounts of water are accidently in contact with the electronic circuit boards inside the stand.

DATA HANDLING

When a report is generated, save the report in the cloud software and, if necessary, further on in a desired folder on the local computer used to visualize the software interface.

See also Appendix and Chapter 9. BRS Software for details regarding data handling.

The report files can be generated anytime during the experiment, and can be used for further data analysis and curve plotting in Microsoft Excel or other software capable of reading this file format. The name of the data file is automatically generated, consisting of the actual date and time. For example, a file saved on 1st of October 2012 at 12:30 will get the name "report_20121001_1230_049.xls".

All data is adjusted to a user defined sampling time interval (i.e., day, hour or quarter of hour) and it is generated in a Microsoft Excel file containing four sheets: Process Data, Process Parameters, Feed Data and Discharge Data. The following data are stored in the files:

1) In the Process Data sheet:
    a. Time (dates and times) since the start of the experiment
    b. Flow rate (Nl/day)
    c. Organic feeding (gVS/day)
    d. Feeding (g/day)
    e. Digester volume (ml)
    f. Process temperature (°C)
    g. Process operation mode (manual or automatic)
2) In the Process Parameters sheet:
    a. Time (dates and times) since the start of the experiment
    b. OLR (gVS/l/day)
    c. HRT (days)
    d. SGP (Nl/l/day)
    e. Organic yield (Nl/gVS)
    f. Yield (Nl/kg)
3) In the Feed Data sheet:
    a. Time (h, days) since the start of the experiment
    b. Substrate amount (g)
    c. Substrate organic amount (gVS)
    d. Substrate concentration (%)
    e. Substrate type
4) In the Discharge Data sheet:
    a. Time (hours, days) since the start of the experiment
    b. Sludge amount (g)

The generated file contains the volume of gas already normalised (1.0 standard atmospheric pressure, 0 ºC and zero moisture content). The calculations are carried out to compensate for pressure, temperature and saturated moisture content at the above given conditions (based on the values of pressure and temperature registered by the sensors from Unit BRS-B).

9 BRS SOFTWARE

9.1 USERNAMES AND PASSWORDS

The BRS provides user interaction through two different interfaces: the cloud web interface and the local machine web interface. The cloud web interface is used to control the system and experiments during normal operations, while the local machine interface is used for network configuration, time configuration and upgrading. Before using the system, it is important to make note of the default passwords and, for safety reasons, change them to user defined ones. Always take care to store the passwords in a safe location for later reference. If the passwords are forgotten or misplaced, the cloud interface password can be reset by BPC upon proven ownership of the machine and identity while the local machine interface can be reset by utilising the reset function located on the back of the unit.

Local machine web interface

Username	user
Password	bpc

Cloud web interface

Username	user provided email address
Password	bioprocesscontrol

9.2 FIRST TIME CONNECTING AND SETTING UP THE NETWORK

AUTOMATIC CONFIGURATION

The BRS system comes preconfigured for use with DHCP (Dynamic Host Configuration Protocol) and NTP (Network Time Protocol), meaning that if the network environment it is to be connected to supports these features, no manual configuration of the system is required.

a) Connect the shielded Ethernet cable to the gas volume measuring device, Unit BRS-B.
b) Connect the shielded Ethernet cable to the internal network or other suitable network equipment.

Important! Make sure that the network cable is connected prior to connecting the power.

c) Connect the motor module's DC-plug to the Unit BRS-B.
d) Connect the power supply (12 V DC) first to the motor module, and then to a standard 100-240 V ~ 50/60 Hz power socket.

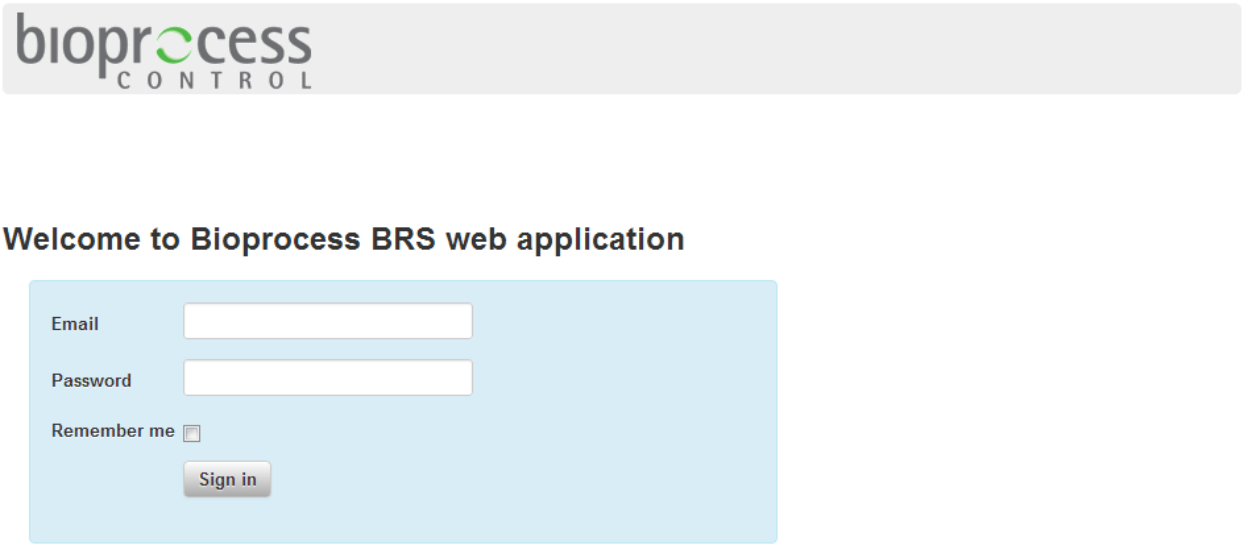
Important! Make sure that the motor module's DC-plug that supports the Unit BRS-B with power is already connected before connecting the power adapter.

Once the unit is powered on, it will automatically acquire the needed information and connect to the BPC cloud solution[1] within a few minutes. Please note that in order to function properly, the BRS system needs to have access to an internet connection.

To access the web interface of the system, enter the following address (please note the s in https, indicating secure encryption) in the address bar of a web browser running on a computer connected to the internet:

https:// simulator.bioprocesscontrol.com

Important! When the system is connected for the first time, it might take up to 15 minutes before the system registers a connection in the BRS cloud software (connection state can be seen in the top right corner and in the System page on the last seen section of the cloud interface). This situation is absolutely normal and it should not be a cause for concern.



When presented with the login page for the BRS web application, enter the login information provided with the system and press the button marked “Sign in”.

MANUAL CONFIGURATION

If the setup of the network where the BRS system is to be used does not support DHCP, or for some other reason it is desirable to not use DHCP, the BRS can be manually configured instead. First, it is required to reset the system from the default shipping configuration into a predefined fixed configuration. This is achieved by the following steps:

a) Connect the motor module’s DC-plug to the Unit BRS-B.

[1] The BRS communicates with the internet using port 80 (data transfer) and port 123 (time synchronization)

b) Connect the power supply (12 V DC) first to the motor module, and then to a standard 100-240 V ~ 50/60 Hz power socket.
c) Wait approximately five minutes for the BRS to boot up and start the internal software.
d) Locate the pin-sized hole on the back of the unit marked “Reset” and gently insert a needle shaped object into the hole to press the reset switch located inside.
e) When the switch has been pressed properly, a red light should turn on inside the unit for a short while, indicating that the system is rebooting.
f) When the system is finished rebooting (approximately two minutes) a blue light should turn on to indicate that the system is up and running again.
g) Disconnect the power supply from the wall power socket.

When the following reset procedure has taken place, the BRS system will now be configured to have 192.168.10.11 as its IP address and it will be ready for manual configuration of the network settings through a computer connected directly to the Unit BRS-B.

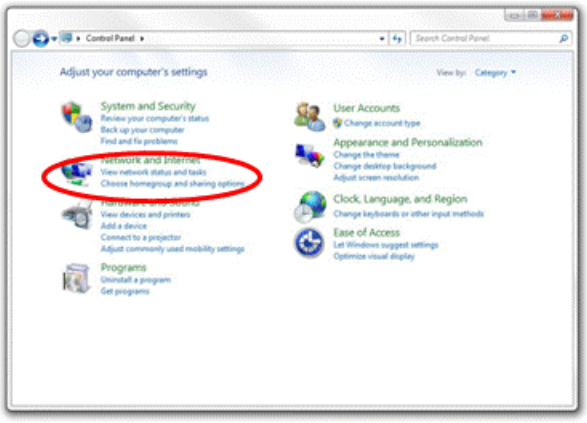
Important! Make sure the computer is not connected to a wireless network. If possible, temporarily completely disable the wireless capability.

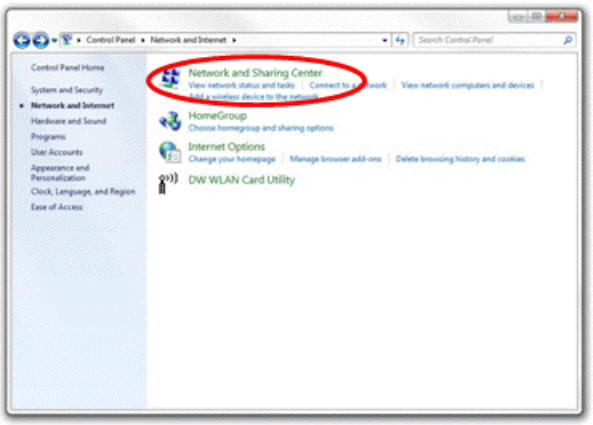
a) Connect the shielded Ethernet cable to the gas volume measuring device, Unit BRS-B.
b) Connect the shielded Ethernet cable to a computer.

Important! Make sure that the network cable is connected prior to connecting the power.

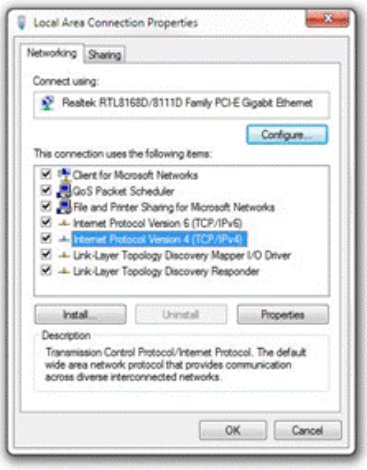
c) Connect the power supply (12 V DC) to a standard 100-240 V ~ 50/60 Hz wall power socket.

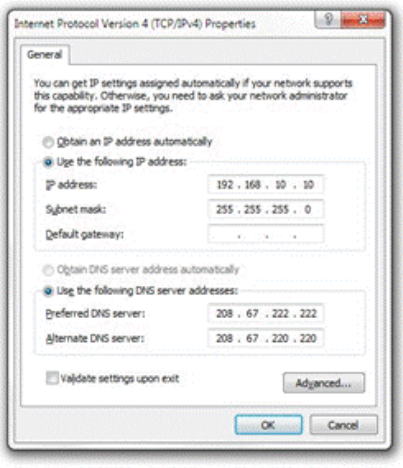
WINDOWS 7





a) In the Windows Start Menu, select “Control Panel”.
b) In the Control Panel, select “Network and Internet”.
c) Select “Network and Sharing Center”.





d) On the left side of the window, select “Change adapter settings”.

e) Right click on the appropriate network adapter and select “Properties”. Usually this is named “Local Area Connection”, possibly followed by a number. It is important that the adapter corresponding to the connected Ethernet cable is selected.

f) Select “Internet Protocol Version 4 (TCP/IPv4)” and click on the button marked “Properties”.

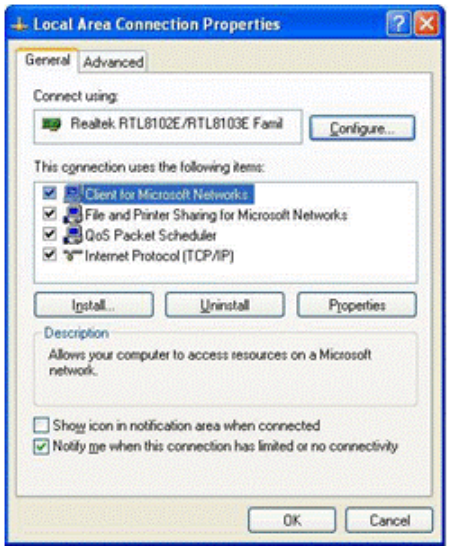
g) Write down the initial settings (e.g., IP address, subnet mask).

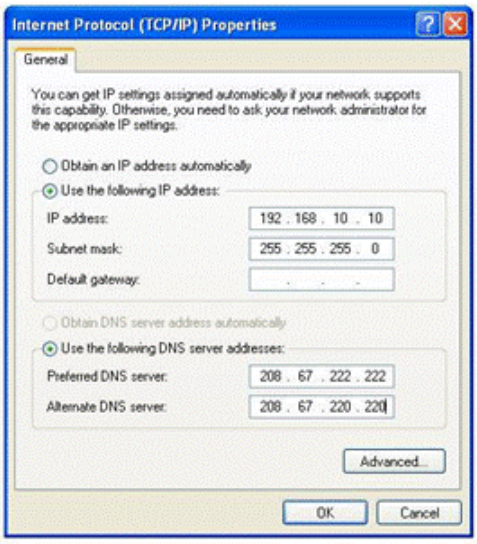
h) Select “Use the following IP address” and enter the following values in the fields:
   1) IP address: 192.168.10.10
   2) Subnet mask: 255.255.255.0

i) Select “OK”.

j) Click “Close” in the remaining window.

WINDOWS XP





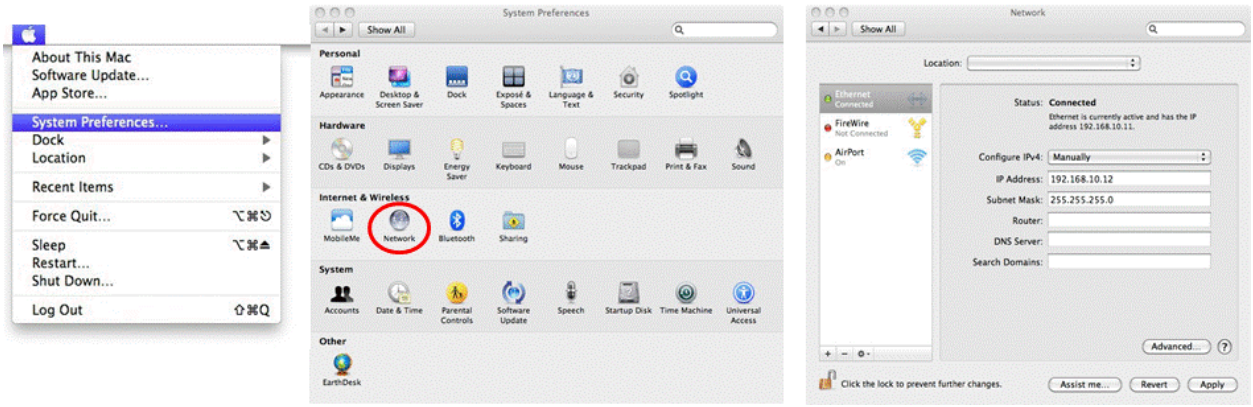
a) In the Windows Start Menu, select “Control Panel”.

b) Select “Network Connections”.
c) Right click on the appropriate network adapter and select “Properties”. Usually this is named “Local Area Connection”, possibly followed by a number. It is important that the adapter corresponding to the connected Ethernet cable is selected.
d) Select “Internet Protocol” and click on the button marked “Properties”.
e) Write down the initial settings (e.g., IP address, subnet mask).
f) Select “Use the following IP address” and enter the following values in the fields:

1.1 IP address: 192.168.10.10
1.2 Subnet mask: 255.255.255.0

g) Select “OK”.
h) Select “OK” in the remaining window.

MAC OS X



Select the Apple Menu button and select “System Preferences”.

a) Select “Network”.
b) Write down the initial settings (e.g., IP address, subnet mask).
c) Select “Manually” from the “configure IPv4” dropdown menu and enter the following values in the fields:

1.3 IP Address: 192.168.10.10
1.4 Subnet mask: 255.255.255.0

d) Select “Apply”.

ALL SYSTEMS

To access the instrument, open a web browser (Google Chrome is recommended as it provides the best and most compatible feature set for the BRS).

In the address field enter, http://192.168.10.11

Bellow is located a quick guide to make sure that all settings have been made correctly.

BRS

IP Address	192.168.10.11
Subnet mask	255.255.255.0

Computer

IP Address	192.168.10.10
Subnet mask	255.255.255.0

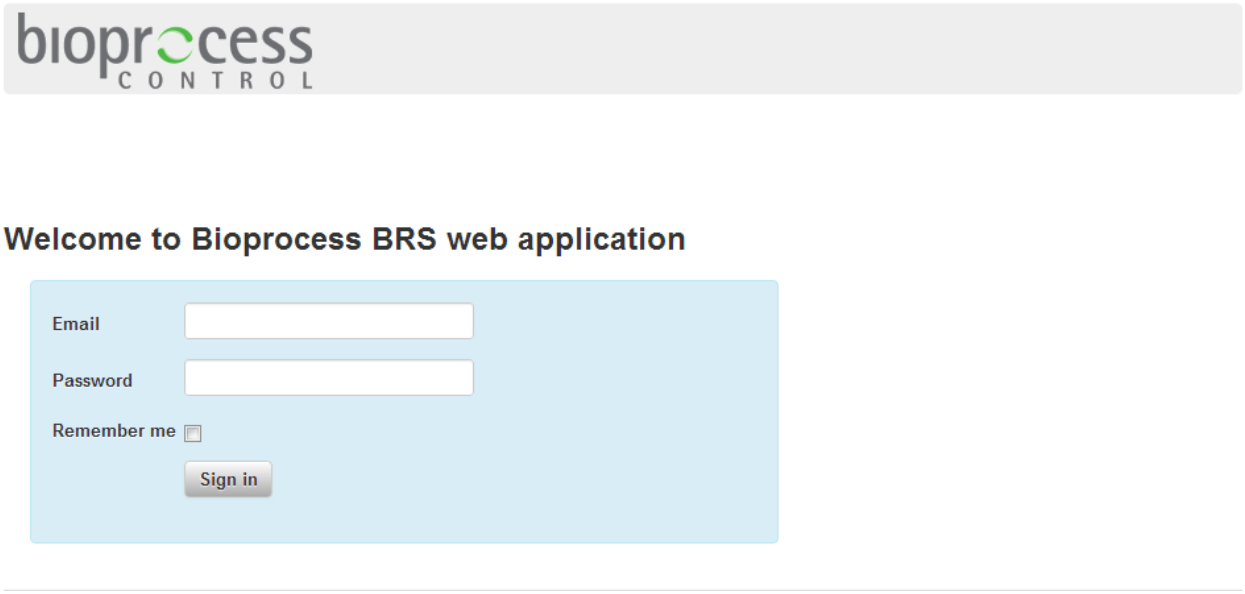
Please note that the IP address for the computer and the IP address for the BRS are different. This is a design requirement of the IP protocol. Care needs to be taken so that the same address is not used in both locations as it will render the system inaccessible from the designated computer.

After setting up the computer so it is able to communicate with the BRS system, please follow the steps below:

a) Log in locally to the BRS by clicking on “login to the BRS system” and entering the user name (user) and the password (bpc).
b) In the web browser window, showing the BRS local web application, click on the tab marked “System”.
c) On the right hand side, select the appropriate time zone where the instrument will be used. If NTP (setting the time and date of the system automatically) is to be used, make sure that check-box named “Syncronize time automatically over the internet” is marked. Otherwise, make sure that the check-box is not marked, make sure that the time and date on the computer being used to setup the BRS is set properly and click on the button marked “Use this time for the instrument” to set the internal clock of the BRS to the same time and date as that of the computer.
d) Enter the required network information followed by selecting “Apply network settings” and clicking “Yes” in the confirmation dialogue.
e) Wait approximately 5 minutes for the BRS to change the settings and reboot.
f) Disconnect the power supply from the wall power socket
g) Disconnect the provided shielded Ethernet cable from the computer (not the Unit BRS-B) and connect it to the internal network or other suitable network equipment.
h) Connect the power supply to a wall power socket.

9.3 Function and Operation

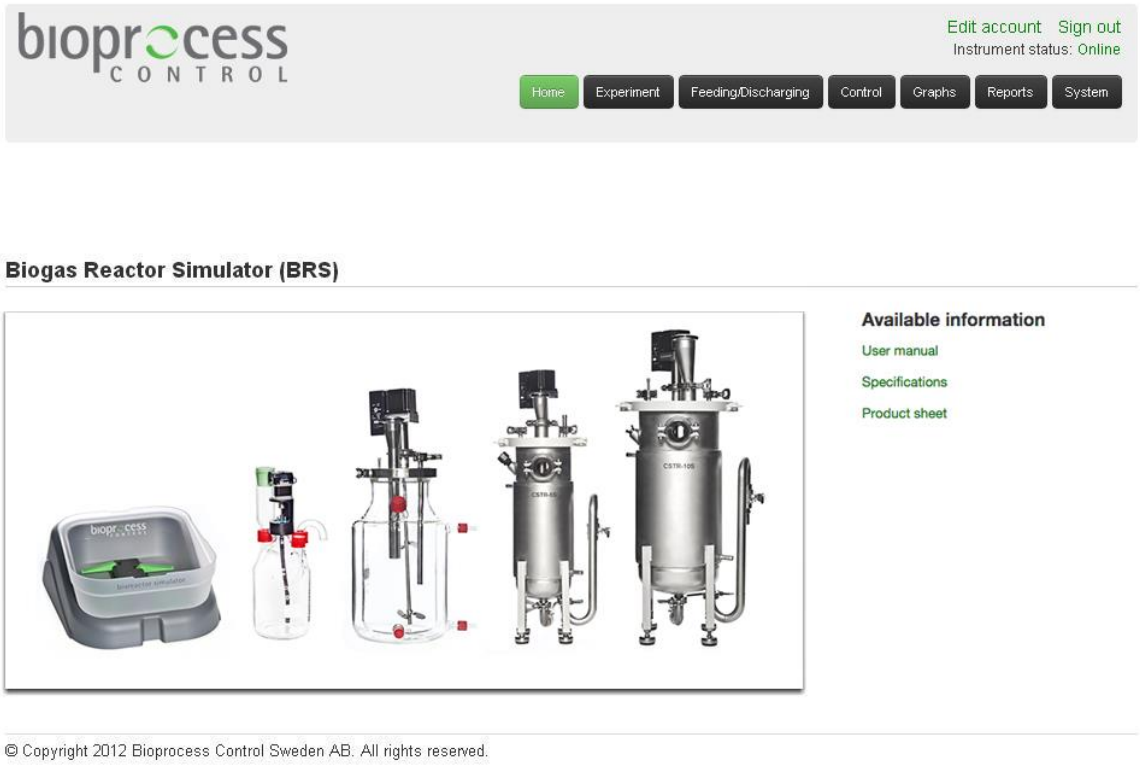
Log in



The page is used to log in to the BRS.

a) Enter the following website address: https://simulator.bioprocesscontrol.com
b) Enter your assigned e-mail address
c) Enter your password: bioprocesscontrol (default password). Please note that this password should be changed by the user for security purposes.
d) Press “Sign in”

HOME



The web interface is organized in a number of pages, all reachable from the start page named "Home", which is the first page the user enters. Documentation and instructions regarding the BRS is available on the page. The pages are organised in the order an experiment is setup, executed, monitored and finally documented.

The following pages are available:

Home

The home page also contains links (to the right) to different kinds of information, such as user manual, technical specification and product information sheets.

Experiment

The user prepares an experiment by setting up individual data for each reactor/line.

Feeding/Discharging

The user has the possibility to specify type of substrate, its concentration, and schedule the time for feeding/discharging and one of the following variable inputs: amount, requested OLR or HRT.

Control

The user can start, pause and end an experiment. The user can also control the speed of the motors driving the reactor stirrers.

Graphs

Two graphs, showing the accumulated gas flow rate and OLR & HRT vs. time, are displayed.

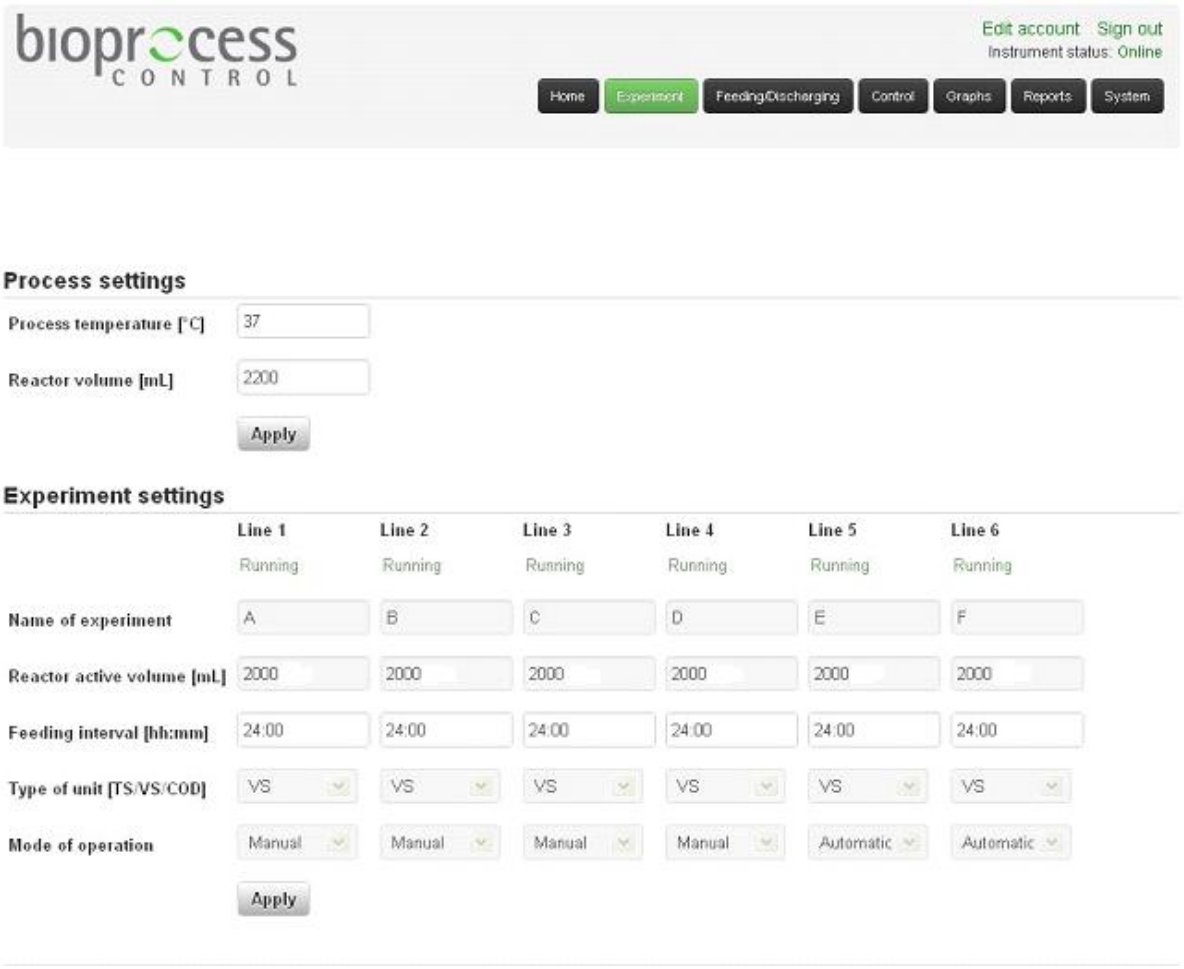
Reports

The user can generate a report from the page. The report contains experiment data for each reactor/line.

System

This page contains the configuration of IP addresses and cell volume settings, the system log and set date and time. Performing a system reboot is also possible from this page.

EXPERIMENT



This page is used to setup an experiment. The user starts by inserting the process settings and continues with the experiment parameters for each individual reactor.

Process settings

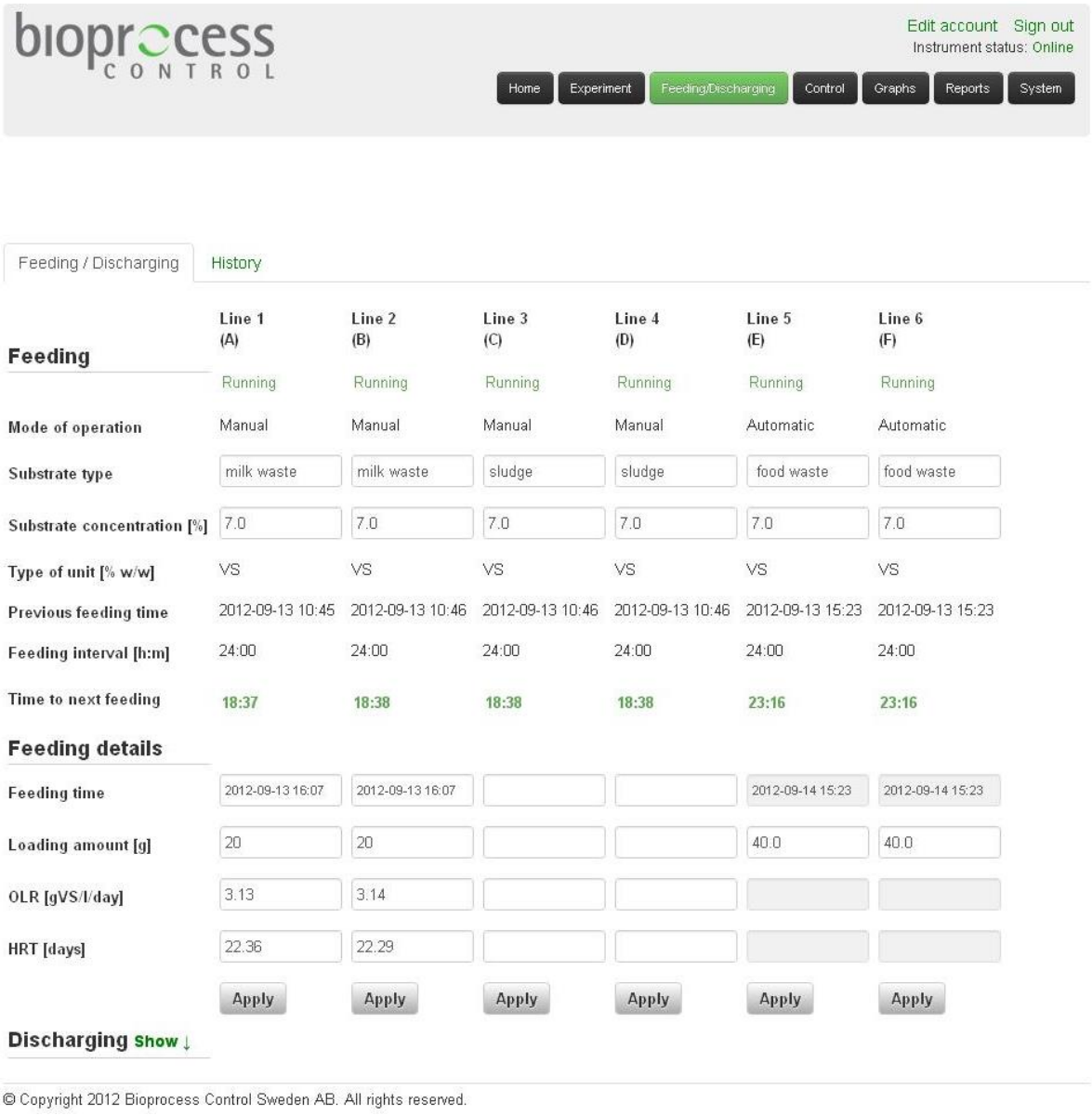
Some settings are common for all cells, for example the process temperature and the reactor volume.

Experiment settings

The user enters the name of the experiment and relevant values for the active volume of the reactor, the feeding interval and the unit for the substrate concentration (i.e. TS, VS, COD). The BRS allows the user to run the process in both manual and automatic feeding and discharging modes.

When the user has filled in the values for one line, the data is saved by pressing the button "Apply". The procedure is repeated for each particular line.

FEEDING/DISCHARGING



This page is used to control the substrate feeding and discharging of digested slurry. The system operation mode appears based on the selection at the previous page, either as manual or automatic, and it cannot be changed from this page.

Feeding

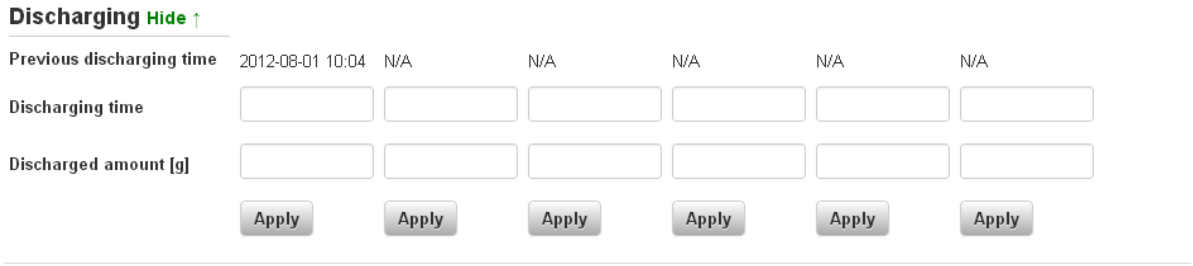
The user has the possibility to specify the type of substrate and its concentration (expressed in TS, VS or COD units as w/w%). The information related to the previous feeding time, the feeding interval and the time to next feeding appears in this page. If the time until the next feeding has already expired, it will be marked in red, otherwise it will be green.

Feeding details

In this section, the user will introduce the values for the feeding time and one of the interested parameters such as loading amount, OLR, or HRT. Depending on which parameter is chosen, the

other two are directly calculated to give the user the optimal support for how to feed the reactor. The unit for the OLR is related to the previous characterisation of the substrate (e.g., gVS/l/day, gCOD/l/day).

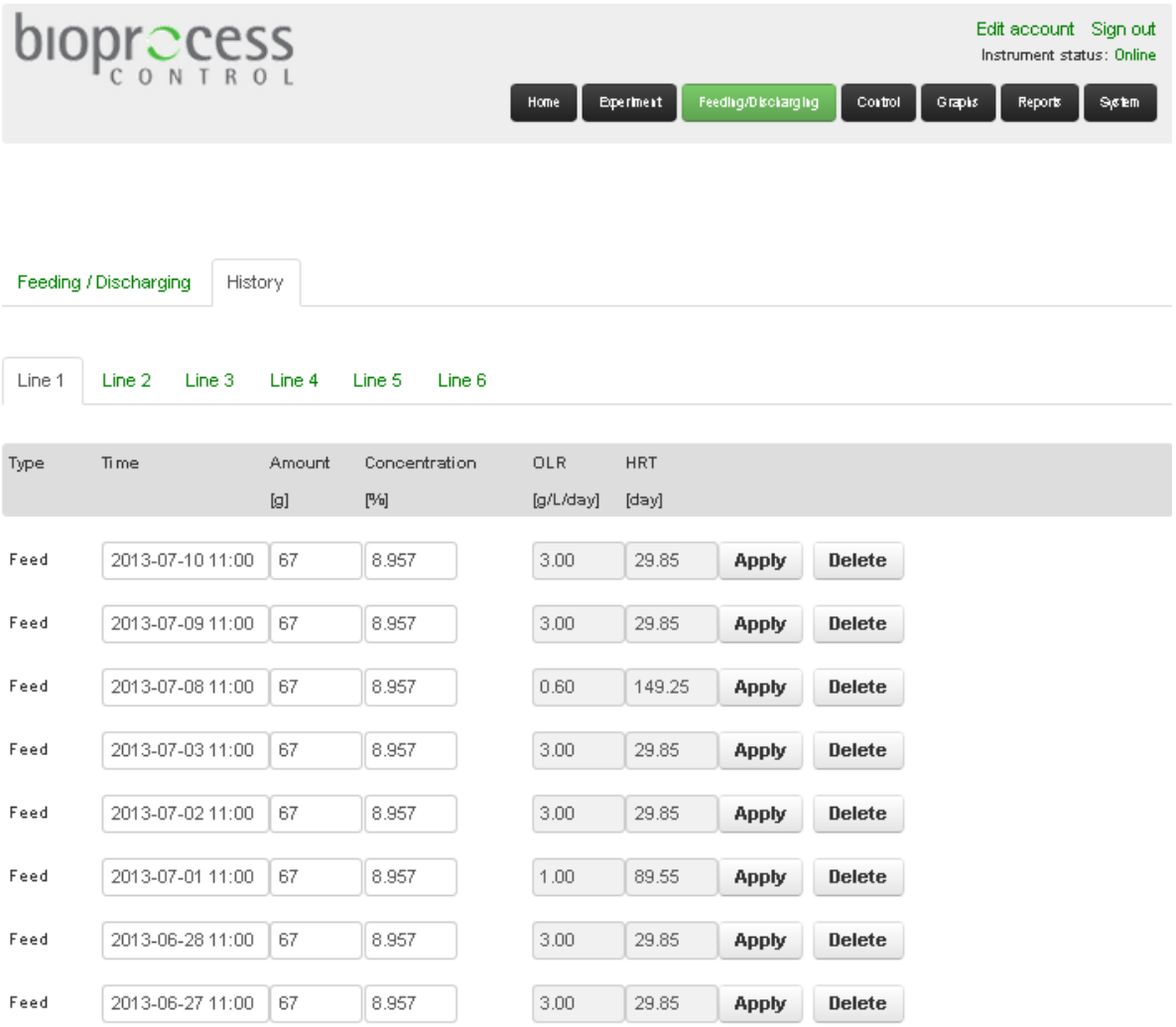
After introducing the values for one line, the user has to press “Apply” in order to store the data. The procedure is repeated for each individual reactor.



Discharging

The user has the possibility to simultaneously view another section related to the discharging step by activating the hidden Discharging function (Show ↓). The previous discharging time will be displayed and the user will be able to introduce the new discharging time and the discharged amount. All data will be saved into the report generated.

If it is considered that each feeding is followed by a discharging step where the amount of digested sludge removed from the reactor is equal to the added organic material, then it is not necessary to insert any information in this section. In this case, the Discharging function (Hide ↑) can be activated during the experiment.

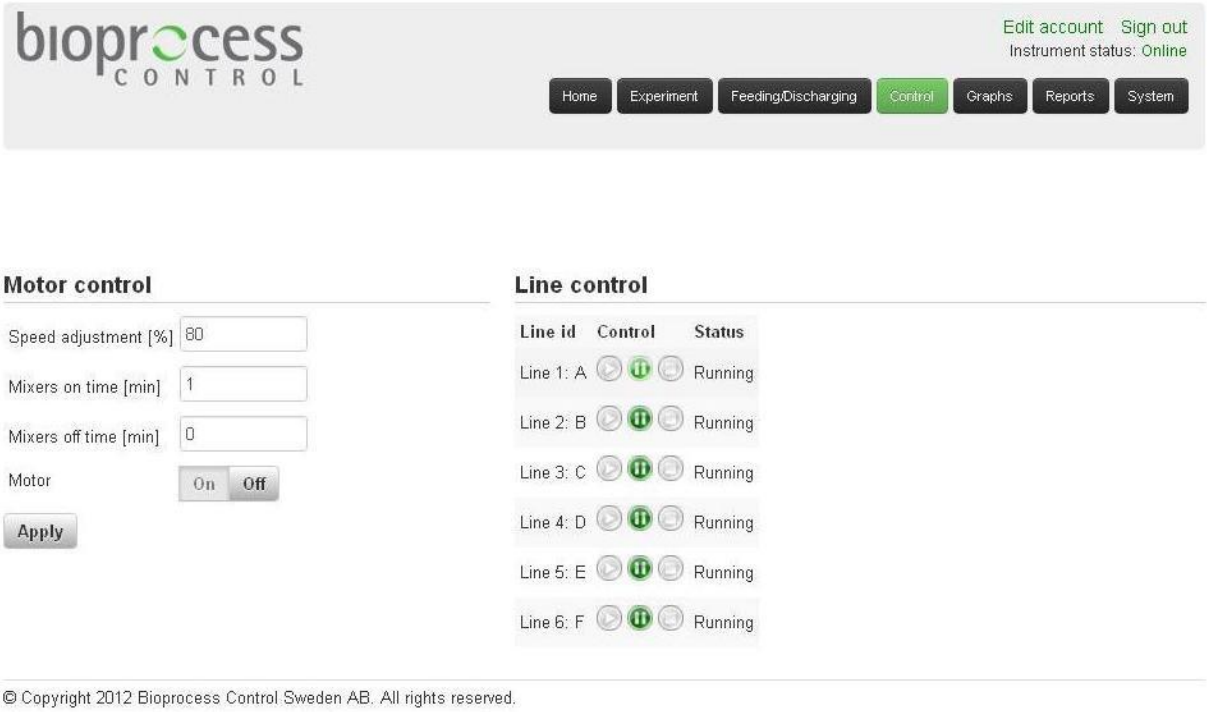


History

Through this function the user can have access to the history of each reactor. The previous feedings and discharges can be seen with regard to the time of feeding/discharging, amount and substrate concentration. The corresponding parameters ORL and HRT are also calculated and displayed for each particular feeding.

The historic information from the reactors can be accessed by pressing the button Line x (where $1 \leq x \leq 6$) one by one. The user has the possibility to correct (edit or delete) data regarding previous feedings and discharges.

CONTROL



This section handles the Control page. The page shows different controls that can be changed by the user.

Motor Control

Through this function the user can control the speed and the mixer on/off time. The motor status is either on or off. To activate the settings, the button "Apply" has to be pressed. The settings are the same for all motors.

Important! The motor speed should only be set at a value which is equal or higher than 80%, to prolong the life of the motors.

Line control

Each line has a set of buttons that control the experiment. The first is the start experiment button. When hovering over it with the mouse and pressing it the text “Are you sure? This will erase all previous experiment data!” is displayed.

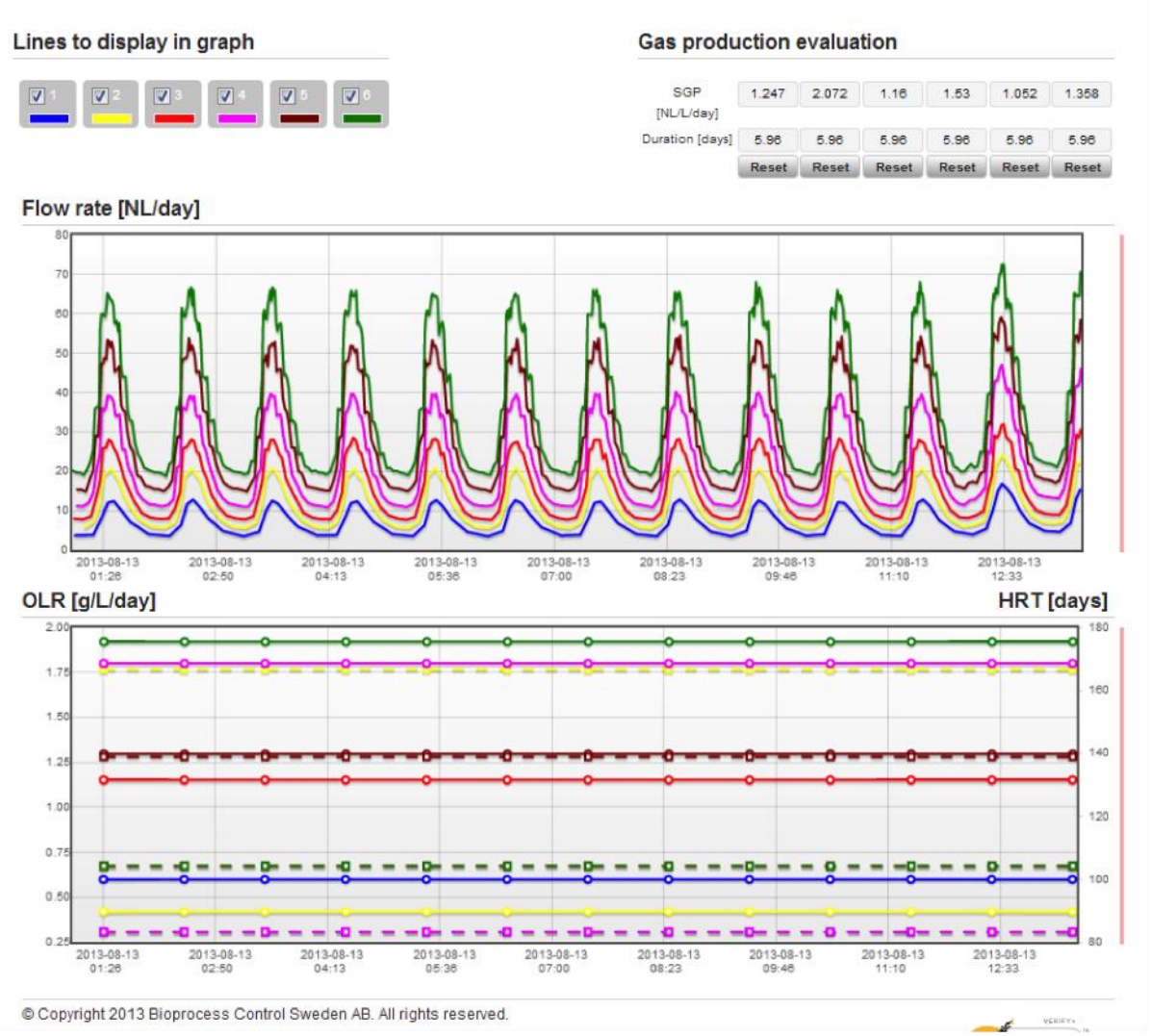
Important! When pressing the “Start experiment” button, a new session is started and all data from the previous session will be deleted.

An experiment may be paused at any time. This is done by pressing the corresponding “Pause” button. During pause no data is recorded, but the time is still registered. By pressing the “Pause” button again the experiment will continue normally.

When the “Pause” button has been pressed, the “End experiment” button becomes available. By pressing the “End experiment” button neither data nor time are further recorded. The collected data is available until the next time the Start experiment is pressed.

After starting/pausing/stopping an experiment (e.g. Line x), the following message will appear at the top of the page: “Line x was successfully started/paused/stopped”.

GRAPH



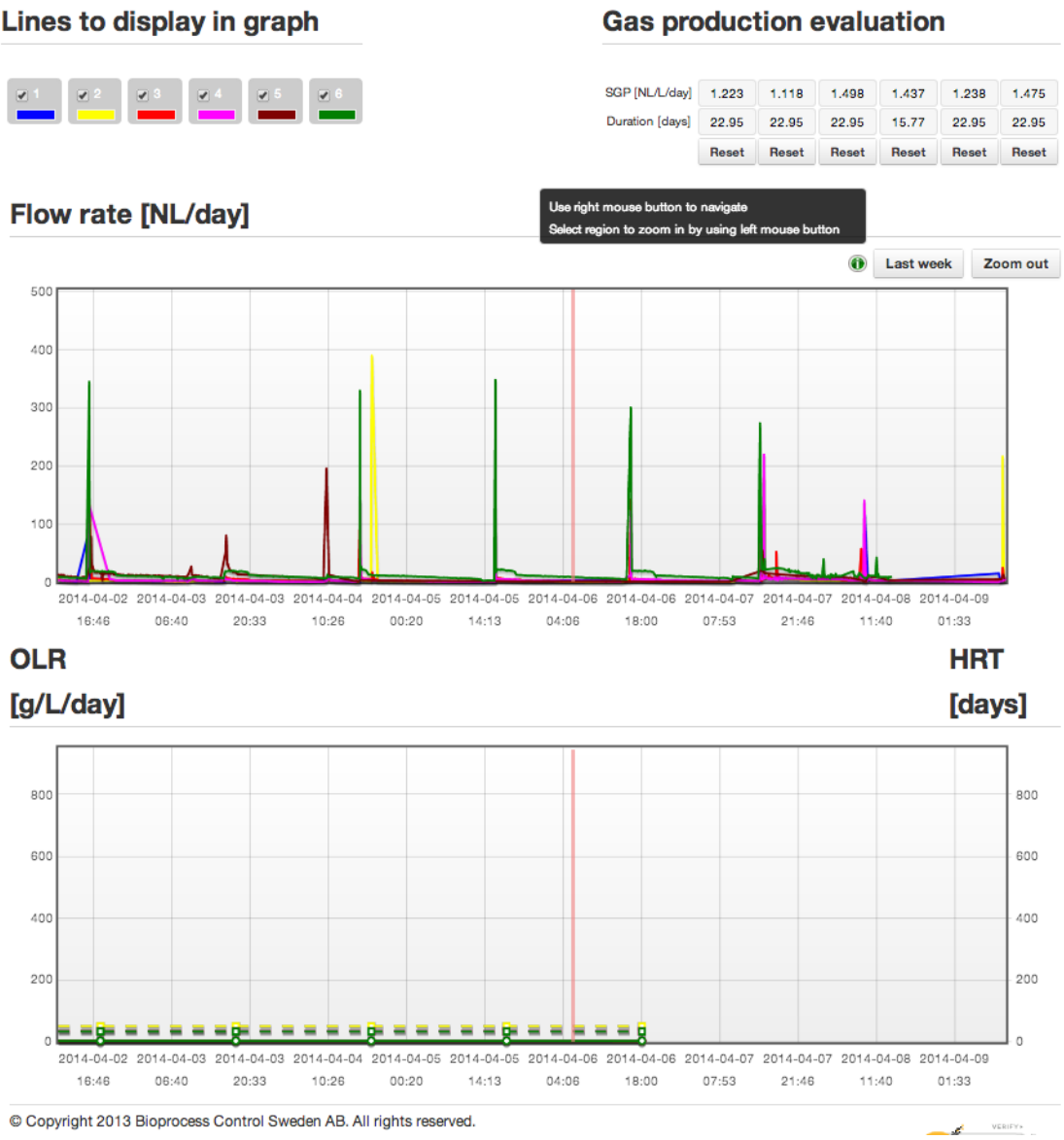
This section shows what the Graphs page may look like. In some browsers the data may initially not be displayed and reloading the page may be necessary.

Lines to display in graph

All 6 lines/cells have a checkbox. Active cells have a colour assigned to them. If a cell is not active, the assigned colour is grey. When hovering over an active cell, the latest opening cell time is displayed.

Flow rate, OLR and HRT

The two graphs show variation in time of the gas flow rate, OLR and HRT, respectively calculated and reported in real-time. The values displayed in the graphs are normalized to 1.0 atm, 0 ºC and zero moisture content. By hovering the mouse pointer over a specific measurement point, information regarding this measurement can be obtained (e.g. Line: 6; Time: 2014-04-05 18:00; Flow rate: 173.33 Nl/day; OLR: 3.00 g VS/l/day; HRT: 33.33 days).



Above the graph window there are two buttons available: “Last week” and “Zoom out”.

i) “Last week” button adjusts the graph window to display the previous week data in an overview.

ii) “Zoom out” button adjusts the graph window so that more data is being displayed. This button can be pressed several times to zoom out several steps.

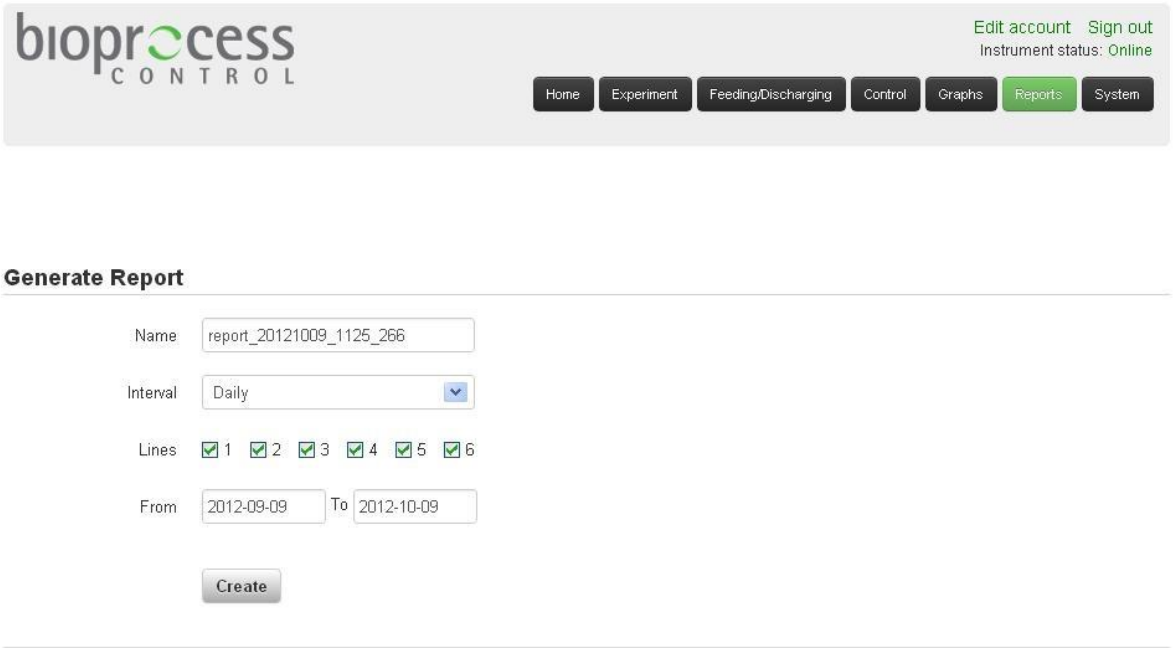
In order to *navigate/pan*, the right mouse button is used (right-click-and-hold and drag).

In order to *zoom in*, the left mouse button is used to highlight a square area in the graph (left-click-and-hold and drag) which is then displayed in the graph window, in a zoomed state.

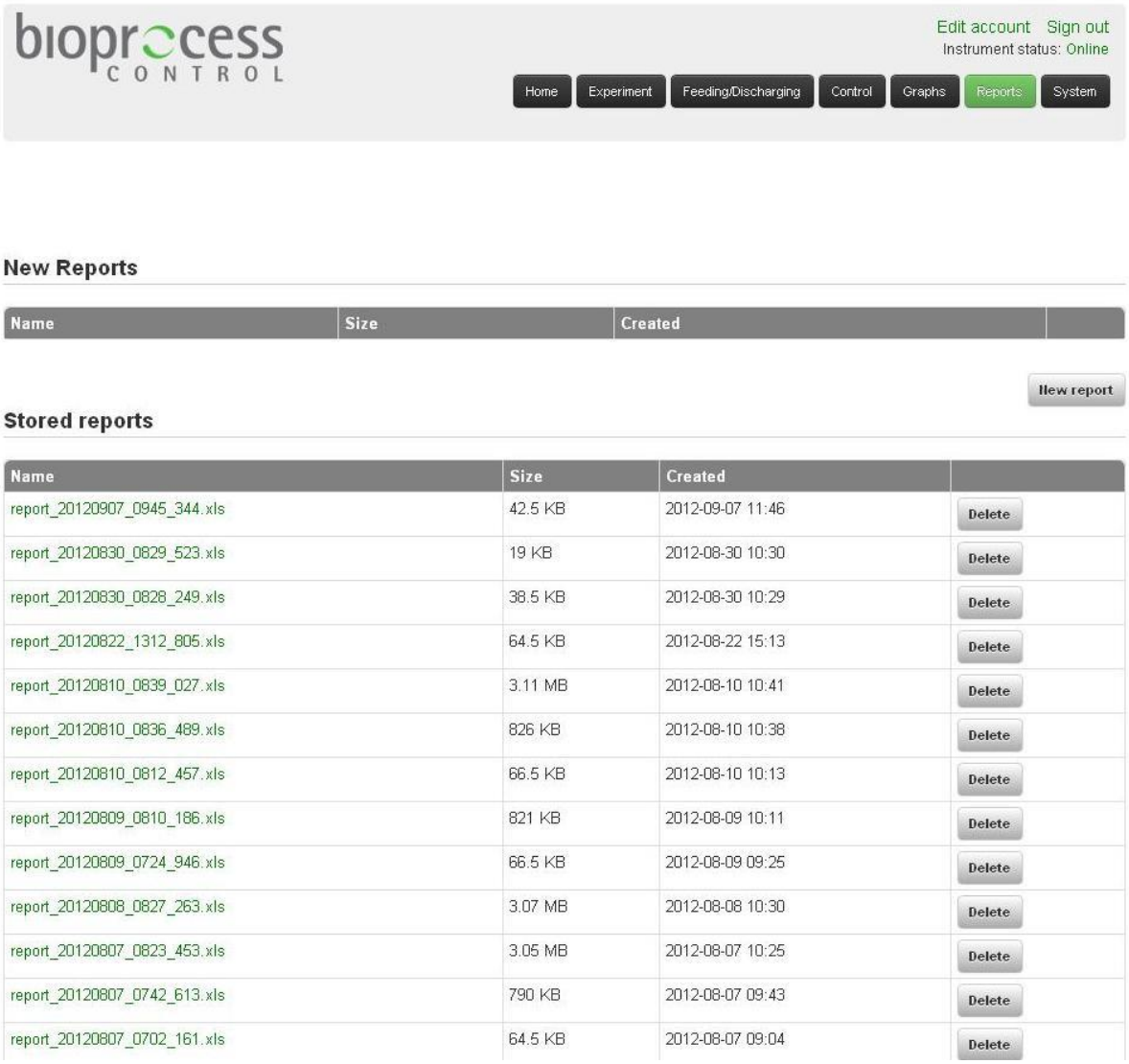
Gas production evaluation

The specific gas production (SGP) is calculated and displayed for the period of time passed since the last reset of the calculations.

REPORTS

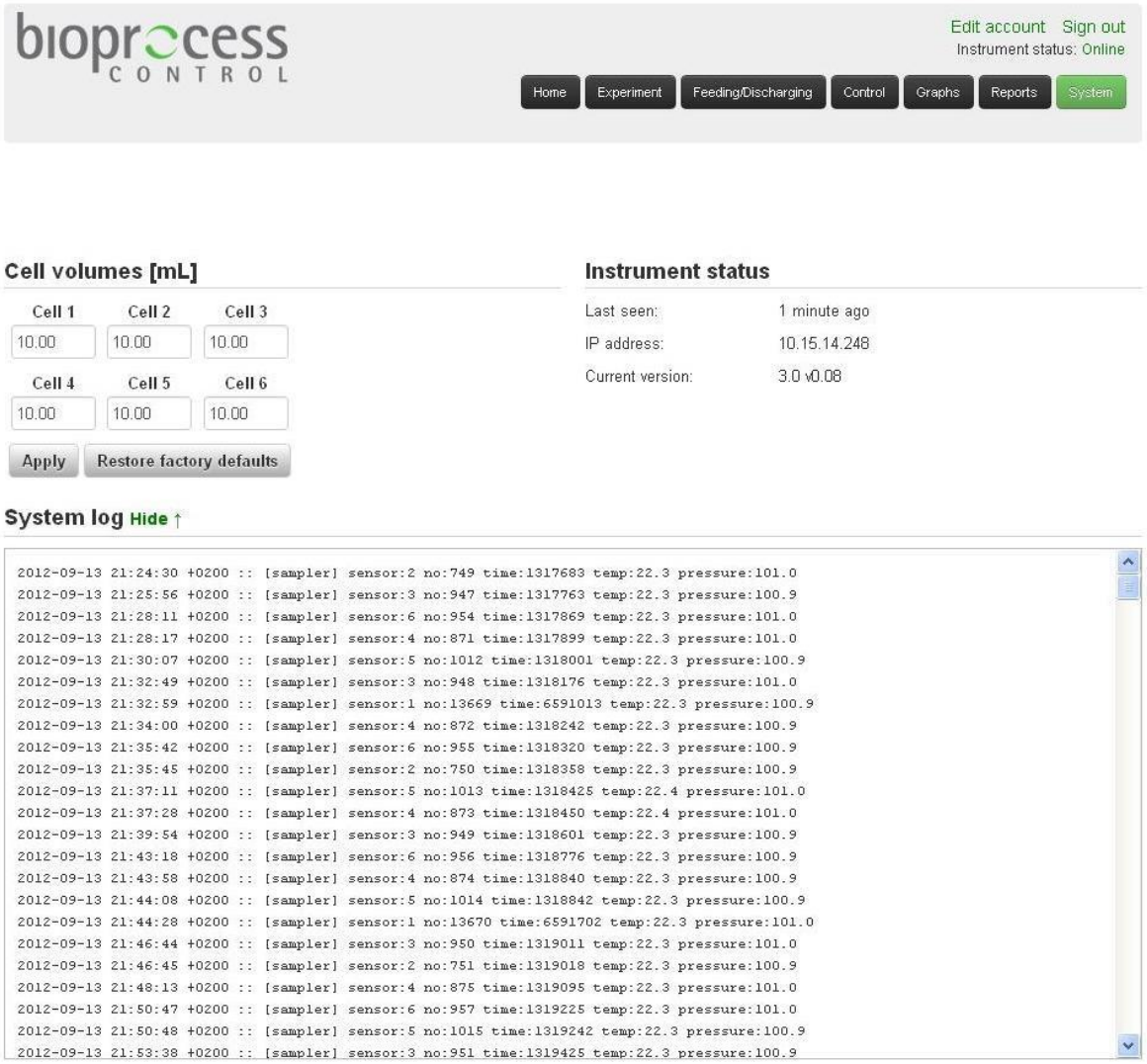


When pressing the "New report" button on the Reports page, a new window will open, containing a unique report name, and where the frequency of the reporting period (i.e., quarter of hour, hour, day), the specific lines/reactors from which the results should be included, and the reporting period may be selected. For generating the report, the button "Create" should be pressed.



The reports generated by the user are stored on the cloud software to a maximum capacity of 20 MB. The maximum storage capacity can be increased upon request. The reports are saved as Excel files with typical names “report_date_time_random code”.

SYSTEM



This section shows what the System page looks like. The page also gives the user the possibility to log the status/latest actions of the system.

Cell volumes

Each flow cell has a unique volume. When the cells are manufactured, the flow cells are calibrated and the volumes are pre-saved. When an experiment is started, the user of the BRS should check that the calibration values are correct in order to find out if they were changed to default values (i.e, 10.00).

Instrument status

The last time when the system registered any data is displayed together with the local IP address of the instrument and the current version of the software. The local IP address of the system can be used if there is a need to access the local web interface of the system (used for changing network settings, time settings and installing updates to the local software).

System log

The system log provides the user with an updated view of what the BRS unit logging software has registered. This includes general events, such as flow cell openings (together with time, temperature and pressure). It also includes errors experienced by the various subsystems of the BRS.

When contacting BPC with support questions, it is good to have an up to date copy of the system log as well as a copy from when a problem occurred at hand, to be able to provide these upon request.

CONNECTIVITY

In order for the system to function properly, it needs to have a reliable internet connection available. If the internet connection is temporarily lost, the system will cache the data locally but no new data will be accessible through the web user interface. Once the internet connection of the system is restored, all cached data will be uploaded with appropriate time stamps and will be made accessible. While the system is capable of sustaining local data logging while experiencing both frequent and prolonged connection losses, it is recommended to try to avoid having the system offline as much as possible.

As with all computer equipment, care should be taken to ensure that the system functions after an unscheduled reboot. Make sure that the experiment is running correctly and that data is being collected in an appropriate manner. Also make sure that any other connected equipment, such as the thermal water bath, has restarted safely and with the correct settings.

SOFTWARE UPGRADE

Care should always be taken to keep the built-in software of the BRS up to date. BPC will, from time to time, issue software updates that can be installed on the system through an easy procedure. These updates can contain both new features and bug fixes so it is imperative that, when an update is received, the system is updated at an appropriate time. While there are no known issues with installing an upgrade while an experiment is underway, it is recommended to wait for a running experiment to finish before applying an upgrade, unless other reasons make an upgrade warranted.

In order to install an update issued by BPC, append #upgrade after the BRS local IP. In order to ascertain the local IP of a specific BRS system, login to the web user interface and go to the “System” tab. Located under “Instrument status” there is a field called “IP address”. An example of a url used to reach the upgrade page of an instrument would thus be http://192.168.10.11/app.html#upgrade. Click on the “Choose File” button and select the .zip file sent by BPC. Note: Do not unzip this file and never make any changes to the files contained inside of it. Also, make sure that the filename does not include any parentheses. Some operating systems, such as Microsoft Windows, will sometimes append parentheses to filenames when the same file is downloaded more than once. If this is the case, remove the parentheses from the filenames before using it to upgrade the system.

When the file has been properly selected, click on the “Upgrade software” button. During the upgrade process, make sure that the system is not restarted or otherwise loses power. This might result in a failed upgrade. If this happens, redo the entire upgrade process from the start.

It is recommended to leave the BRS to finish its upgrade for five minutes to ensure that everything has been installed properly. When the upgrade is completed, the system will restart, with all previous data and settings intact and ready for use. To verify that the upgrade has taken place, go to the system tab of the system and, in the right hand side, compare the stated software version number to the version number of the file issued by BPC.

10. MAINTENANCE

CLEAN THE EQUIPMENT

REACTORS

Use a bottlebrush and washing-up liquid (detergent) to clean the inside and outside of the reactors. Rinse well with water.
Do **NOT** autoclave the stirrers because they contain plastic and rubber parts which are characterised by uncertain heat stability and are therefore not suitable for autoclaving.

THERMOSTATIC WATER BATH

If normal tap water is used, calcareous deposits may appear on the reactors, in the water bath and on the heating element. Periodical cleaning of the inside of the tank and the heating element with a solution of 10 to 20% hydrochloric acid or a solution of water and vinegar (acetic acid) is advised. Rinse with clean water afterwards.

For cleaning of the different parts, use the following products: (i) alcohol (for cleaning of stainless steel) or alcohol with cotton duster (for cleaning of plastic).

GAS VOLUME MEASURING DEVICE

Rinse with water after use. A soft brush can be used very gently if needed.
Make sure that all the flow cells are in the correct position. The position can be checked by lifting the flow cell and making sure that the software registers the opening of the flow cell.

If CO_2 was removed, the used NaOH must **NOT** be poured into the sink. It should be saved in dedicated vessels and disposed as hazardous waste. See the safety data sheet for the chemicals for further information.

APPENDIX A
FERMENTATION IN CONTINOUS MODE – METHOD DESCRIPTION

This method description is based on the method used in the BPC-laboratory. It can be used as is, used as a base for developing a new method or it can be replaced entirely by the customers own method.

Determination of Total (TS) and Volatile Solids (VS)

Before starting any fermentation test in a continuous mode, the biomass should be characterised with regard to total (TS) and volatiles solids (VS).

The dry matter, i.e., all inorganic and organic compounds, is often expressed as TS and can be measured according to a standard protocol. For a given biomass sample, it is necessary to heat the sample up to 105 °C in order to remove all water content.

VS is represented by the organic compounds in the sample. After finishing the TS measurement, heating the sample up to 550 °C for 2 hours should be done in order to burn the organic matter. The weight difference between the sample after heating at 105 °C and 550 °C reflects the VS content of the biomass.

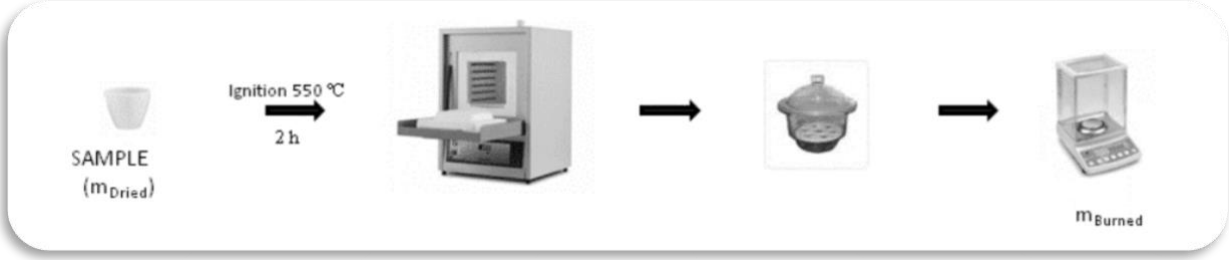
The next three steps are usually followed to determine the TS and VS of a target sample:

1). Preparation
   a) Heat a dish to 550 °C for 1 h.
   b) Place the dish in a desiccator for cooling.

2). TS determination
   a) Weigh the dish and record this value.
   b) Add 2-3 ml of a representative sample into the dish.
   c) Place the dish with the sample in an oven preheated to 105 °C and allow the volatiles to evaporate for 20 h.

3). VS determination

a) Take the dish out of the oven and allow it to cool to room temperature (RT) in a desiccator.
b) Weigh the dish and record this value.
c) Transfer this dish into a furnace pre-heated to 550 °C (ignition).
d) After 2 h, take the dish out of the furnace and cool it to RT in a desiccator.
e) Weigh the dish and record this value.



TS is calculated as the ratio between the amount of dried sample (m_{Dried}) and the initial amount of wet sample (m_{Wet}). VS content provides an estimation of the organic material in the sample and it is expressed either as the percent of the TS or as the percent of the wet sample, the second case being applied in the BPC protocol, when VS is calculated as the ratio between the difference in the amount of sample after drying and burning (m_{Burned}) and the initial amount of sample.

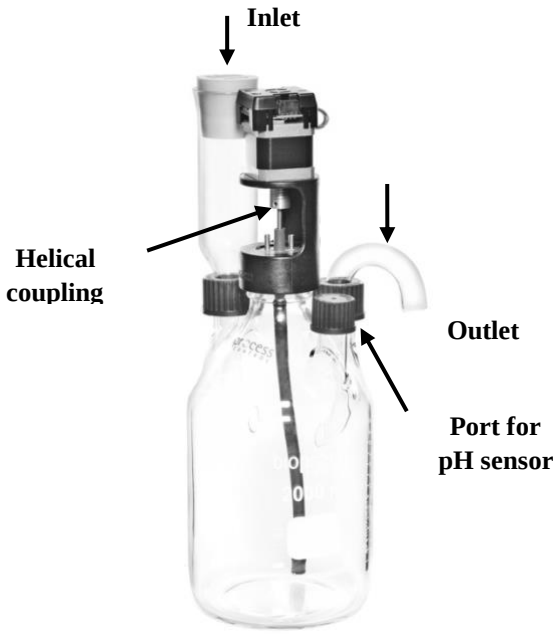
$$TS\ (\%) = \frac{m_{Dried}}{m_{Wet}}$$

$$VS(\%) = \frac{m_{Dried} - m_{Burned}}{m_{Wet}}$$

A template for automatic calculation of the two parameters can be provided by BPC. Please contact BPC in order to get more information.

BRS as a laboratory platform for simulating the operation of a full-scale digester

The kits containing 2 liter continuous stirred-tank reactors (CSTR) (6 reactors/kit) can serve as a laboratory platform for simulating anaerobic degradation processes in a continuous mode of operation. The reactors are equipped with three ports: two of them for feeding the substrate (i.e., feedstock), discharging the digested sludge, and the last one allowing for continuous measurements of the pH (or other variables) during the fermentation process.



MODE OF OPERATION

For the simulation of a full-scale CSTR digester in a laboratory, the inlet and the outlet ports of the 2 liter reactors should be closed with the help of tubing clamps or two-way valves attached to the system through silicone tubing.

Important! The clamps, two-way valves and silicone tubing are not delivered together with the system.

The feeding of the substrate can be performed either manually (by a syringe) or automatically (with the help of a pump). In the first case, when the reactor is connected to the gas flow measuring device both the inlet and outlet ports should be initially closed. In order to avoid any perturbation of the system during the feeding step, the Tygon® tubing from the reactor to the gas flow measuring unit should be closed using a tubing clip (e.g. 25 mm).

First open the outlet port. After connecting a syringe filled feedstock to the silicone tubing from the inlet port, open the inlet port and add a certain amount of substrate to the reactor. The pressure created in the reactor during the addition of substrate will normally be high enough to discharge an equal amount of sludge. At the end of the process the inlet and outlet ports are to be closed, the tubing clip disconnected from the Tygon® tubing and the system will continue to register the accumulated volume of gas. The procedure can be repeated several times per day, depending on user needs.

PROCESS OPERATION IN CONTINUOUS MODE

The design and operation of a biogas plant is based on a combination of economic and technical considerations. Obtaining the maximum biogas yield, by complete digestion of a substrate, would require a long retention time inside the digester and a correspondingly large digester size. In practice, the choice of system design (digester size and type) or of applicable retention time is always based on a compromise between achieving the highest possible biogas yield and having a

justifiable plant economy. Process operation is characterised by the parameters *organic loading rate (OLR), solid retention time (SRT) and hydraulic retention time (HRT)*, which can be optimised with the help of the BRS in laboratory scale experiments.

ORGANIC LOADING RATE (OLR)

The OLR is the quantity of the organic material (e.g., VS for solid waste, COD for waste waters) fed per reactor volume on a daily basis and is expressed as $g_{VS}/(l \times day)$. This parameter considers both the concentration and the amount of incoming substrate and is dependent on the reactor size, thus representing a very good parameter for regulating the feeding of a reactor and at the same time assessing the performances of a reactor.

A recommended value to start with for a mesophilic process (35-39 ºC) is normally around 2-3 $g_{VS}/(l \times day)$; however, processes should also be tested at higher levels of ORL.

The OLR (g_{VS}/l×day) is dependent on the amount (F; g) and concentration (C; %) of the incoming substrate, the active volume of the digester (V; l), and can easily be calculated according to the equation below:

$$OLR = \frac{F \times C}{V \times t}$$

HYDRAULIC, SOLIDS, MICROORGANISM RETENTION TIMES (HRT, SRT, MRT)

The retention time refers to the period a given material spends in the digester and is usually expressed in days. HRT measures the length of time that a liquid remains in the system and is determined by dividing system volume by feedstock volume. SRT is the time that feedstock solids remain in the system, while MRT is the average time that the anaerobic bacteria (microorganisms) remain in the system.

High methane yields can often be achieved through long SRTs and MRTs, whereas high methane production rates require high OLRs and short HRTs. Long SRTs can be attained by reducing the loading rate or by retaining the solids or removing the liquid. The latter procedure permits both long SRTs and short HRTs.

In case of a digester using a CSTR configuration, its SRT and MRT are equal to the HRT. Too short an HRT can lead to a washing-out of the bacteria (due to the fact that more bacteria is leaving the digester than can be reproduced), which can cause digester crashes.

As a recommendation, the HRT should be kept above 20 days for CSTRs to make sure there is no risk of bacteria cell washout. A high HRT will also lead to a longer time for the bacteria to degrade the substrate which in turn will increase the gas yield. However, this will also lower productivity in most cases. Therefore, it is important to find a good balance for HRT.

The HRT (days) can easily be calculated by dividing the active volume of a digester (V; l) with the average inflow (F_{in}; l/day), according to the following equation:

$$HRT = \frac{V}{F_{in}}$$

THE RECOMMENDED VALUES FOR THE PROCESS OPERATION PARAMETERS FOR CSTRS ARE PRESENTED IN THE FOLLOWING TABLE.

	Recommended value	**Comment**
OLR	>3 g VS/(l×day)	Varies from process to process, changes in OLR should be conservative
HRT	30 days	Should be kept above 20 days

APPENDIX B
MATHEMATICAL CALCULATIONS IN BRS SOFTWARE

In this section, some issues important for the calculation of process parameters during a fermentation test in continuous mode monitored by the BRS are presented. In the text below the process parameters are given either as raw or average values: i) raw is the data that is logged in the system when the "Apply" button is pressed, and ii) average value means the average of the parameter for the time basis that is used in the report file.

Organic Load (O)

The organic load (O) is calculated every time a load is applied to the system. This value is averaged and further used in the generated MS Excel report.

Manual and automatic mode $O = F \times C$		
Symbol (unit)	**Parameter**	**Raw/average**
F (g)	Fed amount	raw
C (%)	Concentration of feed	raw

Organic Loading Rate (OLR)

The organic loading rate (OLR) is calculated every time a load is applied to the system. This value is also averaged and used in the generated MS Excel report.

Manual mode $OLR = \frac{O}{(t_j - t_{j-1}) \times V}$ Automatic mode $OLR = \frac{O}{V}$		
Symbol (unit)	**Parameter**	**Raw/average**
F (g)	Fed amount	raw
C (%)	Concentration of feed	raw
V (l)	Reactor active volume	raw
t_j (day)	Time for feeding j	raw

Hydraulic Retention Time (HRT)

The hydraulic retention time (HRT) is calculated every time a load is applied to the system. This value is averaged and used in the MS Excel file which is generated from the BRS system.

Manual mode $HRT = \frac{V \times (t_j - t_{j-1})}{F}$ Automatic mode $HRT = \frac{V}{F}$		
Symbol (unit)	**Parameter**	**Raw/average**
F (g)	Fed amount	raw
V (L)	Reactor active volume	raw
t_j (day)	Time for feeding j	raw

Specific Gas Production (SGP)

The specific gas production (SGP) is calculated every time a report is generated. The normalisation period (e.g., h, day) may be selected.

Manual and automatic mode $SGP = \frac{G}{V}$		
Symbol (unit)	**Parameter**	**Raw/average**
G (l/day)	Gas flow rate	Average
V (l)	Reactor active volume	Average

Organic Gas Yield (Y_{org})

The Organic Gas Yield (Y_{org}) is calculated for the report based on the selected time units by only using the interpolated/averaged values.

Manual and automatic mode $Yorg = \frac{SGP}{OLR}$		
Symbol (units)	**Parameter**	**Raw/average**
SGP (Nl/l/day)	Specific gas production (interpolated value)	Average
OLR (gVS/l/day)	Organic loading rate (interpolated value)	Average

Wet Gas Yield (Y_{wet})

The Wet Gas Yield (Y_{wet}) is calculated for the report based on the selected time units by only using the interpolated/averaged values.

Manual and automatic mode $Ywet = \frac{G}{F}$		
Symbol (units)	**Parameter**	**Raw/average**
G (Nl/day)	Gas flow rate (average value)	Average
F (g)	Fed amount (average value)	Average

APPENDIX C

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Downloadify

Downloadify: Client Side File Creation

JavaScript + Flash Library

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jQuery.flot

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Excanvas

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