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Industrial | Process | R&D

Instruction Manual

Anaerobic Tank Reactor

BE4 ISSUE 5

October 2015 : PC0054034

1 Introduction

This manual contains instructions for the correct use and maintenance of the BE4 manufactured by Armfield Ltd.

The information contained in this manual is intended for the user who is required to read it carefully and to ensure that he has fully understood it before operating the machine.

The user manual must be available for ready consultation at all times.

If the manual is lost or damaged contact the manufacturer for a replacement copy.

WARNING - The manufacturer is not liable for consequences resulting from an improper use of the machine due to the user's failure to read this manual or incomplete reading of it.

The manual is an integral part of each piece of equipment and consequently must be kept throughout the entire service life of the machine and accompany it at all times, even if transferred to another user.

This manual contains instructions required for the safety, receiving, installation, storage, correct operation and maintenance of the BE4.

WARNING - Armfield Ltd. reserves the right to modify the specifications referred to in this manual or the characteristics of each machine. Some of the illustrations in this manual may include parts that are slightly different to those mounted on your machine.

WARNING - All practical work areas and laboratories should be covered by local regulations which must be followed at all times.

2 EC Conformity

Each machine is accompanied by an EC Declaration of Conformity signed by the representative of Armfield Ltd.

The declaration of conformity states the model and serial number.

The equipment has been constructed in compliance with the essential health and safety requirements laid down in the following applicable directives:

2006/95/EC The Low Voltage Directive

2004/108/EC The Electromagnetic Compatibility Directive

2006/42/EC The Machinery Directive

The following harmonised standards were also consulted for the design and construction of the equipment:

BS EN 61010-1:2010	Safety requirements for electrical equipment for measurement, control, and laboratory use
BS EN 61000-6-1:2007	Electromagnetic compatibility (EMC). Generic standards. Immunity for residential, commercial and light-industrial environments
BS EN 61000-6-3:2001	Electromagnetic compatibility (EMC). Generic standards. Emission standard for residential, commercial and light-industrial environments

WARNING - This declaration is only valid if the Equipment is installed, used and maintained in compliance with the above mentioned directives and instructions and with the instructions and equipment described in this manual.

Table of Contents

3 Disclaimer

This document and all the information contained within it is proprietary to Armfield Limited. This document must not be used for any purpose other than that for which it is supplied and its contents must not be reproduced, modified, adapted, published, translated or disclosed to any third party, in whole or in part, without the prior written permission of Armfield Limited.

Should you have any queries or comments, please contact the Armfield Customer Support helpdesk (Monday to Thursday: 0830 - 1730 and Friday: 0830 - 1300 UK time). Contact details are as follows:

United Kingdom	International
(0) 1425 478781 (calls charged at local rate)	+44 (0) 1425 478781 (international rates apply)
Email: support@armfield.co.uk	
Fax: +44 (0) 1425 470916	

4 Copyright and trademarks

5 Symbols

General warning indicating the potential risk of personal injury

Danger warning

Caution: Explosion Risk

Electrical hazard

Cold Burn hazard

High Voltage hazard

Caution: Flammable

Rotating parts hazard

Caution: Biohazard

Caution: corrosive material

Do not remove safety guards from rotating parts

Do not repair or oil machine whilst in motion

This symbol draws your attention to the information

Wear protective gloves

Wear eye protection

Wear ear protection

Wear safety shoes

Wear breathing protection

6 Safety

6.1 Failure to comply with safety standards

Failure to comply with the safety standards described in this manual and those relating to common sense can cause danger to people and the environment and damage the Equipment.

Specifically, such non-observance can cause:

- inability of machine and/or plant to perform key functions;
- damage to the machine and /or plant ;
- electrical, mechanical and/or chemical danger to persons;
- environmental danger due to leakage of hazardous substances.

Failure to observe and comply with these safety standards will invalidate the warranty.

Keep these instructions and all related documents together, ensure that they are legible and easily accessible to all employees.

Do not remove any safety equipment before operating the Equipment or during its operation. Make sure that there is no evident danger before powering up the Equipment. The system must be inspected regularly to check for damage and to ensure that all safety devices are in good working order.

The Equipment contains moving parts. Do not insert limbs or materials other than the processing material while the Equipment is functioning. In the event of malfunction, danger or lack of appropriate safety systems, shut down the Equipment immediately and inform the qualified personnel.

6.2 Start up, operation and maintenance

The customer is required to verify the suitability of the Equipment for his specific needs, to provide the necessary processing data for a correct selection of the Equipment type and the accessories needed to guarantee the safety of the Equipment. If the user notices that any accessories he considers useful or essential are missing in the order confirmation, it is the customer's responsibility to contact the manufacturer and request that the accessory or accessories be applied to the Equipment.

While the Equipment is being used the safety devices provided must be present and correctly installed. Do not carry out any operation on the safety devices while the Equipment is operating.

6.3 Intended conditions of use

The Equipment is designed so anaerobic digestion can be carried out in a Continuous Stirred Tank Reactor (CSTR), an Upflow Active Sludge Bed Reactor (UASB), and a Packed Bed Reactor (PBR).

The Equipment must always observe the operating limitations for which it was constructed and those stated in the order confirmation: observe the temperature, pressure, capacity, viscosity and speed limits. Unless otherwise stated in the order, the Equipment must not be used in environments subject to the formation of potentially explosive atmospheres.

6.4 Safety guidelines relating to maintenance, inspection and assembly work

The user must ensure that all maintenance, inspection and assembly operations related to the Equipment is carried out by qualified technicians.

Technicians must carefully read this instruction manual before acting on the Equipment. Only authorised and trained personnel are permitted to work on the Equipment.

6.5 Arbitrary production and transformation of spare parts

Changes or modifications to the machine, within the limits that do not go beyond extraordinary maintenance, are only permitted if agreed on beforehand with the manufacturer.

Only original spare parts or parts specifically declared as compatible by Armfield Ltd. must be used for regular maintenance operations.

These parts have been designed specifically for the system. There is no guarantee that non-original parts can withstand the loads, and function correctly and safely.

The use of non-original parts voids the warranty.

6.6 Control of Hazardous Substances

The Control of Substances Hazardous to Health Regulations

The COSHH regulations impose a duty on employers to protect employees and others from substances used at work which may be hazardous to health.

COSHH covers substances that are hazardous to health. Substances can take many forms and include:

- chemicals
- products containing chemicals
- fumes
- dusts
- vapours
- mists
- nanotechnology
- gases and asphyxiating gases and
- biological agents (germs). If the packaging has any of the hazard symbols then it is classed as a hazardous substance.
- germs that cause diseases such as leptospirosis or legionnaires disease and germs used in laboratories.

The regulations require you to make an assessment of all operations which are liable to expose any person to these hazards. You are also required to introduce suitable procedures for handling these substances and keep appropriate records.

Since the equipment supplied by Armfield Limited may involve the use of substances which can be hazardous (for example, cleaning fluids used for maintenance or chemicals used for particular demonstrations) it is essential that the responsible person in authority implements the COSHH regulations or local equivalent.

Safety data sheets

The regulations also ensure that the relevant Health and Safety Data Sheets must be available for all hazardous substances used in the laboratory.

Products you use may be 'dangerous for supply'. If so, they will have a label that has one or more hazard symbols. These products include common substances in everyday use such as paint, bleach, solvent or fillers. When a product is 'dangerous for supply', by law, the supplier must provide you with a safety data sheet.

Note: medicines, pesticides and cosmetic products have different legislation and don't have a safety data sheet. Ask the supplier how the product can be used safely.

Any person using a hazardous substance must be informed of the following:

- Physical data about the substance.
- Any hazard from fire or explosion.
- Any hazard to health.
- Appropriate First Aid treatment.
- Any hazard from reaction with other substances.
- How to clean/dispose of spillage.
- Appropriate protective measures.
- Appropriate storage and handling.

Although these regulations may not be applicable in your country, it is strongly recommended that a similar approach is adopted for the protection of the users operating the equipment. Local regulations must also be considered.

More information can be found on http://www.hse.gov.uk/coshh/index.htm

Any such chemicals used must be stored, handled, prepared and used in accordance with the manufacturer's instructions and with all applicable local regulations. Protective clothing (e.g. gloves, eye protection) should be worn when appropriate, and users should be supplied with any relevant safety information (e.g. the correct procedure in the event of contact with skin or eyes, the correct procedure in the event of a spill, etc.).

6.7 Water Borne Hazards

The equipment described in this instruction manual involves the use of water/fluids, which under certain conditions can create a health hazard due to infection by harmful micro-organisms.

For example, the microscopic bacterium called Legionella pneumophila will feed on any scale, rust, algae or sludge in water and will breed rapidly if the temperature of water is between 20 and 45°C. Any water containing this bacterium which is sprayed or splashed creating air-borne droplets can produce a form of pneumonia called Legionnaires Disease which is potentially fatal.

Legionella is not the only harmful micro-organism which can infect water, but it serves as a useful example of the need for cleanliness.

Under the COSHH regulations, the following precautions must be observed:

- Any water/fluid contained within the product must not be allowed to stagnate, i.e. the water must be changed regularly.

- Any rust, sludge, scale or algae on which micro-organisms can feed must be removed regularly, i.e. the equipment must be cleaned regularly.
- Where practicable the water/fluid should be maintained at a temperature below 20°C or the water should be disinfected. If this is not practicable then the water should be disinfected if it is safe and appropriate to do so. Note that other hazards may exist in the handling of biocides used to disinfect the water.
- After use the water/fluid system should be filled and run with water containing a mild disinfectant such as 'Milton' to kill any micro-organisms or algal growth then flushed with clean water and left empty.
- A scheme should be prepared for preventing or controlling the risk incorporating all of the actions listed above.

Further details on preventing infection are contained in the publication "The Control of Legionellosis including Legionnaires Disease" - Health and Safety Series booklet HS (G) 70.

6.8 Hot/Cold Surfaces and Liquids

This unit is designed to operate with a maximum liquid temperature of 60°C and minimum liquid temperature of 5°C.

However, under fault conditions various components could become hot or cold and produce temperatures that could cause skin burns. There is also a potential risk of scalding from hot liquids or vapours (e.g. steam).

Before disconnecting any of the pipes or tubing:

- Stop the liquid pump.
- Leave time for the equipment to return to room temperature.
- Check that the temperature of the Equipment and liquid is at a safe level

Do not touch any surfaces close to 'Hot Surfaces' warning labels, or any of the interconnecting tubing, whilst the equipment is in use.

6.9 Leakage of hazardous fluids

If the Equipment is used to pump/operate with hazardous liquids (toxic, corrosive, flammable, etc.), the volumes of fluid that leak through the seals must be collected and disposed of without endangering human health or the environment and in accordance to local legislation.

6.10 Protective clothing

Wear appropriate protective clothing to protect body parts.

Safety gloves

Wear suitable gloves to protect your hands from various types of possible hazards: mechanical, electrical, chemical and high/low temperatures.

Clothing

Wear appropriate clothing to protect your body from chemical hazards.

Footware

Wear safety footwear to protect your feet from falling objects.

Eye Protection

Wear suitable eye protection to protect your eyes from various types of possible hazards: mechanical debris, chemicals and hot water/steam.

Ear Protection

Wear suitable ear protection to protect your ears from excessive noise.

Breathing Protection

Wear suitable ear protection to protect your ears from excessive noise.

6.11 Machine maintenance

Do not disassemble the Equipment before emptying the contents/fluids (if applicable). Even if the tubes are all empty, some liquid could remain in the unit. The fluid(s) can be hazardous to human health and the environment, and can be very hot/cold.

All maintenance work must be carried out with the machine isolated from the power supply.

Before beginning maintenance on the Equipment remember to isolate the power supply. All the devices must be secured against automatic or accidental restart. (Where possible turn the main switch to OFF and remove the key). In particular situations where you need to run the Equipment while servicing at least 2 persons must be present so that in the event of danger one person will be able to disconnect the power supply or raise the alarm. Once maintenance has been completed remember to restore the safety devices and check that they are in good working order.

To give increased operator protection, the unit incorporates a Residual Current Device (RCD), alternatively called an Earth Leakage Circuit Breaker, as an integral part of this equipment. If through misuse or accident the equipment becomes electrically compromised, the RCD will switch off the electrical supply and reduce the severity of any electric shock received by an operator to a level which, under normal circumstances, will not cause injury to that person.

At least once each month, check that the RCD is operating correctly by pressing the TEST button. The circuit breaker MUST trip when the button is pressed. Failure to trip means that the operator is not protected and the equipment must be checked and repaired by a competent electrician before it is used.

7 General Overview

The water carriage system of sewerage provides a simple means for removal of offensive and dangerous waste from household and industry. If these wastes are to be kept out of rivers and receiving waters, they must be unloaded from the transporting water at the end of the sewerage system. This is carried out in sewage treatment plants or unloading stations.

However, some waste matter is in solution and some finely divided or colloidal and cannot be strained, skimmed or settled, in which case it can be subjected to biological treatment whereby it is either removed from the water or so changed in character as to be rendered innocuous.

Anaerobic wastewater treatment is widely used in developed countries for the treatment and stabilisation of these waste sludges.

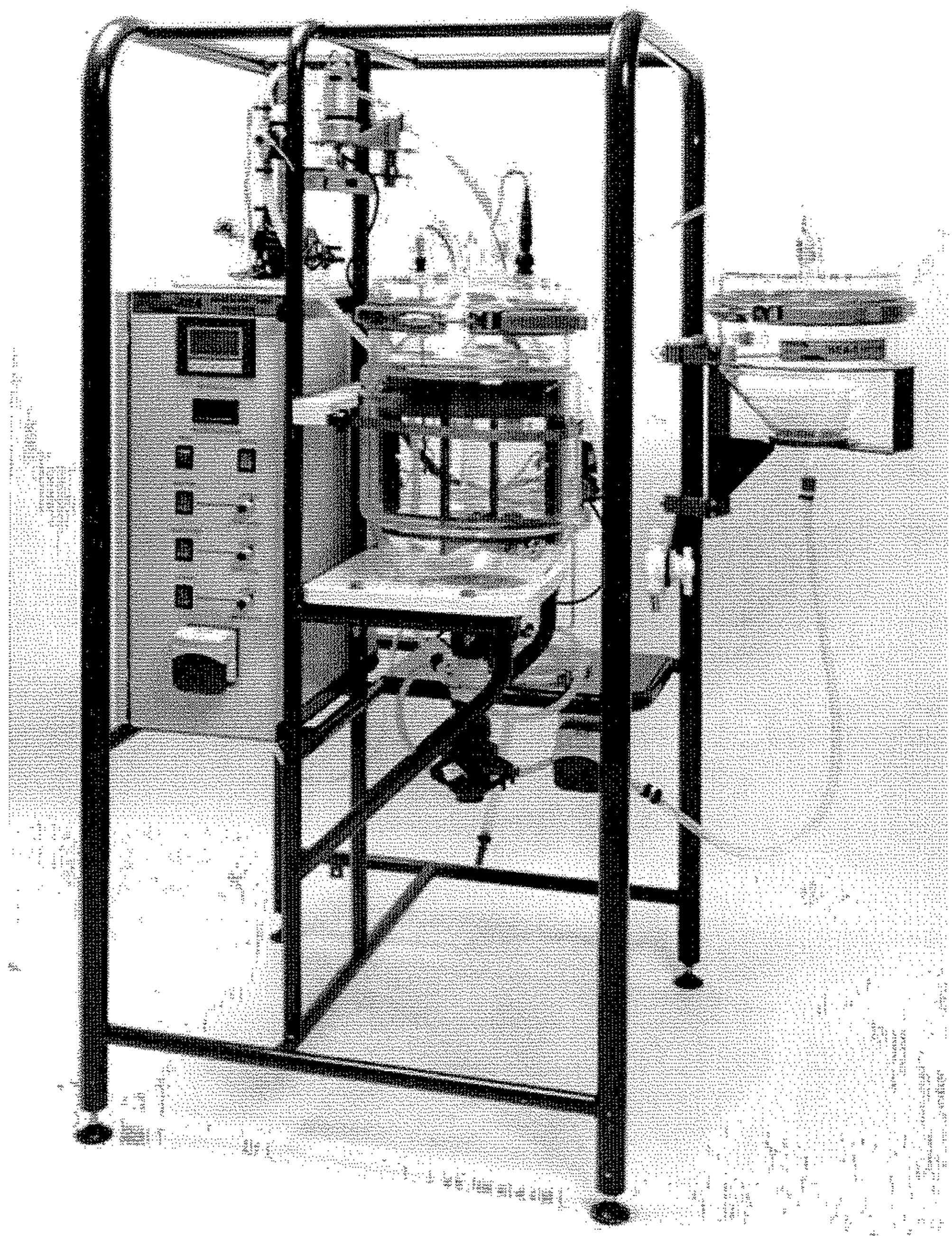
The major objectives of waste matter (sludge) digestion are the neutralisation of odours, the reduction of its tendency to rot, a decrease in the number of pathogens and a decrease in the microbial activity in general. The products of decomposition are stable humus like solid matter, sludge liquor and gases of decomposition.

A product of the anaerobic process is methane gas which, in industry, is collected and used to offset energy costs.

The Armfield Ltd ANAEROBIC TANK REACTOR (BE4) is a pilot scale unit which has been designed to allow thorough investigation into this important biological process.

There are various types of anaerobic reactors; the BE4 has been designed so anaerobic digestion can be carried out in a Continuous Stirred Tank Reactor (CSTR), an Upflow Active Sludge Bed Reactor (UASB), and a Packed Bed Reactor (PBR).

By feeding an influent of known chemical composition to reactors containing the appropriate bacteria under controlled conditions it is possible to gain an understanding of the mechanisms involved. Also, it is possible to discover the effect of adjustment of all relevant parameters including type of influent, type of bacteria, temperature of reaction, residence time (hydraulic loading) and pH.



BE4 Anaerobic tank reactor (fitted with optional settler)

8 Equipment Diagrams

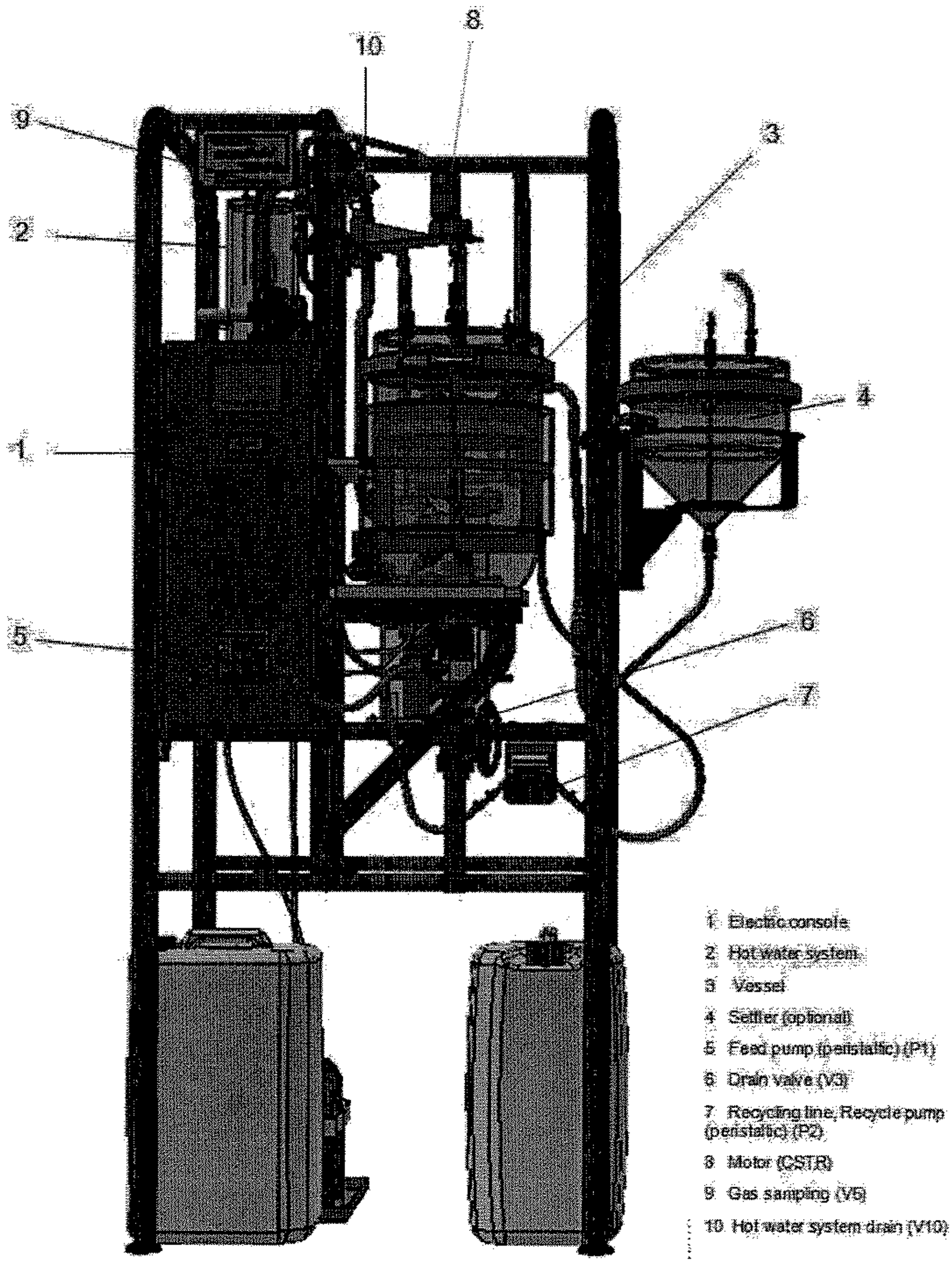


Figure 1: Front View of BE4 Anaerobic Tank Reactor

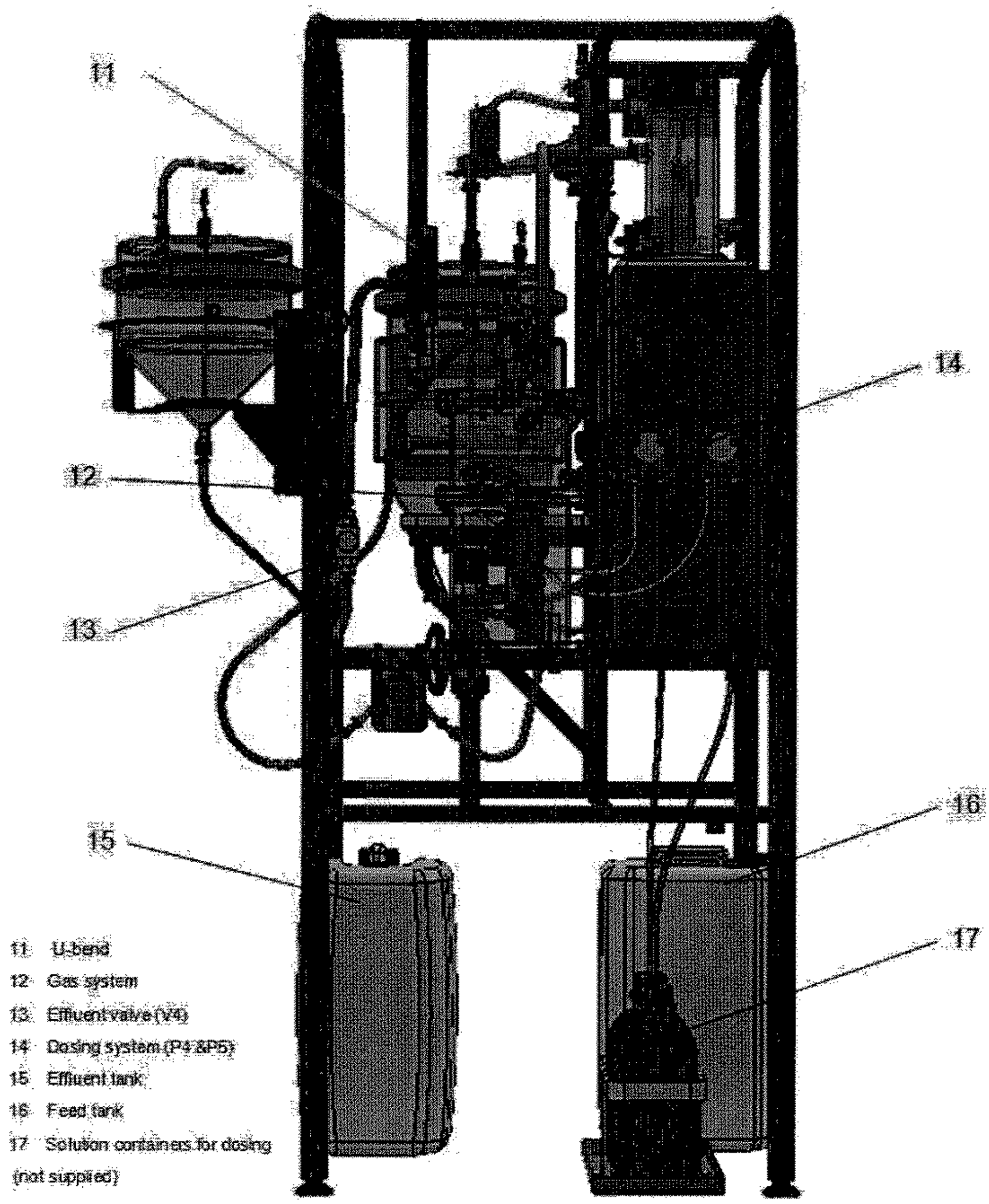


Figure 2: Rear View of BE4 Anaerobic Tank Reactor

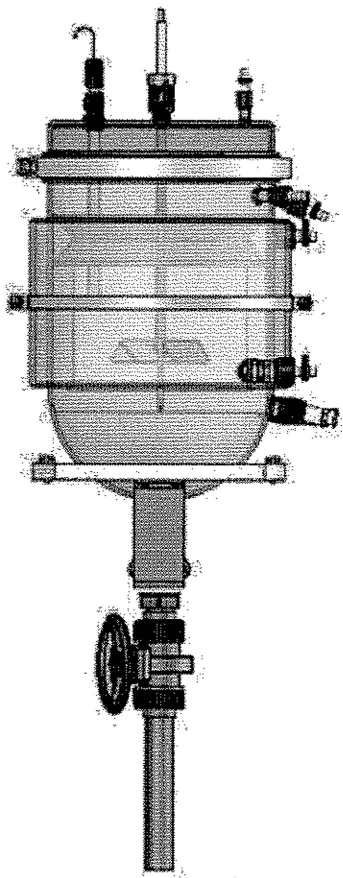


Figure 3: Reactor tank

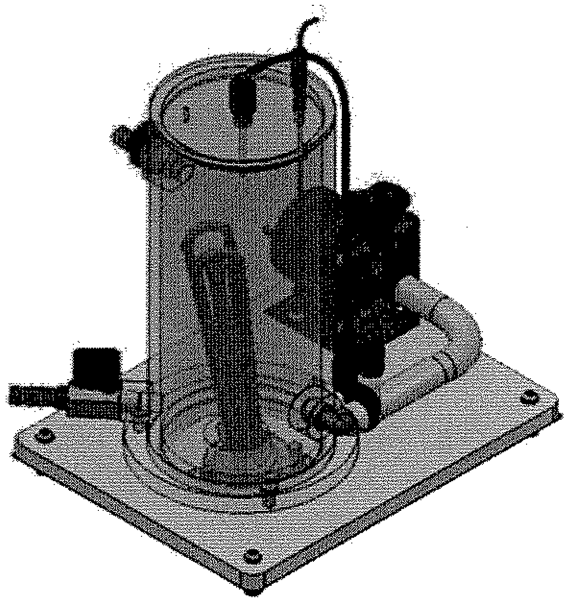


Figure 4: Hot water circulation unit

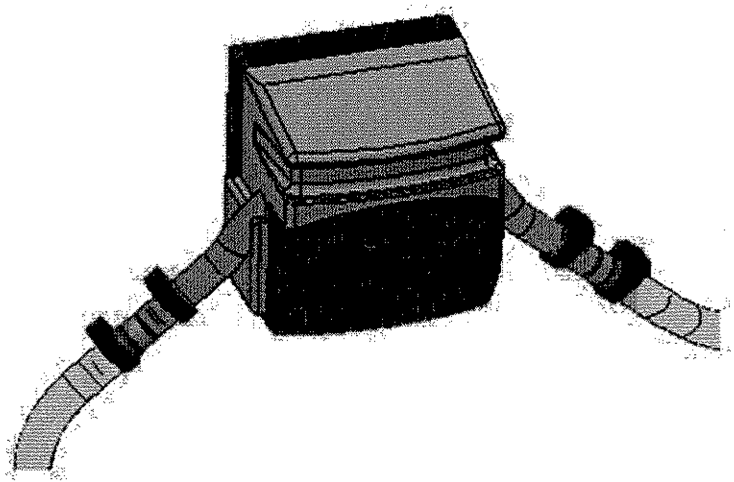


Figure 5: Feed and Recycle pump

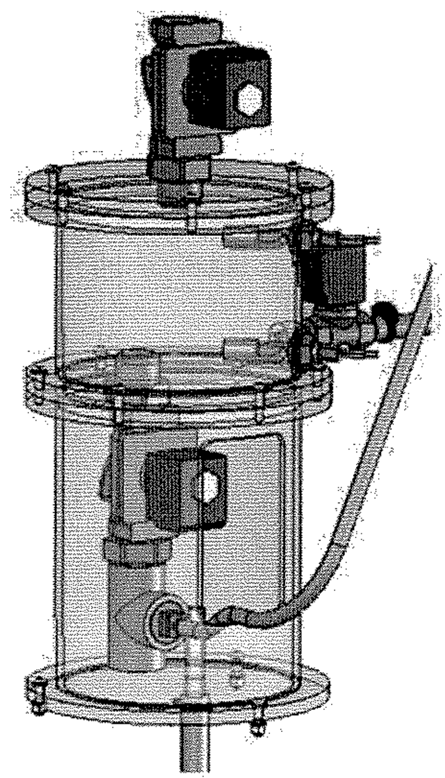


Figure 6: Gas collection system

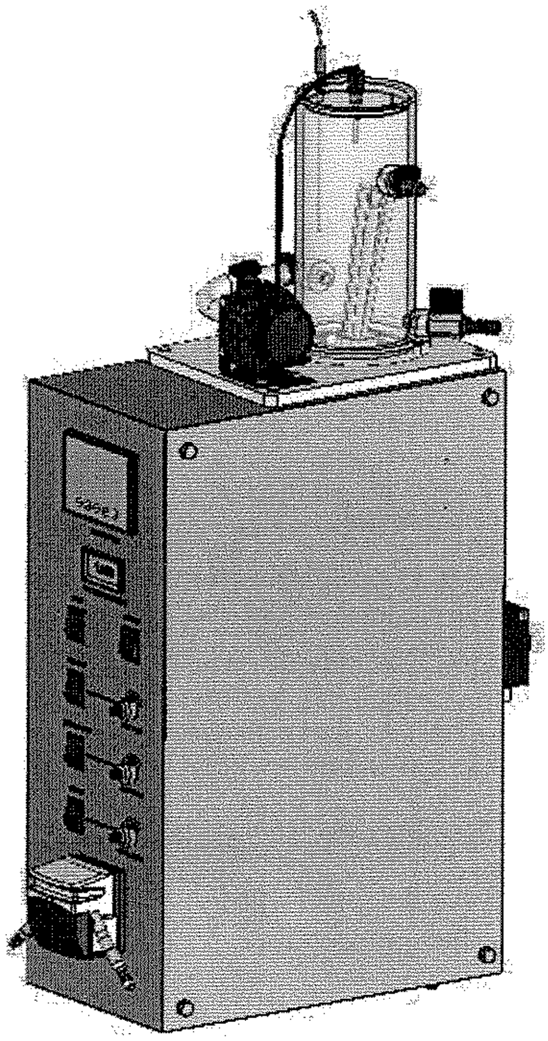


Figure 7: Electric Console

8.1 Process Flow Diagrams

Please see the following wiring diagrams attached at the rear of this manual. If you are viewing this manual electronically please see accompanying pdf.

BE4 Anaerobic Continuous Stirred Tank Reactor with optional settler CSTR version 2

BE4 Anaerobic Packed Bed Reactor PBR version 2

BE4 Anaerobic Upflow Anaerobic Sludge Blanket Reactor UASB version 2

9 Description

Where necessary, refer to the drawings in Equipment Diagrams section 8.

9.1 Overview

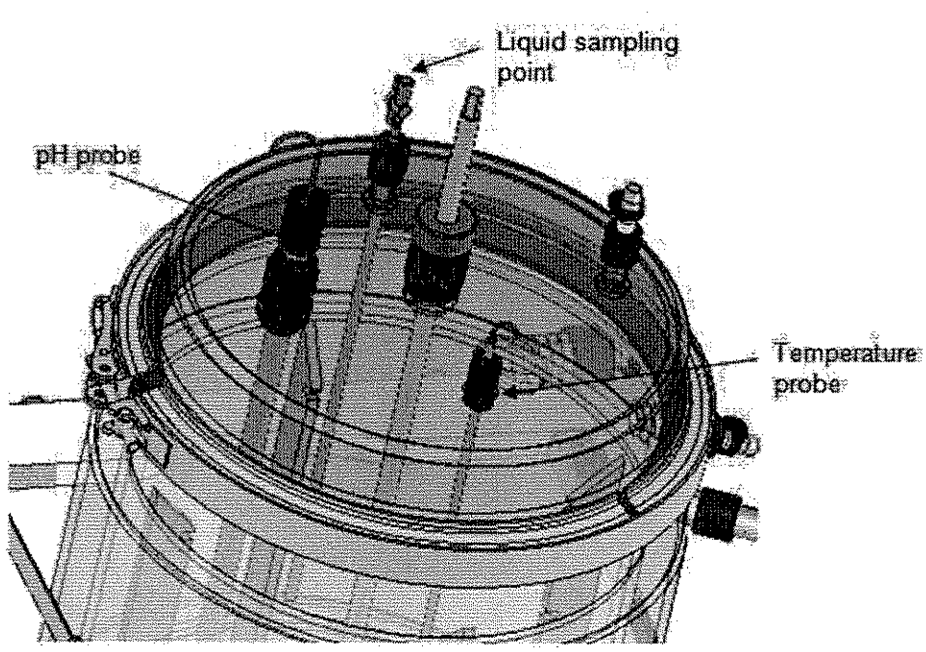
The reactor has a total liquid volume of 20 litres and incorporates a hot water jacket so that the temperature of the wastewater and activated sludge is held constant through gentle heating. The feed or influent is pumped into the reactor by a variable speed peristaltic pump (P1). A 10-turn potentiometer on the console allows variation of the feed pump motor speed and therefore the flowrate into the reactor when it is switched on. Variation of the flow rate from 0.06 to 4.8L/hr is achieved by changing the diameter of the tube fitted to the peristaltic pump (tubes supplied).

As the liquor rises through the reactor it is converted to biogas through acidogenesis followed by methagenesis by different micro-organisms.

The liquor can be recirculated to improve mass transfer by using the peristaltic recirculation (P2) which joins with the central feed line at the bottom of the reactor.

There is a drain valve (V3) at the bottom of the reactor for emptying and cleaning.

Temperature and pH can be monitored and controlled through a thermocouple and pH probe respectively. These two sensors are assembled at the lid of the reactor.



Reactor lid features

The effluent passes through the "U" bend arrangement which acts as a gas lock and allows the liquor level in the tank to be higher than the outlet. This prevents scum from being removed and blocking the outlet.

The effluent is then sent to storage where samples can be taken or it can be used as feed material to a secondary optional settler for further processing. A sample of liquid can also be obtained at different heights within the reactor (and settler) through a variable height sampling tube fitted with a stopcock. This is installed through the lid of the reactor and settler.

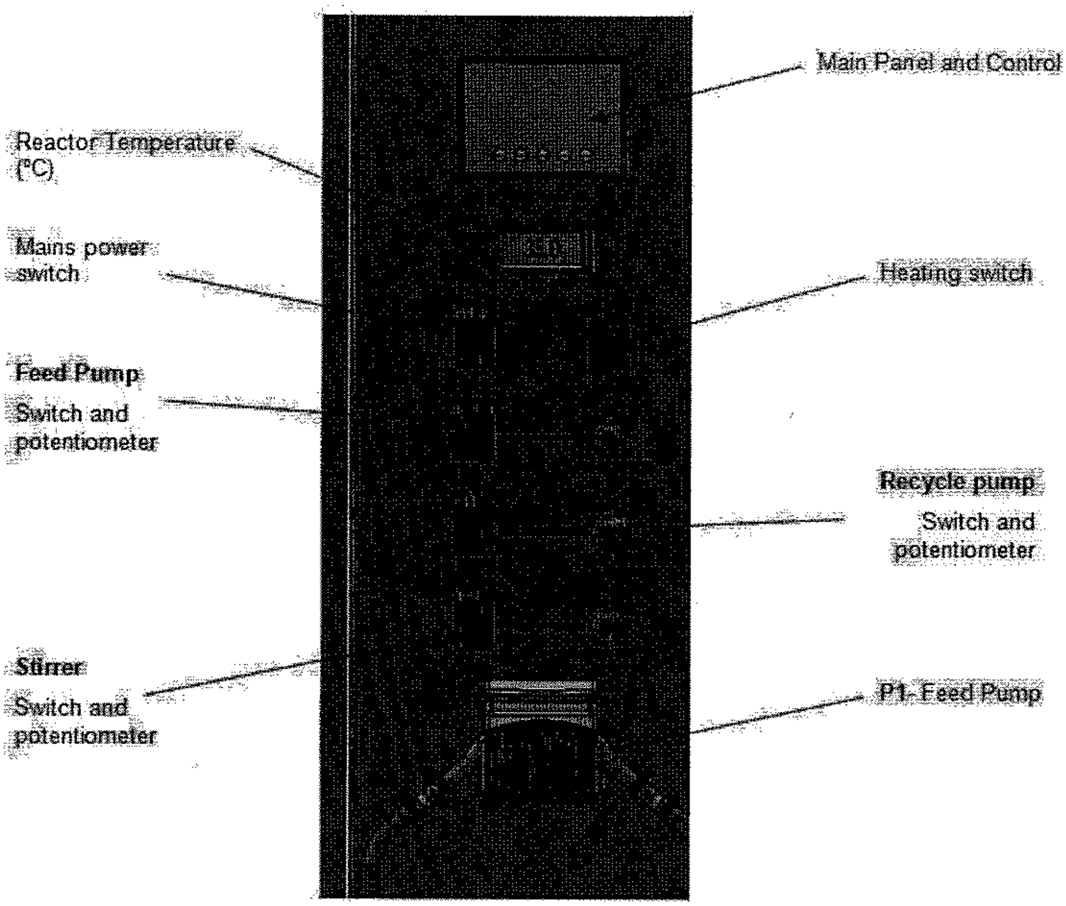
A 3-way valve (V5) on the gas line allows gas samples to be taken. The gas produced is collected in a gas chamber with a 2.2 L volume. The gas enters through a liquid seal at the bottom and displaces water as it bubbles into the top chamber. When selected via the PLC, a series of solenoid valves automatically open and close as and when required to refill the top chamber with water and exhaust the collected gas. A counter records how often the chamber is refilled with water allowing the gas production rate to be calculated.

The gas can either be collected (vessel not provided) or be vented to atmosphere where it is safe to do so.

The reactor can be reconfigured to operate as a Continuous Stirred Tank Reactor (CSTR), Packed Bed Reactor (PBR) or an Upflow Active Sludge Blanket Reactor (UASB).

A versatile PVC baffle is supplied which can be modified according to the type of reactor to be tested. The baffle, arranged as a cruciform, is installed inside the reactor to promote mixing when the impeller is used as a CSTR. The baffle incorporates slots in the vertical arms that allow perforated horizontal supports to be installed above and below the packing when using media such as Bioballs to create a PBR. The angled tops on the arms also allow a deflector to be fitted when creating a UASB. Two alternative glass lids are supplied with the reactor. The first lid incorporates a gas tight seal allowing an impeller to be operated inside the reactor for CSTR and PBR configurations. The impeller can be moved all the way upwards so that it does not interfere on the PBR configuration. The second reactor lid possesses a tri-phase (GLS) separator that is used with the baffle and deflector for a UASB configuration.

9.2 Electric Console



Control console

The BE4 Anaerobic Reactor is controlled from a control console. Switches turn on the mains power, heating system, feed pump, recycle pump and stirrer.

The temperature inside the reactor is constantly displayed. The speed of the feed pump, recirculation pump and the stirrer can be varied independently using the appropriate potentiometer on the front panel.

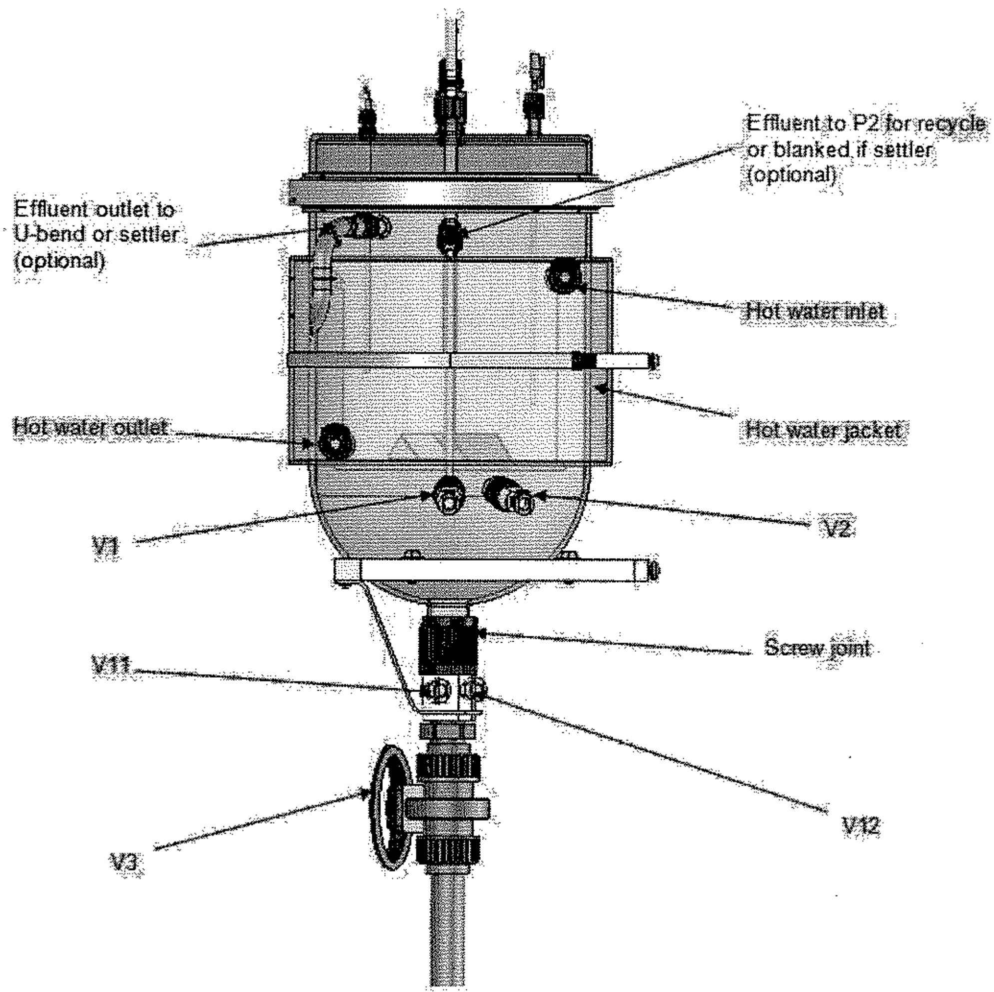
A PLC near the top of the console is used to control the hot water circulator temperature and pH of the reaction via pH dosing. It also displays the gas production rate and the pH of the reactor. For further detail see Operating the PLC in section 11.2.1.

9.3 Tank reactor

The reactor is a 20L glass vessel of 310 mm diameter equipped with a water heated jacket for temperature control of the reactor contents. At the base of the reactor (below the jacket) self-sealing, quick release connections (V1 and V2) can be found for dosing of solutions which allow pH control.

The reactor is supported by a plate attached to the main frame and is connected to a PFTE collar where self-sealing, quick release connections for the feed (V11) and recirculation (V12) lines are found. A butterfly type drain valve (V3) located at the bottom of the reactor can be connected to a 25 mm (1") bore flexible tube for safe draining of the reactor contents.

The jacket on the reactor has inlet and outlet connections for hot water from and to the water heating system.

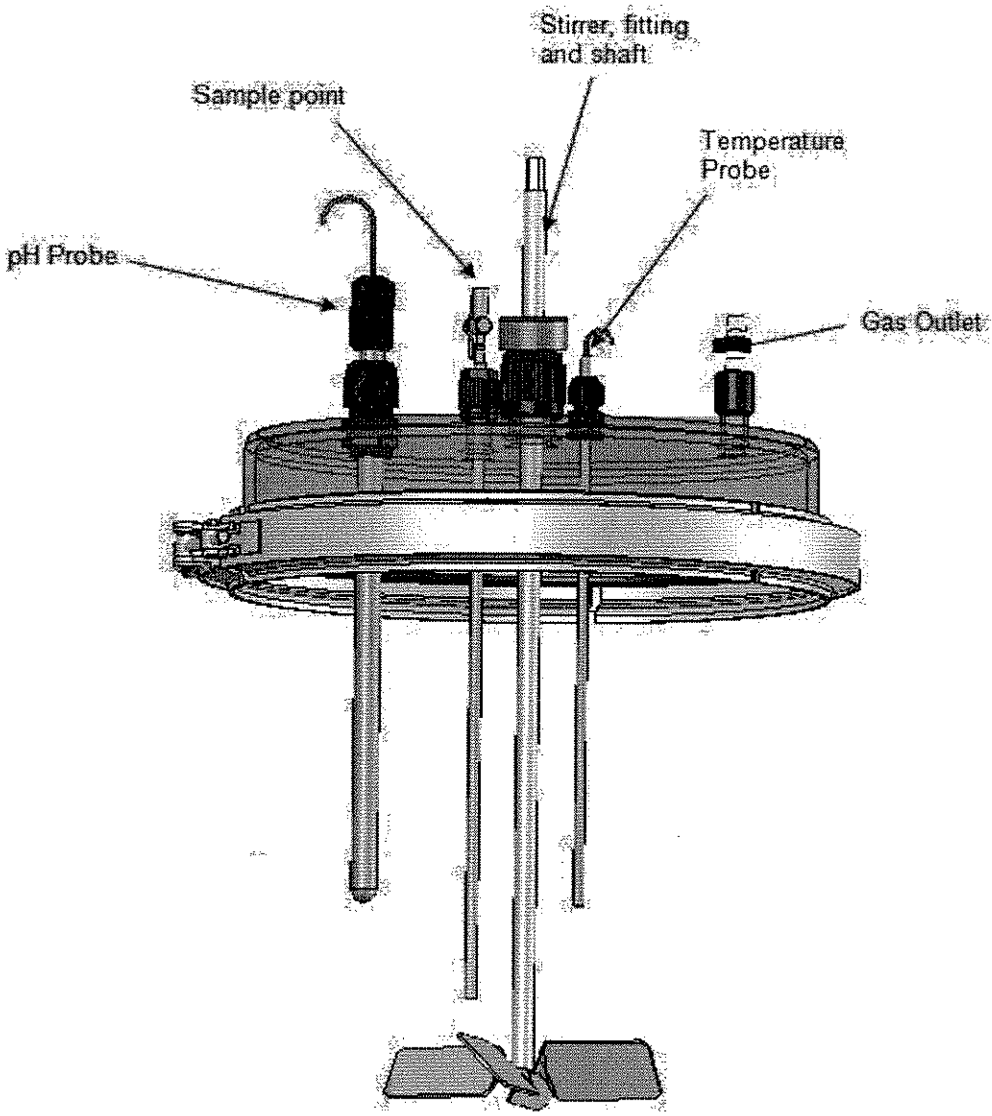


Rear view of tank reactor

9.4 Lids

The reactor is supplied with two lids which are employed to suit the configuration of the unit.

Lid number one possesses cable glands and fittings for temperature and pH sensors, gas produced outlet, shaft/stirrer configuration, and in-situ liquid sample port. This lid is to be used with the vessel as a CSTR and PBR configurations.

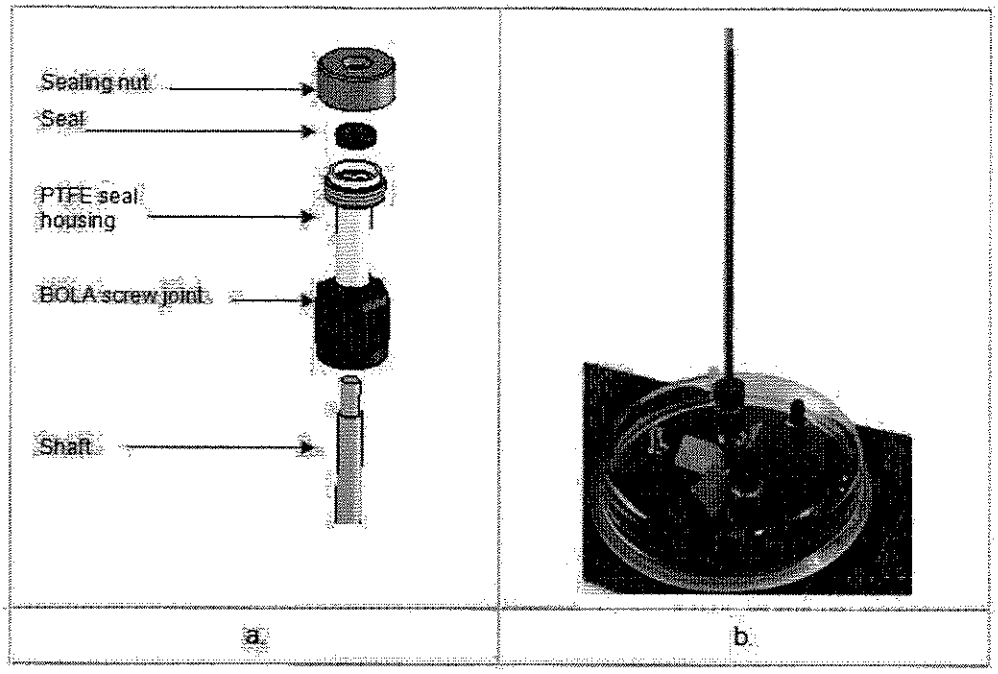


Vessel's lid for CTR and PBR configurations

9.5 Stirrer

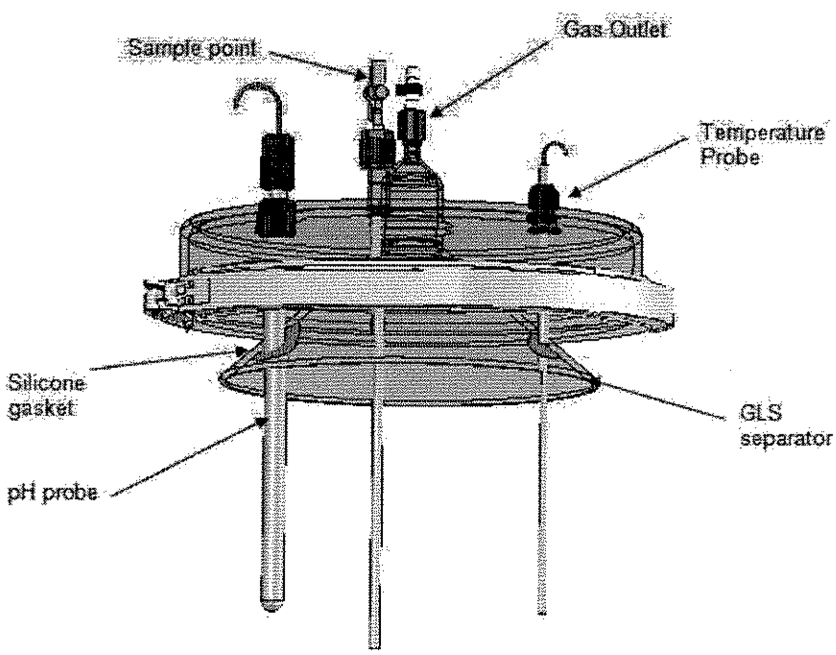
The shaft and impeller are secured to the lid by a GL25 BOLA fitting. To guarantee sealing while the stirrer is in operation a PTFE seal housing and a gas seal are fitted around the shaft as shown in the figure below (a). A sealing nut secures them both in position.

For PBR configuration, release the sealing nut and BOLA screw joint. Carefully pull the shaft upwards until the impeller touches the inside of the lid then retighten the sealing nut as shown in the figure below (b).



Fittings for stirrer (a) and vessel's lid for PBR configuration

Lid number two is a delicate piece of glass configured with a GLS (Gas-Liquid- Solid) separator. This lid possesses cable glands and fittings for temperature and pH sensors, gas produced outlet, and in-situ liquid sample port. This lid is used to create a UASB reactor. Two push-on silicone foam gaskets are supplied to seal the pH and temperature probes where they pass through the funnel to assure sealing.

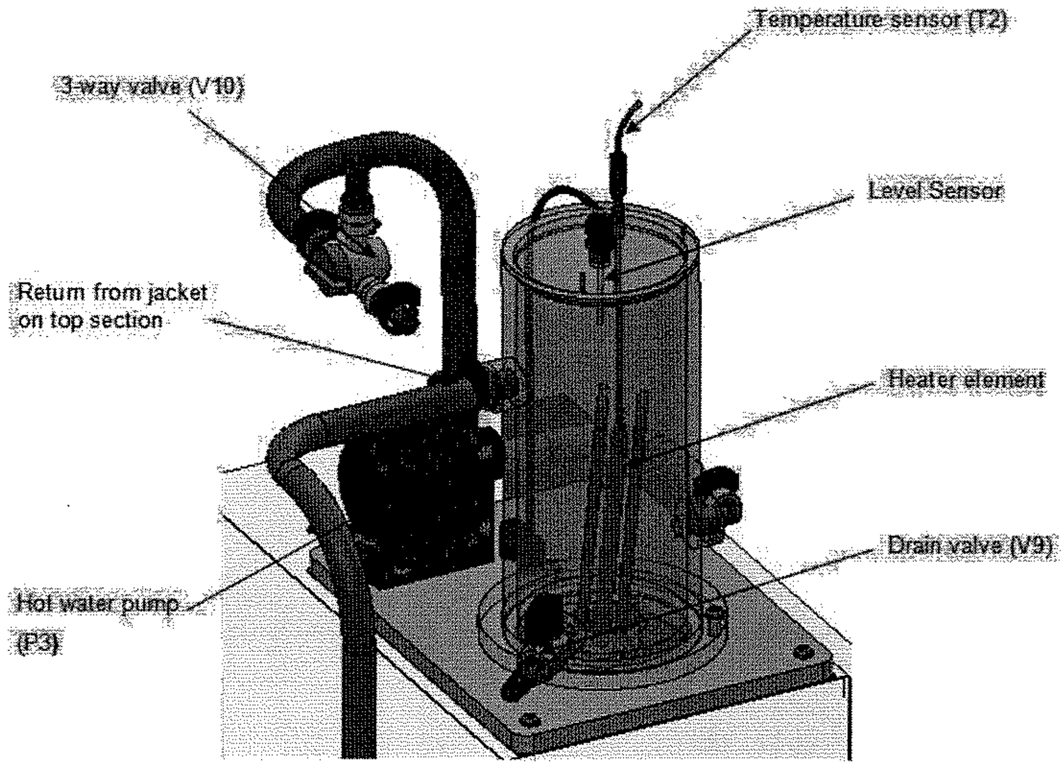


Vessel's lid for UASB configuration

The tank and lids are secured with a metal 'V' clamp. A silicone foam gasket is located between them to guarantee appropriate sealing between the parts. The gasket is washable and can be reused.

9.6 Hot Water Circulator

The temperature of the reactor is controlled through a water jacket connected to a hot water circulator. The hot water circulator vessel should be filled with deionised water before use. The vessel should be drained after use if the equipment is not going to be used for some time.



Hot water circulation unit

A PLC on the control console maintains the temperature of the jacket and therefore the temperature of the contents. The Set Point temperature, Proportional Band, Integral and Derivative times may be adjusted by the user. Alternatively the heater power setting may be entered manually as a percentage value if constant power is required. For further explanation see Operating the PLC section 11.2.1.

9.7 pH probe

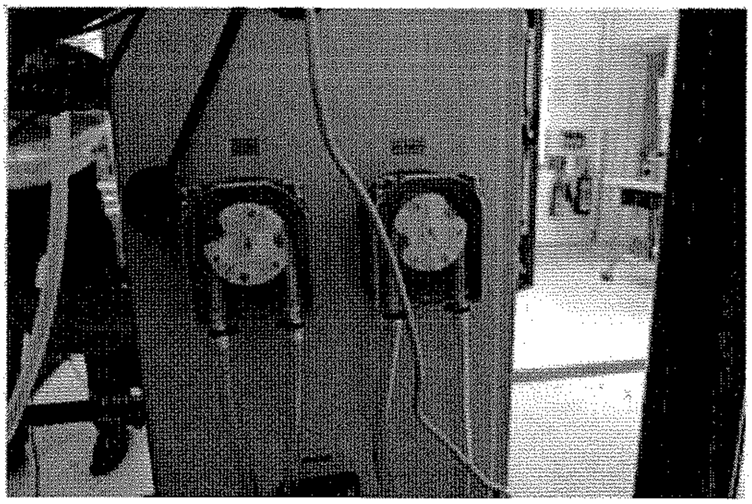
Between trials the pH electrode should be removed from the column and stored in storage solution. The electrode has been designed for use in bio-reactors.

The pH electrode is suitable for measuring the pH of solutions in the range of 0 to 14pH. The temperature range of the sensor is 0-135°C with an immersion depth of 260 mm.

260 mm pH probe

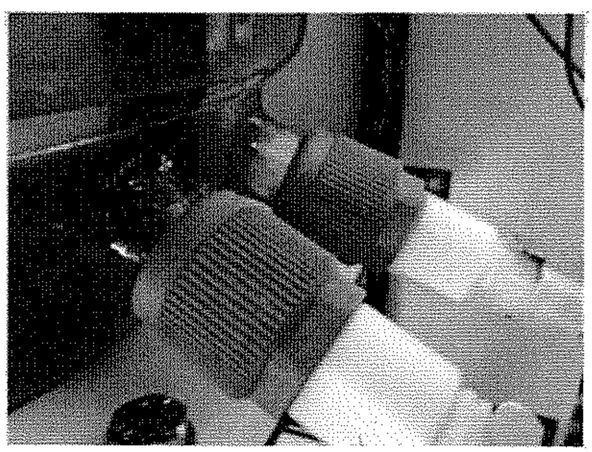
9.8 pH Dosing

The unit is fitted with a pH dosing system consisting of two blue peristaltic pumps (P4 and P5) which are located at the rear of the electrical console. The pumps are supplied with Verderprene tubing of 1.6 mm internal diameter which will provide a maximum flow rate of 18 ml/min. The pH system is actuated by the PLC and its operation is explained in Operating the PLC section 11.2.1.



Peristaltic pumps (P4 and P5) at the rear of the console

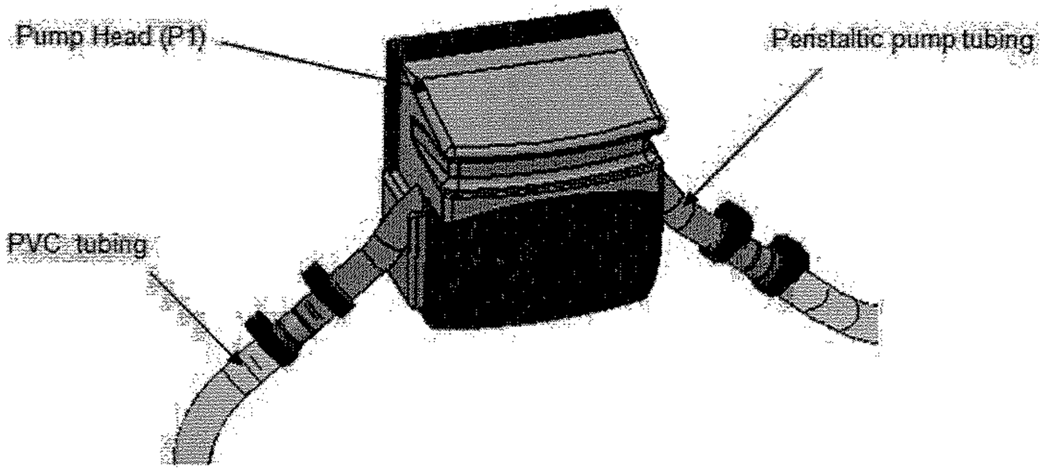
Each of the pumps will supply solutions of acid or alkali (not supplied) to the tank reactor through the self-sealing quick release connectors V1 and V2 located at the rear of the tank reactor. Each pump is labelled at the rear of the console.



In-valved connections V1 and V2

9.9 Feed Pump (P1)

The feed pump (P1) is mounted on the front of the electric console. The pump has a maximum flow rate of 5 L/h (when 8 mm tubing is connected). The peristaltic tube used has a lifetime of approximately 1000 hours and it is recommended that this is checked and replaced every 2 to 4 weeks when operating continuously.



Feed pump (P1)

Variation on the feed flow rate is possible through using different tubing diameter. The unit is provided with three tubing sizes of 1.6 mm, 4.8 mm, and 8 mm. These allow a range of flow rate of 0.06L/h – 5 L/h. The variation on the flow rate is obtained alongside the adjustment of P1 speed using the potentiometer on the electric console.

9.10 Recirculation Pump (P2)

The head of the recirculation pump is the same as in P1 but the important difference is the motor specification as is able to achieve 230 rpm.

The speed of pump P2 and therefore the recirculation rate is using the 10-turn potentiometer located on the front of the electric console.

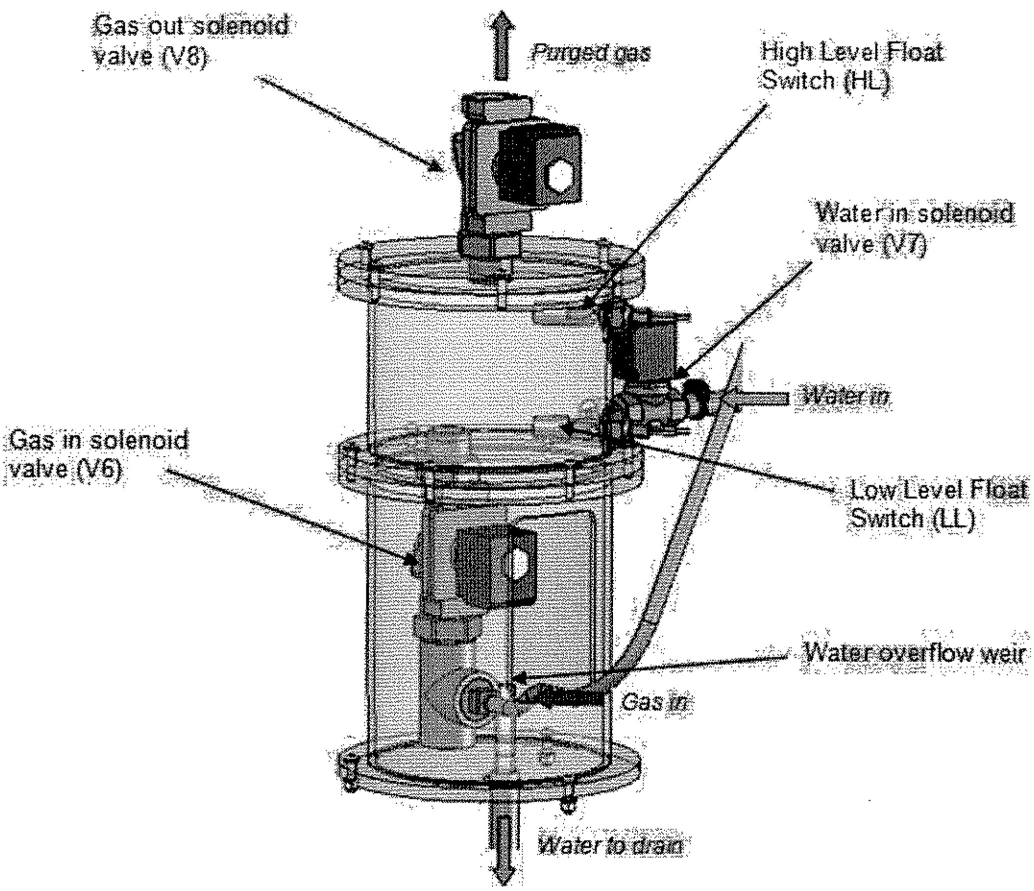
The recycle line transports the effluent from the top of the tank down back to the base of the tank where is mixed with the feed line (if in operation) before entering the vessel. The maximum flow achievable is approximately 50L/h when using 8 mm diameter peristaltic tubing.

9.11 Gas Collection

Gas produced in the reactor during the bacterial digestion process is collected in the gas collection chamber (T3) using a water displacement system which has been designed to impart a small and constant back pressure on the reactor.

The gas collection chamber collects 2.2 L of CH_4 and CO_2 gas over water. The gas collection chamber is automated operated via the PLC using three solenoid valves (SOL1 (V6), SOL2 (V7) and SOL3 (V8)) and two float level switches, low level (LL) and high level (HL). Water is displaced by the gas into the bottom chamber where an overflow weir creates a liquid seal. Water flowing over the weir is led to a suitable drain.

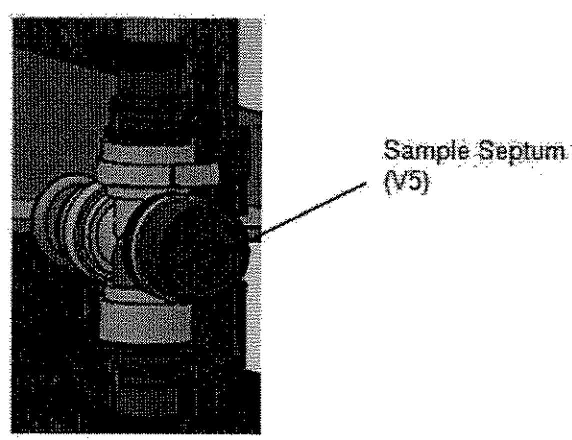
The number of refilling cycles is counted so gas production rate can be calculated.



Gas collection chamber

9.12 Gas Sampling

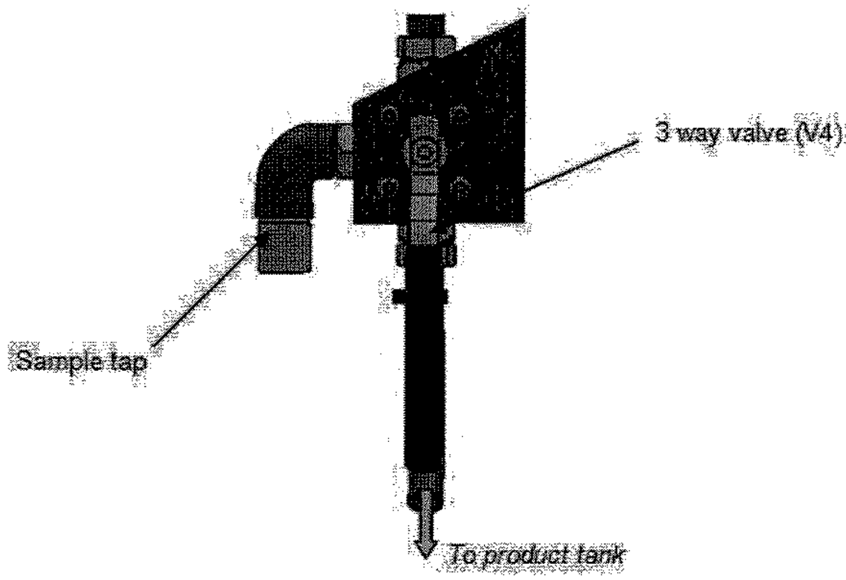
A gas septum (V5) on the gas line from the reactor to the gas collection chamber can be used to collect samples of gas recently produced. Samples are taken using a hypodermic needle (not supplied) to prevent methane and CO_2 leaking into the room.



Gas sample septum

9.13 Effluent Sampling

A sample valve (V4) on the effluent line from the reactor to product tank can be used to collect samples of recently treated effluent.

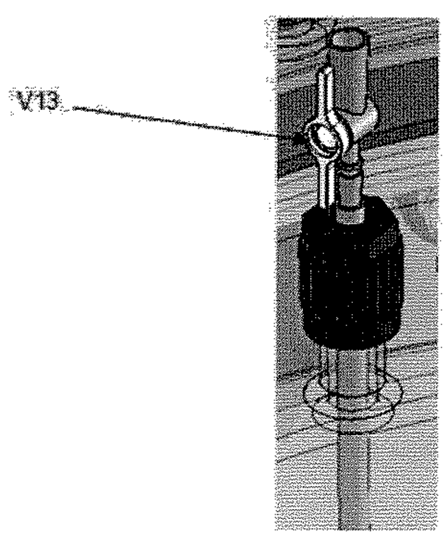


Effluent sample valve

9.14 Inline Sampling

A stainless steel tube extends across the height of the tank so that samples from inside the reactor can be taken at the required height throughout the experiment using sample valve (V13). The valve (stopcock) is located on the lid of the reactor and settler. To take a sample the use of a syringe (not provided) is required.

Note: Carefully place the syringe at the port of V13. Open V13 and pull the syringe to take the liquid sample.

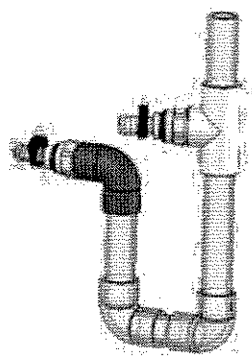


Inline sample valve

9.15 U-bend

The U-bend is constructed using clear PVC so that the liquid level can be observed. It acts as a gas lock and allows the liquor level in the tank to be higher than the outlet. This prevents scum from being removed and blocking the outlet.

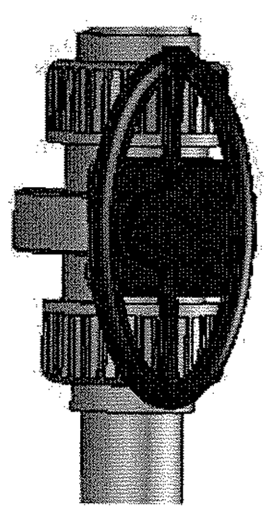
On the BE4, the unit's frame is configured so that the U-bend support can be moved on its axis upwards/downwards and left/right to suit the vessel or vessel/settler configurations.



U-bend

9.16 Drain Valve

A manually operated butterfly valve (V3) at the base of the reactor allows draining of the reactor's contents. The valve can be connected to a flexible tube for draining the liquid into suitable vessel without splashing.



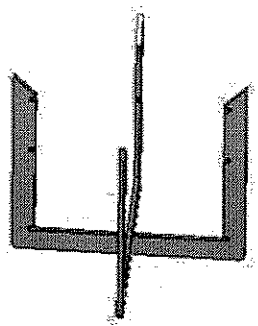
Reactor Drain Valve (V3)

9.17 Accessories

The following accessories are used for the different vessel configurations:

9.17.1 Baffles (cruciform)

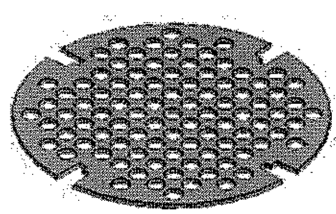
Two U-shaped plates are connected together via notches at the base of the cruciform to create four vertical baffles. When used in conjunction with the impeller, these baffles promote improved mixing.



Cruciform which performs as baffles

9.17.2 Bio-balls support

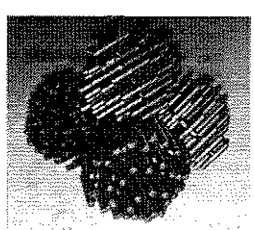
Two perforated plates with 4 notches can be located on the cruciform by rotating several degrees. One support is located at the base to support the bio-balls for the PBR configuration. A second support can be located part way up the cruciform or near the top, as required, to prevent the bio-balls from rising up the reactor.



Bio-balls support

9.17.3 Bio-balls

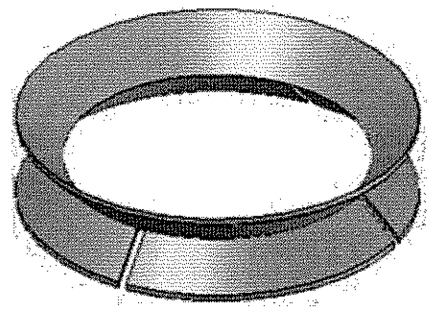
These are the standard packing material supplied with BE4 to operate the tank as a packed bed reactor; the biological solids can attach to or be kept within the interstices. The bio-balls are located within the two plates support on the cruciform.



Bio-balls

9.17.4 Deflector

This item is used for the UASB configuration. It is formed from PVC and is supported by the legs of the cruciform.

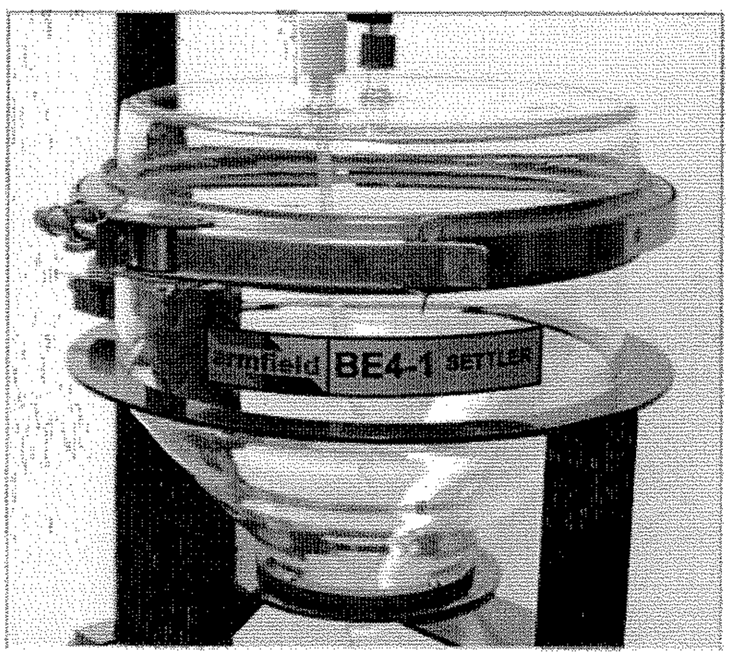


Deflector

9.17.5 Gaskets for UASB lid

These two items are used with the pH and temperature probes inside the funnel in the UASB lid (lid No. 2) to provide sealing.

9.17.6 Settler (Optional BE4-1)

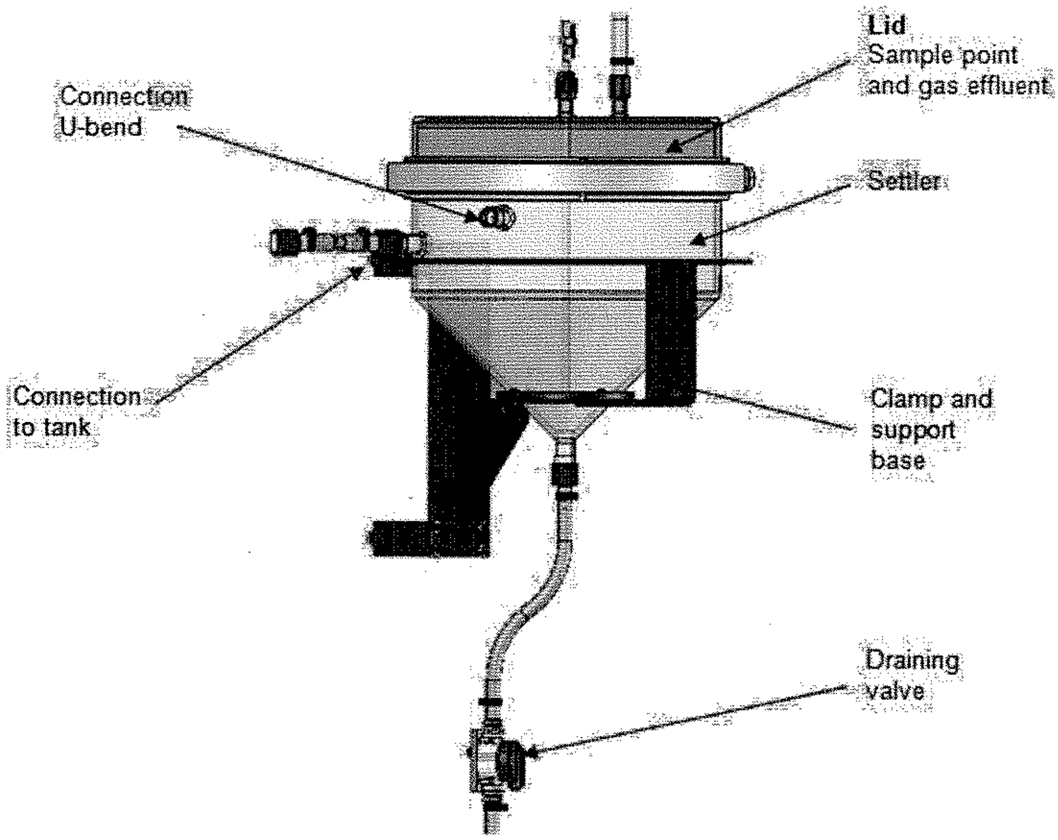


BE4-1 Settler

A glass settler of 11 L capacity and conical shape can be used with the vessel on the BE4 to perform anaerobic contact process (or two-stage anaerobic reactor configuration). The essence of this configuration is that the biomass that is flocculated in the reactor, along with the undigested influent solids that are taken out of the system, is retained through a solid separation device and returned to the first stage reactor where it is mixed with the influent wastewater.

The settler arrangement possesses a glass settler with lid, tubing connections and fittings, clamps for mounting, liquid sampling and a drain valve.

A 'V' clamp and a silicone-foam gasket are also provided for the settler and lid optional configuration.



BE4-1 Settler, main parts

10 Installation

10.1 Advisory

Before operating the equipment, it must be unpacked, assembled and installed as described in the steps that follow. Safe use of the equipment depends on following the correct installation procedure.

10.2 Mains Water Supply for BE4 (all versions)

The equipment requires connection to mains water. This is to be connected to solenoid valve (SOL2 (V7)) on the gas collection chamber.

Make sure you use a reinforced hose with an appropriate hose clip for this connection.

10.3 Electrical Supply

Electrical Supply for Version BE4-A
The equipment requires connection to a single phase, fused electrical supply. The standard electrical supply for this equipment is 220-240V, 50Hz. Check that the voltage and frequency of the electrical supply agree with the label attached to the supply cable on the equipment. Connection should be made to the supply cable as follows:

GREEN/YELLOW	-	EARTH
BROWN	-	LIVE (HOT)
BLUE	-	NEUTRAL
Fuse Rating	-	5 AMP

Electrical Supply for Version BE4-B
The equipment requires connection to a single phase, fused electrical supply. The standard electrical supply for this equipment is 120V, 60Hz. Check that the voltage and frequency of the electrical supply agree with the label attached to the supply cable on the equipment. Connection should be made to the supply cable as follows:

GREEN/YELLOW	-	EARTH
BROWN	-	LIVE (HOT)
BLUE	-	NEUTRAL
Fuse Rating	-	10 AMP

Electrical Supply for Version BE4-G
The equipment requires connection to a single phase, fused electrical supply. The standard electrical supply for this equipment is 220V, 60Hz. Check that the voltage and frequency of the electrical supply agree with the label attached to the supply cable on the equipment. Connection should be made to the supply cable as follows:

GREEN/YELLOW	-	EARTH
BROWN	-	LIVE (HOT)
BLUE	-	NEUTRAL
Fuse Rating	-	5 AMP

10.4 Installing the Software

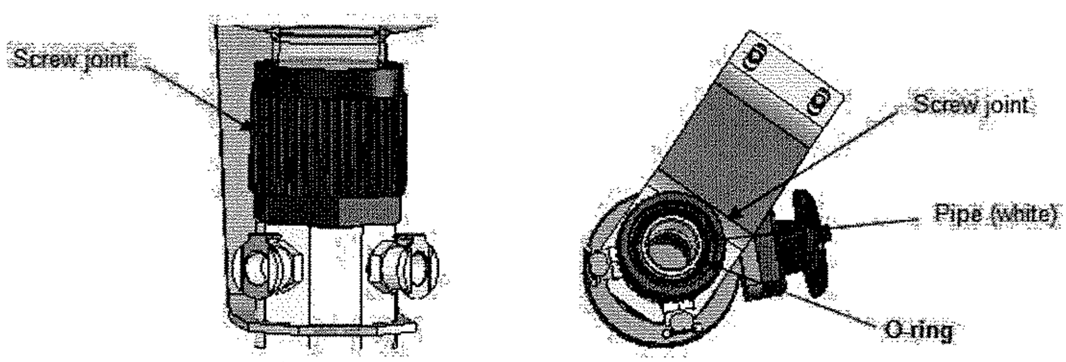
Please refer to the software installation instructions supplied on the Armsoft CD ROM or data stick.

10.5 Installing the Equipment

10.5.1 Reactor and Optional Settler

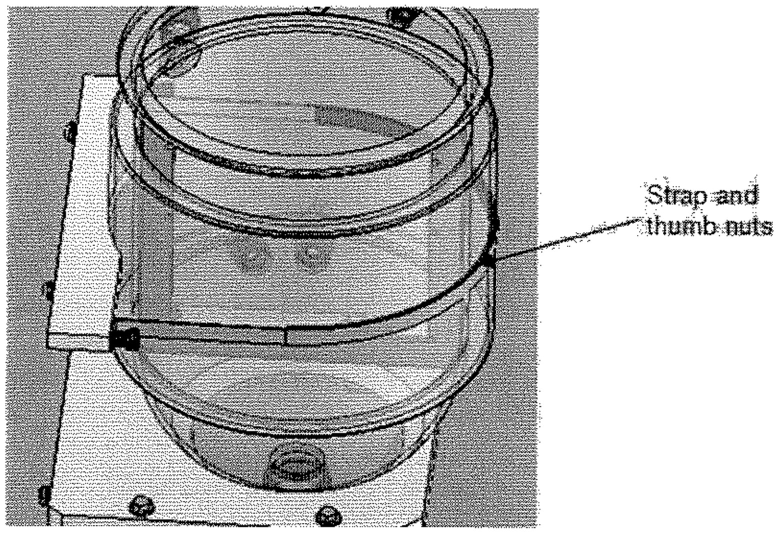
Note: The unit is shipped with the glass reactor removed.

1. SOL2 (V7) on the gas system needs connection to water mains. Ensure the lower chamber on the gas collection system is filled with water so that the lower part of Solenoid SOL1 (V6) is submerged.
2. Before placing the vessel on the base supporting plate, make sure there is an O-ring inside the vessel's screw joint, around the inside pipe.



Side and plan view of screw joint showing details of O'ring

3. Place the glass vessel on the plate so that V1 and V2 are facing the lower chamber of the gas system. Screw the vessel using the screw joint and secure it to the frame using the strap and thumb nuts provided.



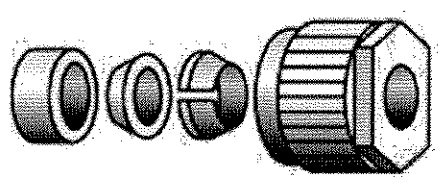
Strap and thumb nuts securing reactor tank

4. V1 and V2

These are in-valved connections fitted to a PTFE adaptor. The adaptor is inserted in a GL25 screw joint which provides sealing and connection to the tank reactor.

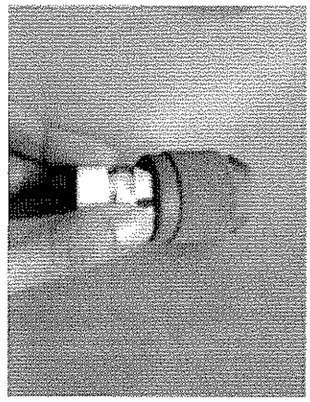
To correctly assemble these fittings to the ports on the vessel it is necessary to consider:

GL25 screw joint has 4 parts: a red screw cap, inner parts consisting of a v- ring, a tapered ring and a sealing ring.

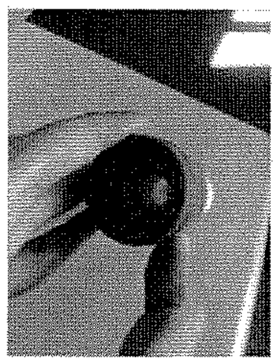


V1 and V2 screw joint and inner parts

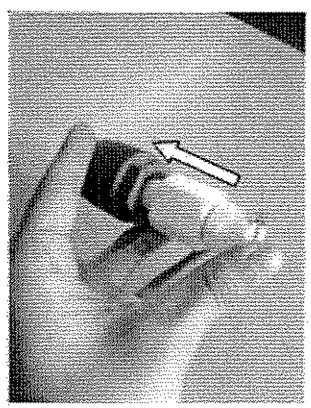
- Insert inner parts inside the screw cap as shown in the figures above and (a) and (b) below
- The adaptor and in-valved connections are joined together and should be inserted in the screw joint. Push them in the screw cap and through the screw joint (Figure c below). Fit into barbs provided at bottom of vessel.



a.



b.



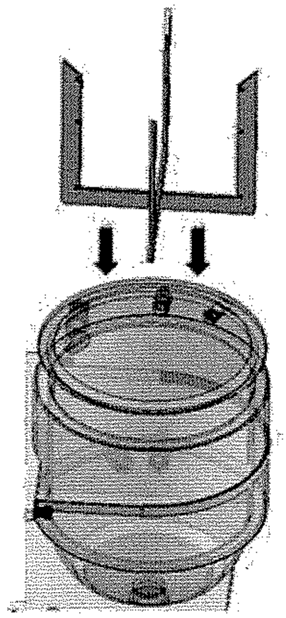
c.

Fitting of parts on V1 and V2

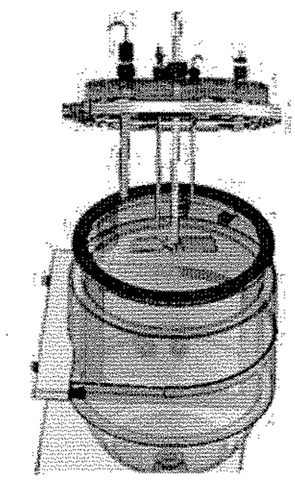
5. The BE4 can be operated as CSTR, PBR and UASB as follows:

   CSTR (Continuous stirred tank reactor)

   To run the unit as a CSTR insert the baffle with the cruciform base sited at the bottom of the reactor (a). Locate the silicone-foam gasket and the CSTR lid with the stirrer on the top flange of the reactor (b). Secure using the 'v' clamp.



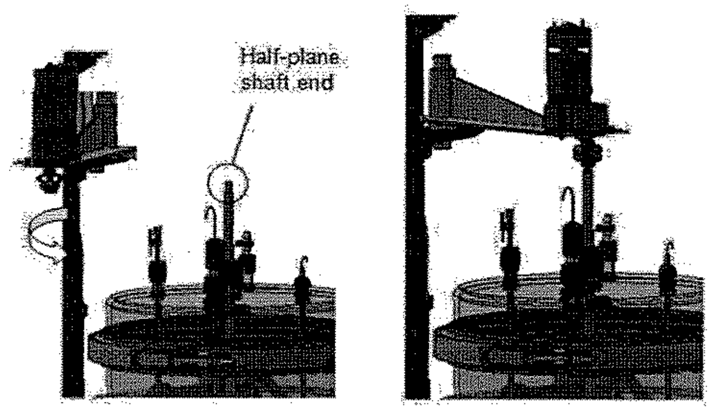
(a) Cruciform to be positioned in tank for baffling



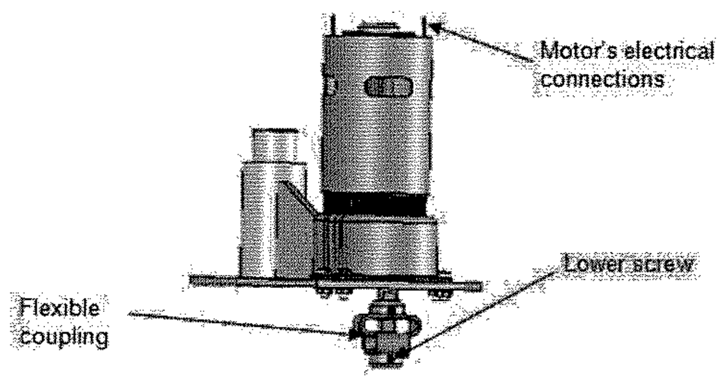
(b) CSTR lid (with stirrer) to be placed on tank

To connect the stirrer motor to the stirrer shaft at the lid, a bracket with the motor has been assembled to the unit's frame. This piece rotates and can be lifted and removed from the frame if required (unplug the motor electric connections).

After placing the tank-lid configuration, rotate the bracket with the motor so that the shaft at the motor terminal can be aligned to the half –plane shaft from the stirrer at the lid. When two pieces are aligned, secure them both at screwing the lower small screw at the flexible coupling.



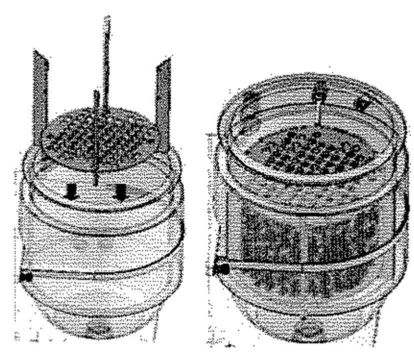
Stirrer shaft assembly



Stirrer motor assembly

PBR (Packed Bed Reactor)

To run the unit as a PBR insert the baffle into the reactor with the cruciform located at the bottom. Place one of the packing support pieces on this cruciform, shown below in (a). Use the notches at the legs of the cruciform to secure the support. Add the "bio-balls" and locate the second piece of packing support into the upper notches of the cruciform (b). You can vary the length of your filtration media according to your experiment.



(a) (b)

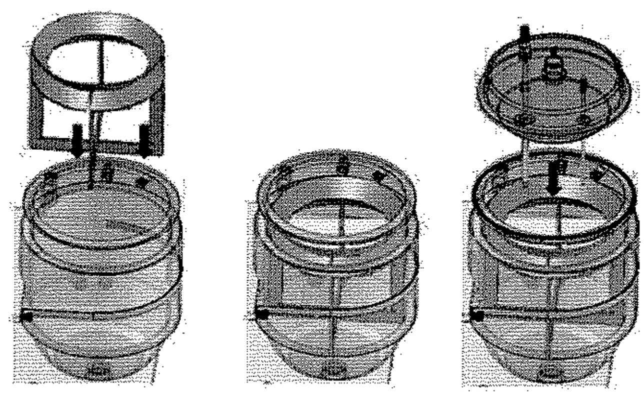
Cruciform acting as support for plates and bio-balls

Use the CSTR lid (impeller attached) but make sure of unscrewing the impeller fitting and moving the impeller all the way upwards so that it does not interfere with the bio-balls and mesh support. Seal the impeller port again to guarantee anaerobic conditions.

UASB (Upflow Active Sludge Blanket Reactor)

To run the unit as a UASB insert the baffle with the cruciform base sited at the bottom of the reactor show in (a) and (b). Rest the PVC deflector ring on the legs of the cruciform so that the notches on the deflector match the legs of the cruciform. These notches ensure the deflector is secured to the cruciform. Hold the silicone gaskets provided inside funnel and then insert the pH and temperature probes from the top of lid. In this way the gaskets help to fix probes on the funnel orifices without leaving any spaces.

Finally place ring gasket on the vessel and 3-phase separator lid on top (c).



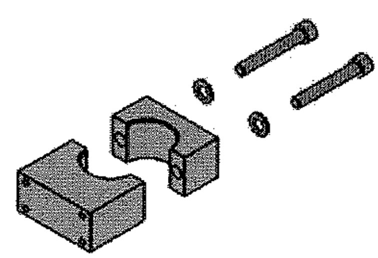
(a) (b) (c)

UASB baffle installation

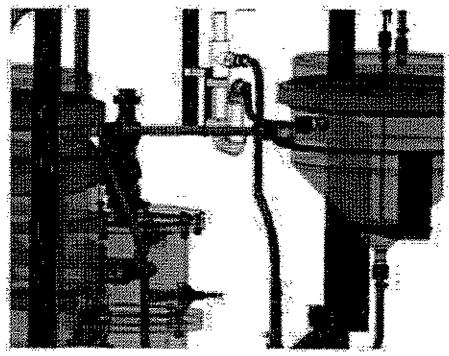
Contact system (optional)

If running as a contact system (optional), remove the U-bend from the effluent of the reactor and use this port to connect the reactor to the settler. Attach the U-bend at the effluent of the settler instead.

To use the settler, firstly clamp the settler support basket to the frame of the unit using the clamps (x2) and screws supplied. Then when the basket is well secured, locate the settler in place. Use one of the settler's port for connection to the reactor through PVC tubing, and the other port to connect the U-bend arrangement. The recommended height of the settler to the reactor can be observed, on the figure below. Finally secure the settler's lid supplied.

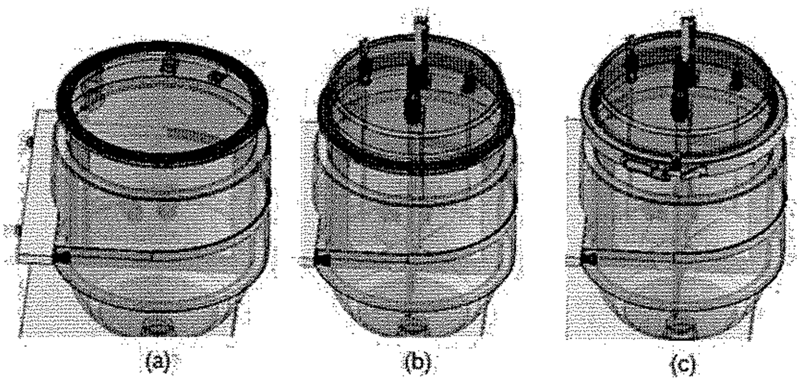


Clamps for settler



BE4-1 Vessel and settler showing U-bend height

6. A silicone-foam gasket (provided) is to be placed between the vessel and the lid (a). Carefully place the lid on the gasket (b) Secure these pieces through the metal clamp adjusting the size of the clamp using a 13mm spanner – do not over tighten. Gently "snap" shut the v-clamp (c).



Gasket and reactor lid assembly

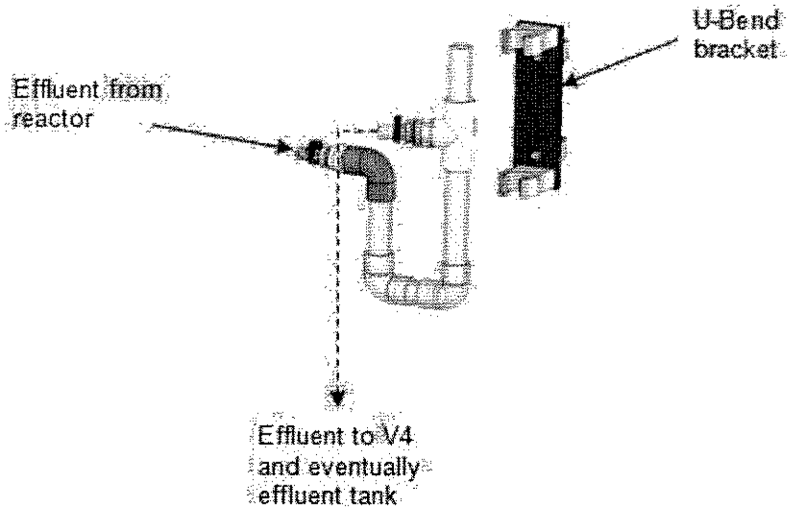
7. Make sure that hot water system is connected. This is achieved by connecting the two silicone tubes provided to the inlet (from V10) and outlet water jacket surrounding vessel.

10.5.2 U-BEND

The U-bend is a piece made of PVC fittings and tube. It acts as a gas lock and allows the liquor level in the tank to be higher than the outlet. This prevents scum from being removed and blocking the outlet.

On the BE4, the unit's frame is configured so that the U-bend support can be moved on its axis upwards or downwards and left to right in order to suit vessel or vessel and settler configurations.

Important: For each of the previous configurations the U-bend arrangement needs to be attached to the effluent of the reactor so that there is not air getting into the reactor as the U-bed acts as a gas lock.



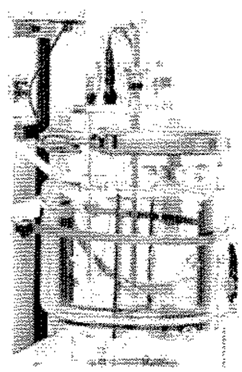
U-Bend arrangement

10.5.3 Temperature Sensors

Locate the 300 mm 'K-type' thermocouple sensors into the gland on the reactor lid, ensure the rod end is fully submerged into the reactor and secured by tightening the gland. Connect the sensor to the corresponding port (T1) at the rear of the electrical control cabinet. Adopt a similar process when fully submersing the smaller thermocouple in the hot water vessel; finally connect to the correct port (T2) at the rear of the cabinet.

10.5.4 pH probe

Locate the 255 mm pH probe into the lid of the reactor, with the probe fully submersed, tighten the gland and connect to the hard wired cable from the cabinet.



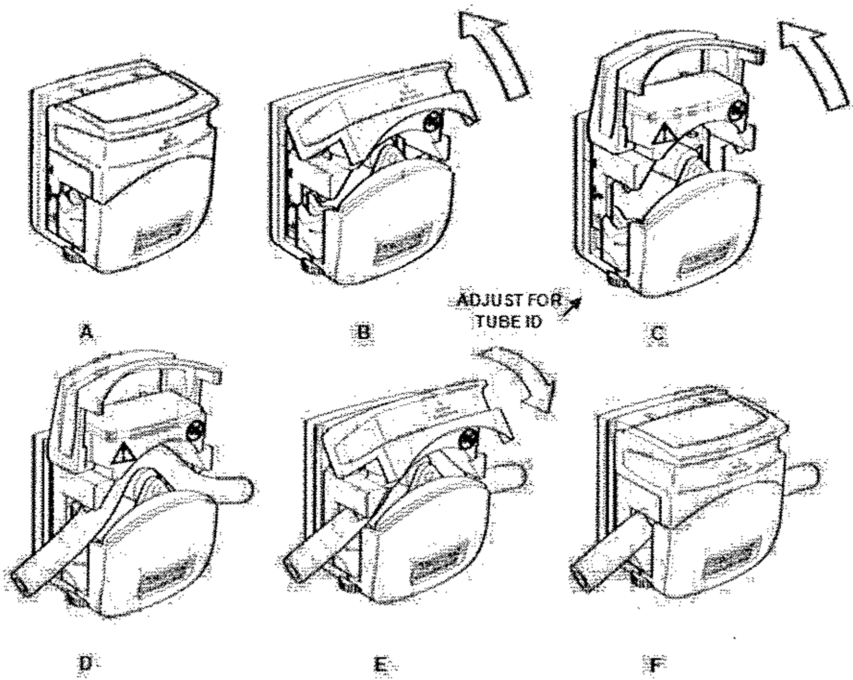
Temperature sensor and pH probe location with reactor

10.5.5 Feed Pump

The BE4 is provided with three sets of peristaltic and PVC tubes for feed rate variation. The peristaltic tubing supplied is Marprene in 1.6 mm, 4.8 mm and 8 mm diameter. Each of these peristaltic tubes is connected to PVC tubing and is fitted with an in-valved hose tail for connection to V4.

Load a length of the peristaltic tubing into the pump head as shown in the figure below.

Note: Marprene tubing lifetime is over 1000+ hours but it is recommended that the tubing is regularly checked.



Loading the feed pump head with tubing

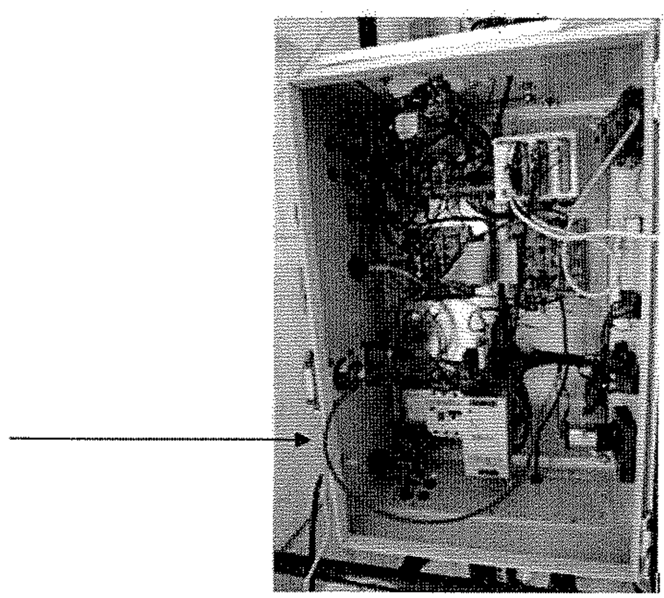
Note: When the unit is not in use the pump head should be lifted as shown in D.

10.6 Commissioning

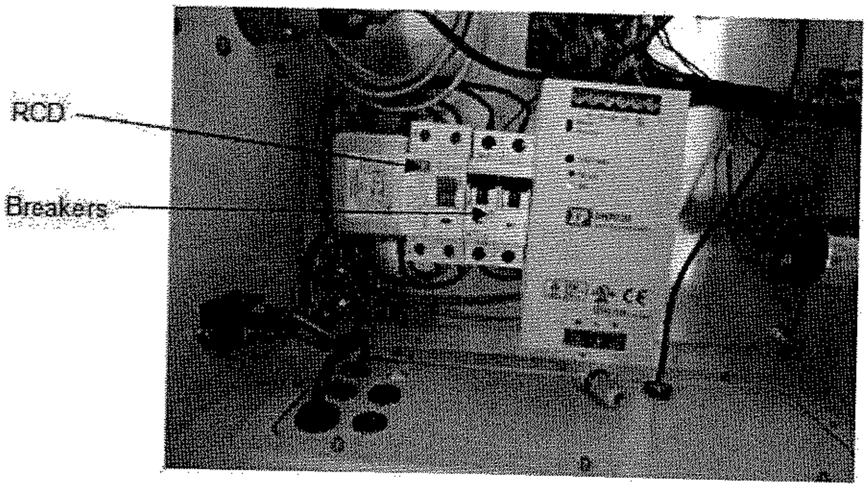
Where necessary, refer to the drawings in Equipment Diagrams section 8.

It is assumed that the equipment has been assembled, installed and connected to services in accordance with the appropriate sections of this manual.

Open the electrical consoles using the pin lock key provided and, ensure that the RCD and the two miniature circuit breakers are in the ON position.



Side view of open electric console



Close-up of RCD and mini circuit breakers in ON position

Water is used as the process liquid for commissioning.

All switches on the front of the control cabinet for heating, recycle pump and feed pump should be in the OFF position.

10.6.1 Switching on the unit

With the mains plugged in at the wall socket turn the power on, switch the "Mains Power" switch ON, located on the front of the control cabinet.

10.6.2 Tank reactor

1. Fill the feed vessel with 25 litres of water and place next to the unit. Drop the flexible tube from the feed pump (P1) inlet into the vessel.
2. Place the flexible tube V4 (effluent) into the feed vessel.
3. Fill the base tank of the gas collection tank (T3) with water until it starts to overflow the down-pipe. Place the tube from the down-pipe to drain.
4. Fill the U-bend with water through the open tube on the TEE using a syringe or funnel creating the gas lock. Set the outlet to drain into the feed vessel.
5. Turn ON the mains switch.
6. Turn on the feed pump (P1); adjust the speed to maximum using the dial. Water will now flow into the reactor, overflow the U-bend and return to the feed vessel. This step will take a number of hours to compete.
7. Turn ON the recirculation pump (P2) at 30% speed.
8. Allow the system to run for approximately 30 minutes so any air bubble can be expulsed.

Alternatively, due to the low throughput of the feed pump, it will much quicker to prime the reactor by manually via a main hose connection. To achieve this follow the procedure below.

1. Fill the U-bend with water through the open tube on the TEE using a syringe or funnel creating the gas lock. Set the outlet to drain into the feed vessel.
2. Connect the flexible tube from outlet of the U-bend to a mains water tap.
3. Slightly turn on the water mains and fill in the reactor.
4. Turn off the water as the level reaches the reactor outlet.
5. Disconnect the flexible tube from the mains tap and return to the feed vessel. Continue to fill the reactor using the feed pump. When the reactor is full, water will overflow down the U-bend and will expulse any trapped air through the U-bend.
6. Turn ON the recycle pump (P2) at 30 % speed.
7. Allow the system to run for approximately 30 minutes so any air bubble can be expulsed.

10.6.3 Reactor and Settler (Optional BE4-1)

1. Fill the feed vessel with 25 litres of water and place next to the unit. Drop the flexible tube from the feed pump (P1) inlet into the vessel.
2. Place the flexible tube from V4 (effluent) into the feed vessel.
3. Fill the base tank of the gas collection tank (T3) with water until it starts to overflow the down-pipe. Place the tube from the down-pipe to drain.
4. Fill the U-bend with water through the open tube on the TEE using a syringe or funnel creating the gas lock. Set the outlet to drain into the feed vessel.
5. Turn on the feed pump (P1); adjust the speed to maximum using the dial. Water will now flow into the reactor, overflow the reactor effluent and fill in the settler. When water in the settler overflows the U-bend, water will return to the feed vessel. This step will take a number of hours to compete.
6. Switch ON the recirculation pump P2 to 30 % speed so the content in the settler is pumped back to the reactor, ensure the valve (V15) is open.

Alternatively, due to the low throughput of the feed pump, it will much quicker to prime the reactor by manually via a main hose connection. This process is much the same as the for the single reactor arrangement. Follow the process above, the only difference being that the settler will start to fill once the reactor outlet level is reached. Fill both the reactor and settler until the U-bend overflows.

10.6.4 Hot water system

1. Fill the hot water vessel with approximately 1600 ml of deionised water (this will almost brim the vessel).
2. Prepare a large beaker/jug of deionised water, approximately 3 litres; this is used to continually fill the vessel whilst the pump is priming the hot water circuit.
3. Ensuring all the hot water jacket connections to the reactor are tightened and the circulation valve (V10) is open (horizontally positioned), turn on the heater system

using the switch located on the front of the control cabinet. The pump will begin to feed water from the vessel to the reactor jacket.

4. Continually fill the hot water vessel with the jug (replacing the pumped water) and observe the hot jacket filling. Ensure the pump does not run dry, indicated by excess noise above the normal low hum and a low flow rate. If seen to be running dry turn the pump off and on again this will expel any trapped air. Once the jacket is filled the circuit is primed and water will start returning to the vessel and circulated around the system.

5. Finally make up the final volume of water to approximately 20 mm from the top, this will ensure the level sensor, located in the vessel lid, is triggered allowing the heater to be activated.

With the reactor filled, the PLC control of temperature can be commissioned. On the PLC set to AUTOMATIC heating control and set the hot water temperature to 35 °C (see 'Operating the PLC' section 11.2.1 for details), observe the reactor temperature start to rise. If 35 °C in the reactor is not reached slightly adjust the set point of the hot water temperature. The reactor can take 2- 3 hours to reach the set temperature.

10.6.5 Temperature sensors

All thermocouples are calibrated before dispatch.

10.6.6 pH probe

It is recommended before any trial that the pH electrode is calibrated. This should be done while the reactor is empty. Remove the pH electrode and calibrate using calibration solutions at pH 4.00 and pH 7.00.

The pH sensor can be calibrated using the PLC. pH calibration solutions 4.00 (low) and 7.00 (high) are required for a 2 point calibration probe are seen in Operating the PLC section 11.2.1.

10.6.7 pH Dosing

To confirm the operation of the pH dosing system PLC control of the pH must be activated within the limit of pH 6.5 – 7.5, see Operating the PLC section 11.2.1 for details. Once the pH control is set, take the following steps.

1. Place the calibrated pH probe in a solution of known pH 7.00, the PLC will should read this value.

2. Prepare two further solutions, one of low pH (approximately pH 4) and one of high pH (approximately pH 11) using dilute 0.1M HCL (Hydrochloric acid) for low pH solution and dilute 0.1M NaOH (Sodium Hydroxide) high pH solution. Alternatively use buffer solutions of known pH.

3. Place the pH probe first in the low and secondly in the high pH solutions, ensure the probe is thoroughly rinsed with distilled water between solutions. Observe the change in the pH display on the PLC and consequently the actuation and direction of the correct dosing pumps located at the rear of the cabinet. The 'acid' pump should activate with the probe in high pH solution and the 'alkali' should activate with the pump in low pH solution. The direction should be towards the reactor.

10.6.8 Gas Collection system

Fill the base tank of the gas collection tank (T3) with water until it starts to overflow the down-pipe. Place a piece of tube from the down-pipe to drain.

Check that a reinforced hose from a mains tap is connected to SOL2 (V7) on the gas chamber. Have the tap partially open. On the PLC, select GAS screen and press START COLLECTION. The low level in the gas chamber will be detected and the gas chamber will fill with water. When the high level switch is reached SOL2 (V7) and SOL3 (V8) will close while the gas inline valve to the chamber, SOL1 (V6) will be open. A few bubbles of trapped air in the valve will rise to the surface but the liquid in the gas chamber will be supported by the atmospheric pressure acting upon the surface of the liquid in the base vessel.

To test the gas collection manually pump or blow air into the reactor. This should bubble up through the reactor, small bubbles in the gas chamber should be seen and water displaced.

10.6.9 General

The equipment is sealed and should not leak, however as a check to prevent possible leaks during operation, leave the reactor vessel and gas chamber fill for at least 2 hours or preferably overnight. Address any connection and tube leaks with PTFE tape or seal rings (not supplied). If there are leaks from V1 or V2 connections, check correct positioning of parts on these fittings. Refer to section Description, V1 and V2 for further details.

Ensure all pumps and heaters are switched OFF. Drain the reactor and settler vessels. Turn OFF the mains power, the unit is now ready for operation.

Note: The anaerobic digestion process is very slow and an experiment can take several weeks to carry out with the equipment running constantly, 24 hours per day. The unit is designed to allow it to be run unattended for long periods.

11 Operation

Where necessary, refer to the drawings in the Equipment Diagrams section.

The apparatus must be set up in accordance with the Installation section. Additionally, ensure that you have read the Safety section at the beginning of this manual.

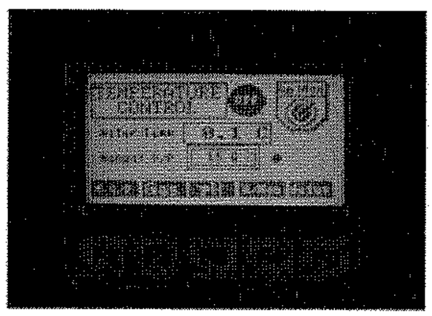
11.1 Operating the Software

Please refer to the software operating instructions supplied on the Armsoft CD ROM or data stick.

11.2 Operating the Equipment

11.2.1 Operating the PLC

The controller will have been configured and tested for satisfactory operation prior to despatch. However, the following procedure will allow the configuration to be checked or changed should the need arise:



PLC for controlling temperature, pH and gas production

11.2.2 Setting Temperature

The temperature of the hot water circulating around the jacketed column is controlled using the PLC. The user then manually adjusts the set point or heater output to obtain the desired reactor temperature depending on which mode of operation is in use. The temperature can be controlled **automatically** or **manually**.

From the temperature control screen use **F4** to select **auto** or **manual**. The display switch shows which mode of operation. Press **F5** to set the proportional band (**F1**), integration time (**F2**) and/or deviation time (**F3**). **F5** takes the user back to the temperature control screen.

11.2.3 Automatic Control

When in **auto** the set point temperature is set by pressing **F1**. The temperature set point is adjusted using **F2**, **F3** and **F4**, the condition is confirmed by pressing **F5** while **F1** returns the user to the previous screen.

11.2.4 Manual Control

If controlling the temperature in **manual**, press **F1** to set the manual output (O/P) of heater capacity (e.g. 75 %). The output is adjusted using **F2**, **F3** and **F4**, the condition is confirmed by pressing **F5** while **F1** returns the user to the previous screen.

11.2.5 Gas Collection

The gas production is calculated based on the time taken for gas to displace water between the high level (HL) and low level (LL) switches.

The volume between the two switches is calibrated by pressing **F4** from the gas collection screen. The vessel volume is changed by pressing **F4** and using **F2**, **F3** and **F4**, the volume is confirmed by pressing **F5**, **F1** returns the user to the previous screen. The volume should be set at 2.2 litres. To start and to stop gas collection press **F5**. The opening and closing of the three solenoid valves is shown in the gas collection screen.

A message will come up on the screen to remind the user to manually fill the gas chamber before the start of gas collection. With the water level at the high level switch gas collection can be started. The system has been set up in this way so a known volume of water is displaced each time.

The previous gas production rate ($Lmin^{-1}$) is displayed on the gas collection screen. This is the calibrated volume displaced over the time taken to displace the known quantity of water.

11.2.6 pH Control

The pH of the reaction is displayed by pressing **F3** from the temperature control or gas collection screen.

The pH sensor can be calibrated using the PLC. pH calibration solutions 4.00 (low) and 7.00 (high) are required for a 2 point calibration. Once on the pH control screen press **F5** (Cal Sensor). Press **F1** to set the calibration point which is adjusted using **F2**, **F3** and **F4**, the condition is confirmed by pressing **F5**. Rinse the pH probe in distilled water before placing the sensor in the low pH solution, press **F2**, the sensor will now measure the pH of the solution, wait until it settles down in a value. Now press **F4** to proceed to calibrating the sensor at the high point. Between calibration solutions ensure the probe is rinsed with distilled water. Press **F1** to set the calibration point which is adjusted using **F2**, **F3** and **F4**, the condition is confirmed by pressing **F5**. With the sensor rinsed place in the high pH solution and press **F2**, the sensor will now measure, wait until it settles down in a value. Press **F4**.

Press **F1** to set this as the default and confirm the calibration.

11.2.7 pH dosing

The pH control is turned on/off by pressing **F3** when in the pH Control screen. To setup the upper and lower pH limits as well as the dosing time press **F4**. The limit is adjusted using **F2**, **F3** and **F4**, the condition is confirmed by pressing **F5**. Pressing **F5** a second time will take the operator back to the pH Control screen where the pH of the reactor is displayed.

Before running and pH control test, the two dosing agents (acid and alkali) must be prepared. Make up 2 litres solutions of 0.1M HCl (Hydrochloric acid) and 0.1M NaOH (Sodium Hydroxide) using volumetric flask (not supplied). Decant the stock solution into labelled glass bottles and place these in the compartment at the base plate of the BE3's frame.

The pumps are labelled as acid or alkali at the rear of the console. Connect the tubing from the peristaltic pumps (P4 and P5) to V1 and V2, and place the pump inlet unto the respective glass bottles containing the dosing solutions.

11.2.8 Process Operation

While operating the BE4 Anaerobic Tank Reactor the user should wear suitable health and safety gear (e.g. Laboratory coat, gloves, covered shoes and safety glasses).

11.2.9 Replacing the heater water

The water from the hot water vessel can be drained using the valve located on the vessel. Connect a suitable hose and open the value to drain. To remove the water from the jacket surrounding the reaction, remove the lower fitting and allow to drain.

Remove any lime scale build-up on the heating element and re-fill the system with distilled water. The process to refill the hot water circuit is described in Commissioning section 10.6.

11.2.10 Gas system

The gas system is required to be flushed out after any periods of extensive use. To flush the system the mains water line must be connected and the gas sampling on the PLC switched on, see Operating the PLC section 11.2.1 for details. Remove the gas intake tube from the reactor (ensure the reactor is not in use and clean), connect this tube to a large syringe a force air into the system until the low level limit is reached and the system refills. Perform a number of times to confirm the operation of the system's components.

11.2.11 Start up procedure

Refer to the Laboratory Teaching Exercises.

11.2.12 Shut down procedure

Lower the set point temperature for the hot water circulator to ambient and turn OFF the heating system.

Turn OFF the recirculation pump P2.

Turn OFF the feed pump P1

11.2.13 Cleaning the Reactor

The process to clean the reactor as follows:

1. Drain
2. Caustic rinse (CIP)
3. Water flush

Drain

Place a 20 L vessel under the column directly below the drain valve (V3). Slowly open V3 and let the contents drain. Remove the feed tube from the feed tank and turn on P1 and pump the remaining liquor into the reactor to drain.

Note: The digested content of the reactor should not be directly disposed down the drain, therefore we recommend to mix the digested mixture with a disinfectant solution before disposal.

There are several products that can be used for this purpose, please contact us if you require further information.

Caustic Rinse

Note: Be extremely careful when handling caustic soda solutions. This procedure requires the use of protective goggles, hand latex gloves, and lab coat (rubber apron can also be worn). Sodium hydroxide is an alkaline (basic) solution that should not come in contact with eyes or skin.

Make up a 20 L solution of 0.5M NaOH. Replace the feed vessel with the dilute caustic. Turn on the feed pump P1 and fill the reactor with the solution until 1 litre of caustic soda has been expelled through the effluent line. Once this stage is reached turn the feed pump off, turn on the recycle pump P2 and recycle the reactor contents at the maxumim flow rate.

Turn on the heating system. Set the temperature to 50°C. Recycle the hot caustic for 1 hour.

With a vessel in place under the reactor open V3 to drain its contents. Remove the clamp off the effluent line and drain. Remove the feed tube from the feed tank and turn on P1 and pump the remaining liquor into the reactor.

Water Flush

Carefully remove the glass lid of the reactor and with a water hose gently rinse the inside of it. Flush water down the recycle line. Put the effluent line to drain or place it in a suitable vessel. Flush water down the "U-bend" effluent line opening V4 to rinse the sample valve.

Put the lid back in place. Replace the feed container with a 20 litre container full of water turn the feed pump P1 on and with V3 open, flush the feed line. Close V3. Flood the reactor. Turn on the recycle pump P2 and adjust to the maximum flowrate. Top up the feed vessel with water. Stop both P2 and P1 when 2 litres of water has passed through the effluent outlet.

11.2.14 Sensors

Remove the pH probe from its coupling, inspect the coupling and clean if required. Place the pH probe in storage solution. Remove the temperature probe and inspect the coupling, clean if required. Replace the temperature probe. Remove the two fittings for pH dosing and clean with water.

11.2.15 Emptying the Gas chamber

Run the gas collection system until the upper vessel of the Gas arrangement is drained, manually forcing air into the inlet via a syringe or pump. Stop the gas collection on the PLC and close or unplug water mains from SOL2 (V7).

Drain water content in lower vessel using the tubing of income gas to SOL1 (V6). Release the tubing from V5 and direct it to a container placed below the lower vessel. Drain the content of the vessel by height difference.

11.2.16 Emptying the Hot Water circulator

When the contents have cooled to room temperature attach a hose to valve (V9) and drain the hot water vessel. Disconnect the hose from the bottom of the reactor jacket and lower this to a drain vessel.

If lime scale builds up on the element and on the glass work of the reactor use a suitable remove using a suitable de-scaler.

12 Equipment Specifications

Reactor Volume	20 L
Heater Power	2 kW
Jacket Temperature	< 55 °C
Recycle Flow Rate	55 L/hr
Feed Flow Rate	0.06 - 5 L/hr
Settler Volume (BE4-1)	11 L
Dosing pumps P4 & P5 Flow Rate	18 ml/min

12.1 Environmental Conditions

This equipment has been designed for operation in the following environmental conditions. Operation outside of these conditions may result reduced performance, damage to the equipment or hazard to the operator.

a. Indoor use;

b. Altitude up to 2000m;

c. Temperature 5°C to 40°C;

d. Maximum relative humidity 80% for temperatures up to 31°C, decreasing linearly to 50% relative humidity at 40°C;

e. Mains supply voltage fluctuations up to ±10% of the nominal voltage;

f. Transient over-voltages typically present on the MAINS supply;

   Note: The normal level of transient over-voltages is impulse withstand (over-voltage) category II of IEC 60364-4-443;

g. Pollution degree 2.

   Normally only nonconductive pollution occurs.

   Temporary conductivity caused by condensation is to be expected.

   Typical of an office or laboratory environment.

13 Routine Maintenance

13.1 Responsibility

To preserve the life and efficient operation of the equipment it is important that the equipment is properly maintained. Regular maintenance of the equipment is the responsibility of the end user and must be performed by qualified personnel who understand the operation of the equipment.

13.2 General

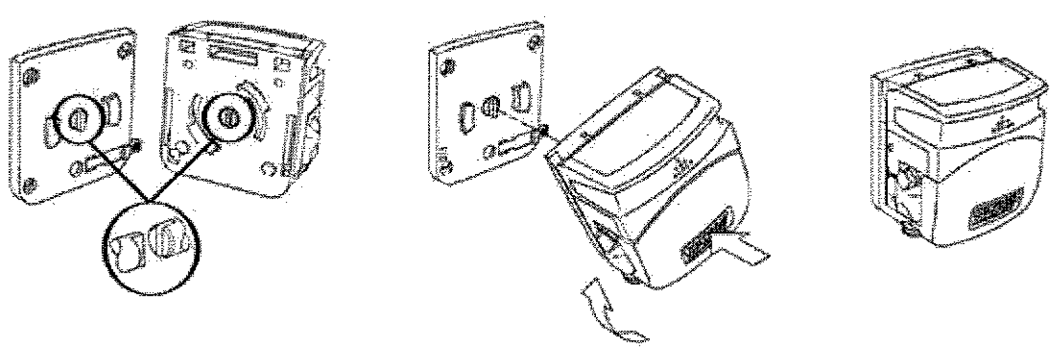
Between each trial the unit should be properly cleaned out, this is outlined in the cleaning procedure.

13.3 Replacing the peristaltic tubing

It is recommended that new tubing be out in place inside P1 prior to the start of a trial and the tubing is inspected and replaced every 30 days during continuous operation. To inspect the tubing first stop the pump. Clamp the tubing from the feed tank and the tubing going to the tank. This is to prevent the contents of the reactor flowing out and to minimise the air in the circuit when the pump is started.

13.4 Installing or uninstalling the feed pump and recycle pump (P1 and P2)

For uninstalling the peristaltic pump (P1 and P2), remove the peristaltic tube and rotate clock-wise the head of the pump. To re install it, after making sure the shaft and the head and base of pump are aligned, rotate anti clock-wise the head of the pump. The peristaltic pump is ready to use. See following figure.



Installing peristaltic pump

13.5 Calibration of feed and recycle pumps

The feed pump calibration is carried out by pumping water at various settings of the speed controller and collecting the pumped fluid in a suitable graduated cylinder.

Check that the tube size on both sides of the pump head is set to 8 mm ID with 1.6 mm hose, if it is not turn the dial at the bottom until it is set correctly.

Disconnect the flexible tube from the reactor inlet. At the end of each tube assembly a ¼" hose barb is attached for connection to V11. In order to obtain free flow for the pump calibration, connect the spare acetal coupling body to the hose barb.

Direct flow to the graduated cylinder. Arrange feed vessels containing water at the suction of each feed pump.

Run each pump at settings of, say, 2.0, 4.0, 6.0, 8.0 and 10.0, collecting and measuring the rate in each instance. A calibration graph of flow rate (litres/hour or litres/day) vs. pump setting can be produced which should be kept with the instruction manual for reference.

Reconnect the flexible tubing of the pump to V11.

13.6 Peristaltic pump tubing sizes

Tube Dia (mm)	0.8	1.6	3.2	4.8	6.4	8
Flow Rate (mL/rev)	0.06	0.25	0.85	1.9	3	4

14 Laboratory Teaching Exercises

14.1 Index to Exercises

This section is divided in two parts. Part A provides a brief description of the different reactor configurations available with the BE4 (or BE4-1) and a list of instruments required to set up each of them. Further details can be found in 'Installing the Equipment' section 10.5.

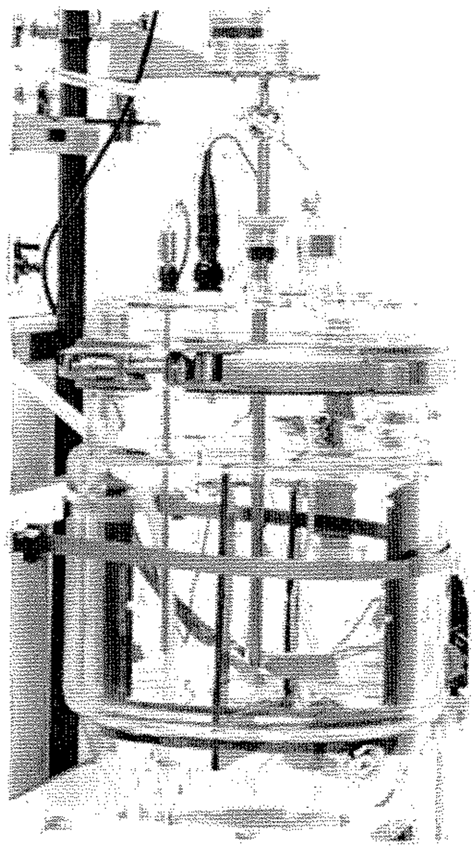
Part B of this section details general information needed to acclimatise, set up, seed and monitor any of the reactor configurations during the anaerobic process. Equations to analyse process efficiency are also included at the end of Part B

Part A

Part B

15 Exercise A - Continuous Stirred Tank Reactor (CSTR)

Equipment required
P2 recirculation pump and connections
Lid No.1 and stirrer
Baffles (cruciform)

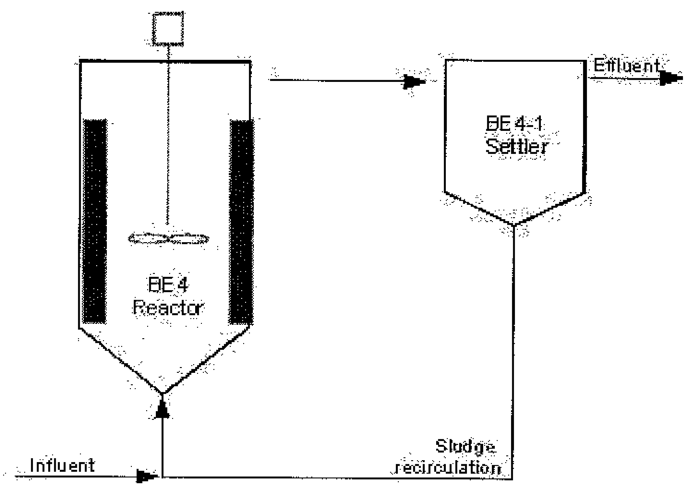


Theory
The CSTR is the simplest and most widely adopted configuration among the anaerobic digester systems. This type of digester is characterised by high-rate mixing, and for being operated at uniform feeding rates and with the previous thickness of raw sludge to guarantee more uniform conditions in the whole digester.

16 Exercise B - Two-stage anaerobic reactor (anaerobic contact process)

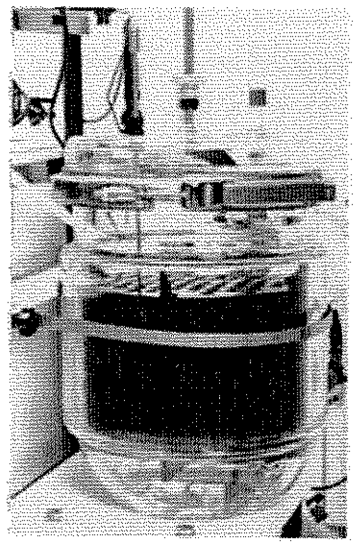
Equipment required
P2 recirculation pump and connections
BE4-A Settler
Lid No. 1 and stirrer
Baffles (cruciform)

Theory
The two-stage anaerobic reactor (anaerobic contact process) involves the use of a complete mix-tank (BE4) followed by a device for the separation of the return of solids (BE4-1 Settler). The principle of the two-stage process is that the flocculated biomass in the reactor, along with the undigested influent solids that are taken out of the system, is retained in the settler and return to the reactor (first stage) where it is mixed with the influent waste water.



17 Exercise C - BE4 as a Packed Bed Anaerobic Reactor (PBR)

Equipment required
For the PBR configuration on the BE4 the following items are required:
Bio-balls
Cruciform
Bio-balls supports (2)
Lid No. 1 with stirrer lifted up



Recirculation of effluent on the PBR provides higher process efficiency (up to 10:1 recirculation rate/feed rate). Make sure all connections to recirculation pump P2 are correctly made.

Theory
This type of reactor is also known as anaerobic filter. It is characterised by the presence of a stationary packing material, in which the biological solids can attach to or be kept within the interstices. The mass of microorganisms attached to the support material or kept in their interstices degrades the substrate contained in the sewage flow.

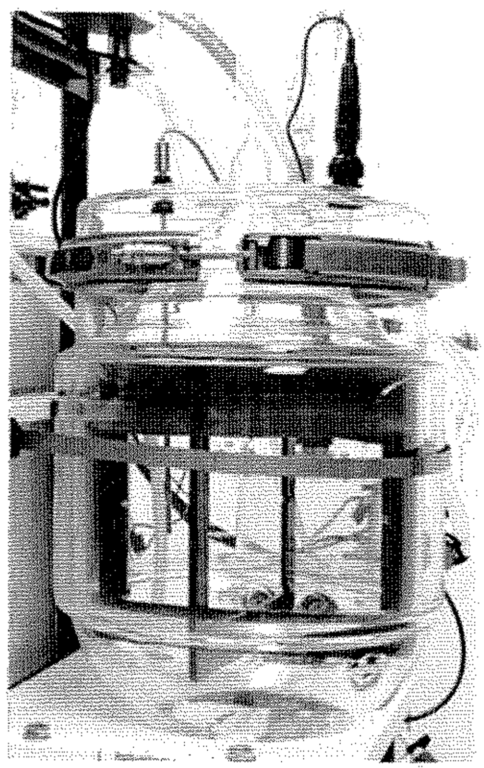
Purpose of packing medium:

- to act as a device to separate solids from gases
- to help promote a uniform flow in the reactor
- to act as a physical barrier to prevent solids from being washed out from the treatment system

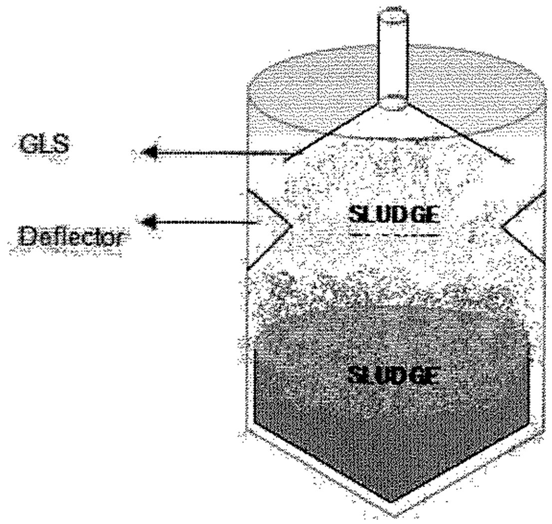
18 Exercise D - Upflow Anaerobic Sludge Blanket (UASB)

Equipment required
For the UASB configuration on the BE4 the following items are required:

- Lid No.2 (GLS device)
- Deflector
- Cruciform
- P2 recirculation pump (recirculation may be used on early stages of the starting up)



Theory
The UASB concept was first conceived by Lettinga and his co-workers in the Netherlands in 1971.The process essentially consists of an upflow of wastewater through a dense sludge bed with high microbial activity. The two layers of sludge are a sludge bed which is formed by solids profile with good settleability close to the bottom, and a sludge blanket which is formed by a more dispersed and light sludge area close to the top of the reactor.



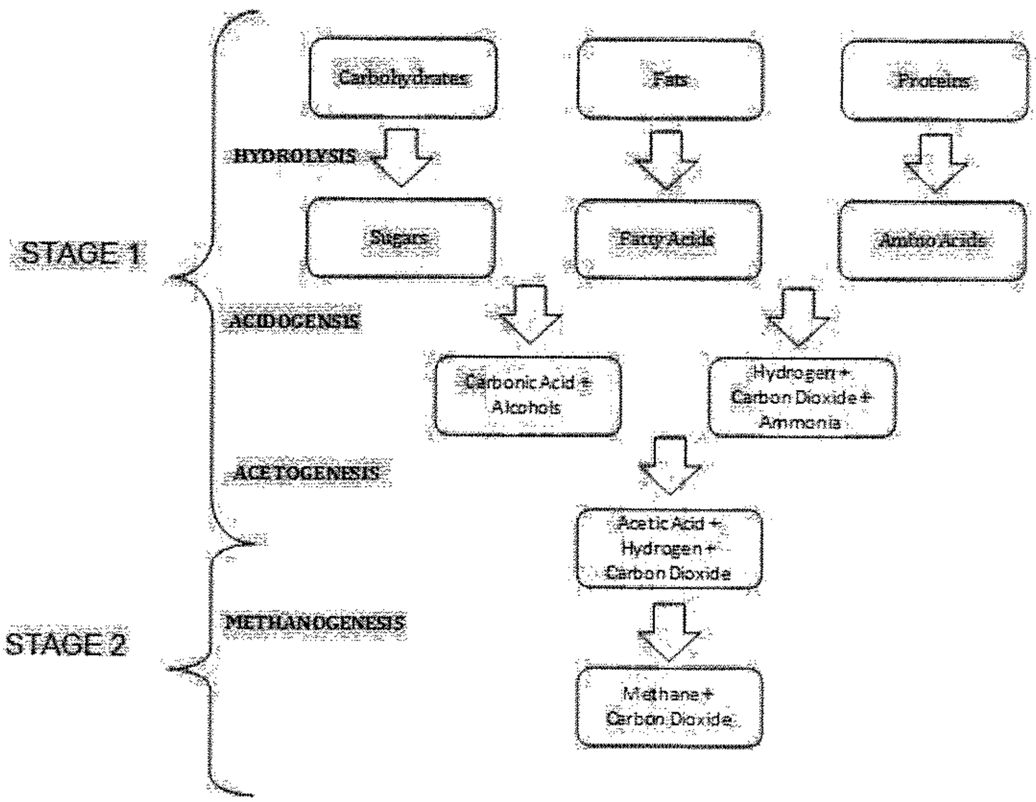
The mixing of the system is promoted by the upward flow of wastewater and gas bubbles. The wastewater enters at the bottom and the effluent leaves the reactor at the top.

Specifics of a UASB are existence of granules sludge and internal three-phase GLS device (Gas/Solid/Liquid separator system). The latter constitutes an essential part of the reactor as it separates the solid particles from the liquid and gas, allowing the liquid and gas to leave the system.

19 Part B

Introduction

In Anaerobic digestion two processes are performed by the micro-organisms. In the first stage organic compounds are broken down into organic acids by fat forming bacteria, this is known as Acidogenesis. In the second stage the acids are converted to methane and carbon dioxide by methane forming bacteria, in a process known as Methanogenesis.



It is assumed that the equipment has been satisfactorily commissioned in accordance with the Commissioning procedure.

The reactor and gas collecting system will be used when performing experiments. The two 25-litre containers will be placed alongside the BE4 and will be used for feeding and output collection purposes.

Recommended conditions during process

Property	Value
Temperature	35 - 37 °C
Feed	Waste water or synthetic wastewater
Feed Volume	2.5 - 3.5 L/d
pH	6.5 - 7.5

Initial Warming Up of a Reactor

After obtaining suitable biomass sludge, screen for fine gravel by passing through a suitable sieve (<1mm) and adjust the solids level to approximately 10 g/l before filling the reactor vessel.

Fill in the U-tube with distilled water through the upper open tubing. This will create a seal when the reactor is fully filled and the effluent makes contact with the water in the U-bend.

Set the desired temperature of the temperature of the controllers to 37 °C (to give a 35 °C reactor temperature). The hot water jacket will slowly bring the contents of the reactor to this temperature (approximately 2-3 hours) and then maintain it. Leave for a minimum of 12 hours before beginning the acclimation of the biomass.

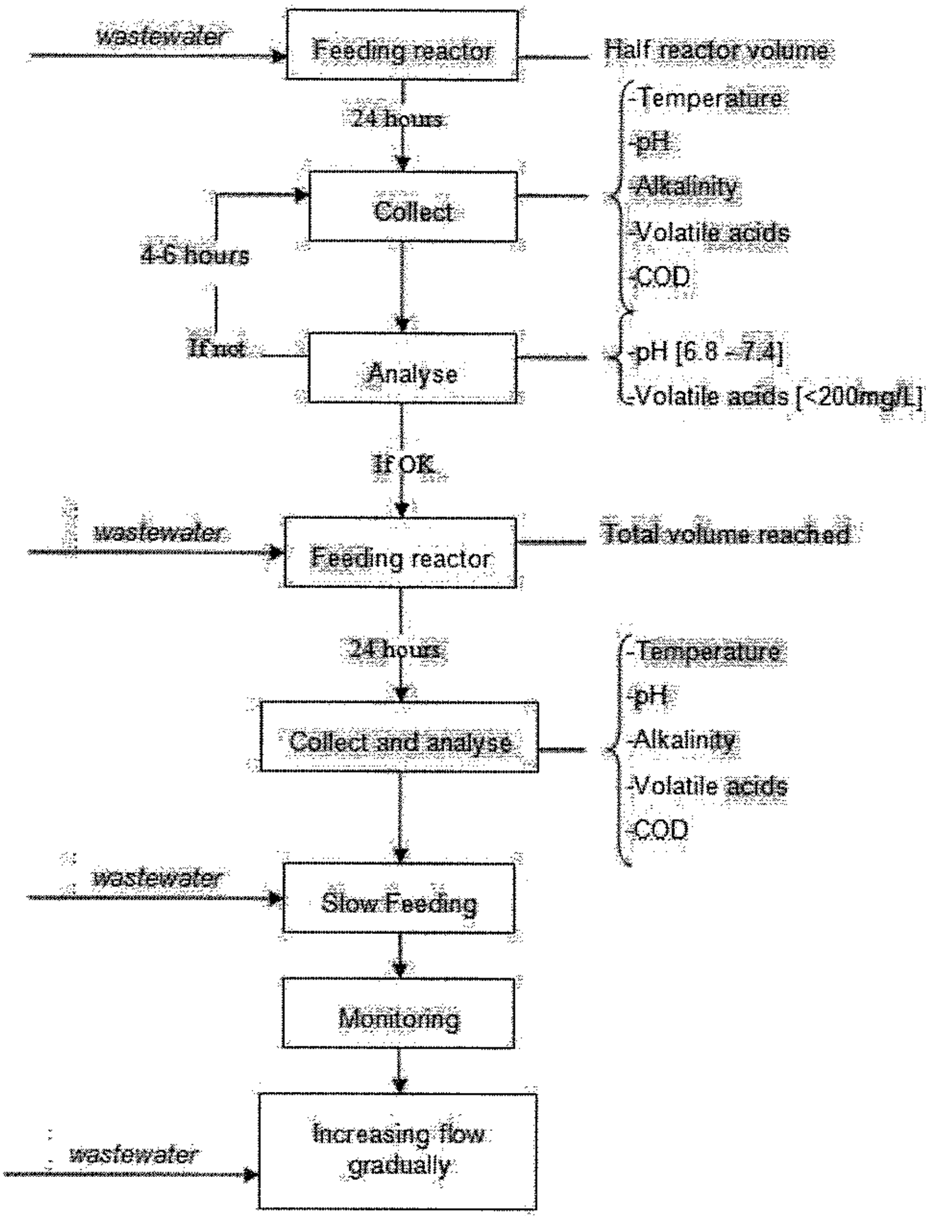
Inoculation of the reactor

The inoculation can be done with the reactor either full or empty, although the inoculation is preferred with the reactor empty, to reduce losses during the transfer process. For the latter condition the following procedures can be followed:

1. Transfer the seed sludge to the reactor, ensuring that it is discharged into the bottom of the reactor. Avoid turbulence and excessive contact with air

2. Leave the sludge at rest for an approximate period of 12 to 24 hours, allowing its gradual adaptation to local temperature.

Feeding the rector with wastewater
After the end of the rest period, the feeding process can begin as follows:



Initial set-up of anaerobic digester chart

Gradual feeding can start at a low rate of 0.3l/d and then increasing it by 0.2 - 0.4 l/d. Once approximately 1.5 l/d is achieved continue feeding for another couple of days without further increase. The BE4 includes different tube diameters to achieve a range of feed flow between 0.06 l/h to 5.04l/h.

Note: Before starting to feed the reactor, you need to ensure a sleek flow-without air pockets is achieved in the feeding tube(s) on P1. Use of the spare acetal coupling may be needed to do so.

Continuous Operation
With the reactor in continuous operation, the following check must be made throughout the operation.

1. There is enough feed in the feed container so that no air will be pumped into the reactor.
2. The level in the effluent tank so no to overflow - dispose of the effluent in a safe manner.
3. The temperature, pH, and gas production rate are in the expected range (see above chart).
4. Take gas, liquid and effluent samples as required.
5. Save the data recorded on the computer. (ArmSoft and LabView versions available).

Synthetic Waste Water (Feed)
Synthetic waste water is prepared by dissolving weighed amounts of chemicals in distilled water and then mixing with measured volumes of trace metal solutions A and B. Trace metal solutions can be prepared in advance. These solutions can be stored at ambient temperature for several months.

Composition

Chemical	**Concentration**
Glucose/sucrose	8.0 (g/l)
Ammonium hydrogen carbonate	0.4 (g/l)
Potassium dihydrogen phosphate	0.4 (g/l)
Sodium hydrogen carbonate	0.4 (g/l)
Trace metal solution A	1.0 (ml)
Trace metal solution B	1.0 (ml)

Trace Metal Solution A

$MgSO_47H_2O$	5.0 (g/l)

Trace Metal Solution B

Chemical	**Concentration**
$FeCl_3$	5.0 (g/l)
$CaCl_2$	5.0 (g/l)
KC1	5.0 (g/l)
$CoCl_2$	1.0 (g/l)
$NiCl_2$	1.0 (g/l)

Preparation

Synthetic waste water is prepared by dissolving weighed amounts of chemicals in distilled water and then mixing with measured volumes of trace metal solutions A and B. Trace metal solutions can be prepared in advance. These solutions can be stored at ambient temperature for several months.

The Composition of Synthetic Waste Water with Different COD Levels

Synthetic Waste Water

Chemical/Reagent Parameter	**1**	**2**	**3**	**4**	**5**	**6**
Approximate COD (mg/l)	2000	4000	6000	8000	10000	12000
Glucose (g/l)	2	4	6	8	10	12
Ammonium hydrogen carbonate (g/l)	0.15	0.20	0.30	0.40	0.50	0.60
Potassium dihydrogen phosphate (g/l)	0.15	0.20	0.30	0.40	0.50	0.60
Sodium hydrogen carbonate (g/l)	0.50	0.50	0.50	0.40	0.30	0.30
Potassium hydrogen carbonate (g/l)	0.5	0.5	0.5	0.4	0.3	0.3
Trace metal Solution A* (ml)	1	1	1	1	1	1
Trace metal Solution B* (ml)	1	1	1	1	1	1

Definition of Calculations

1. $$\text{Percentage COD removed} = \frac{\text{COD in (mg/l)} - \text{COD out (mg/l)}}{\text{COD in (mg/l)}} x100$$

2. $$\text{Organic loading rate (F/Mc)} = \frac{\text{COD applied (kg/day)}}{\text{Amount of biomass in the reactor (kg)}}$$

3. $$\text{Volumetric loading rate}\left(\text{kgCOD}/m^3\right) = \frac{\text{COD applied (kg/day)}}{\text{Volume of the reactor}(m^3)}$$

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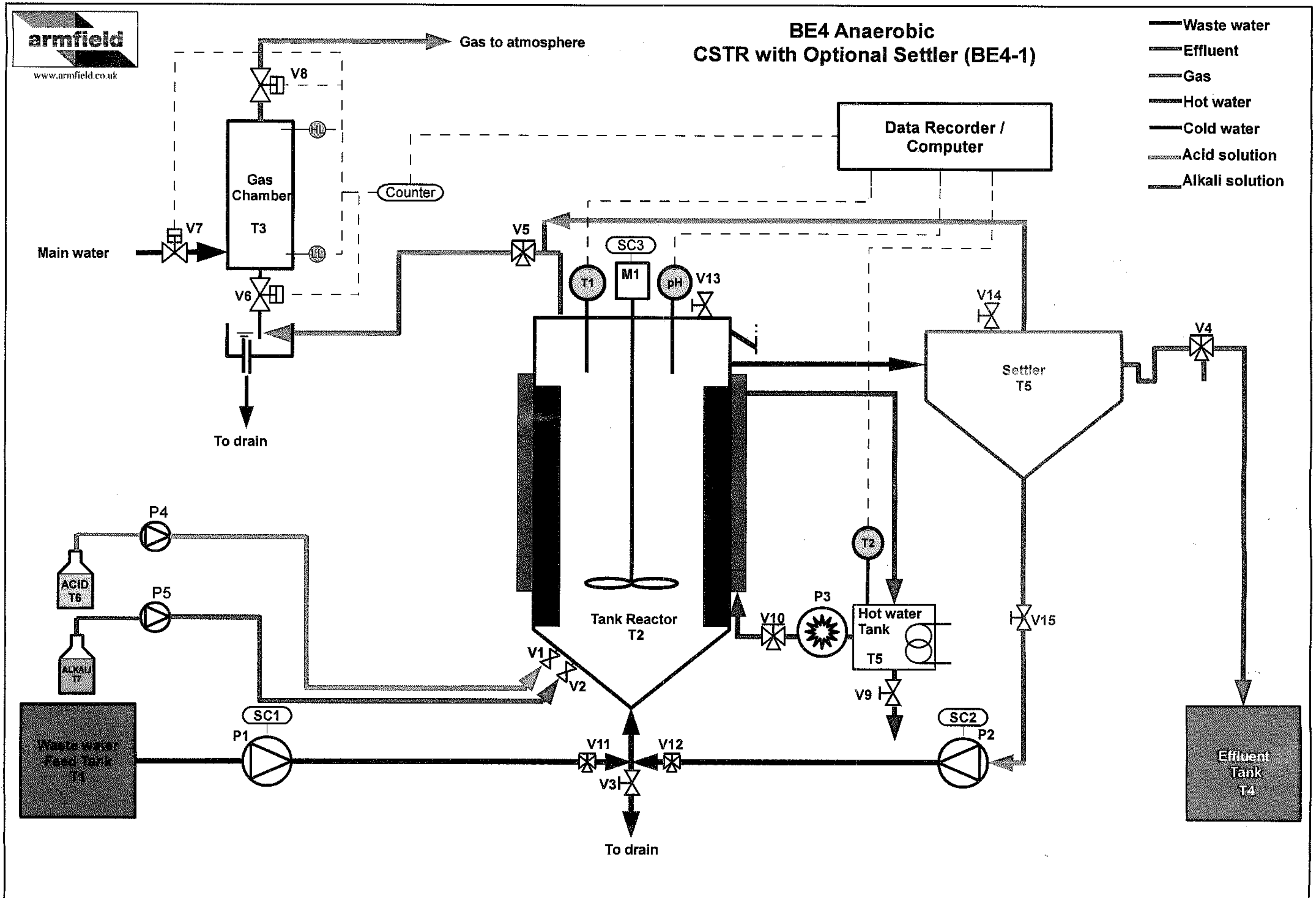
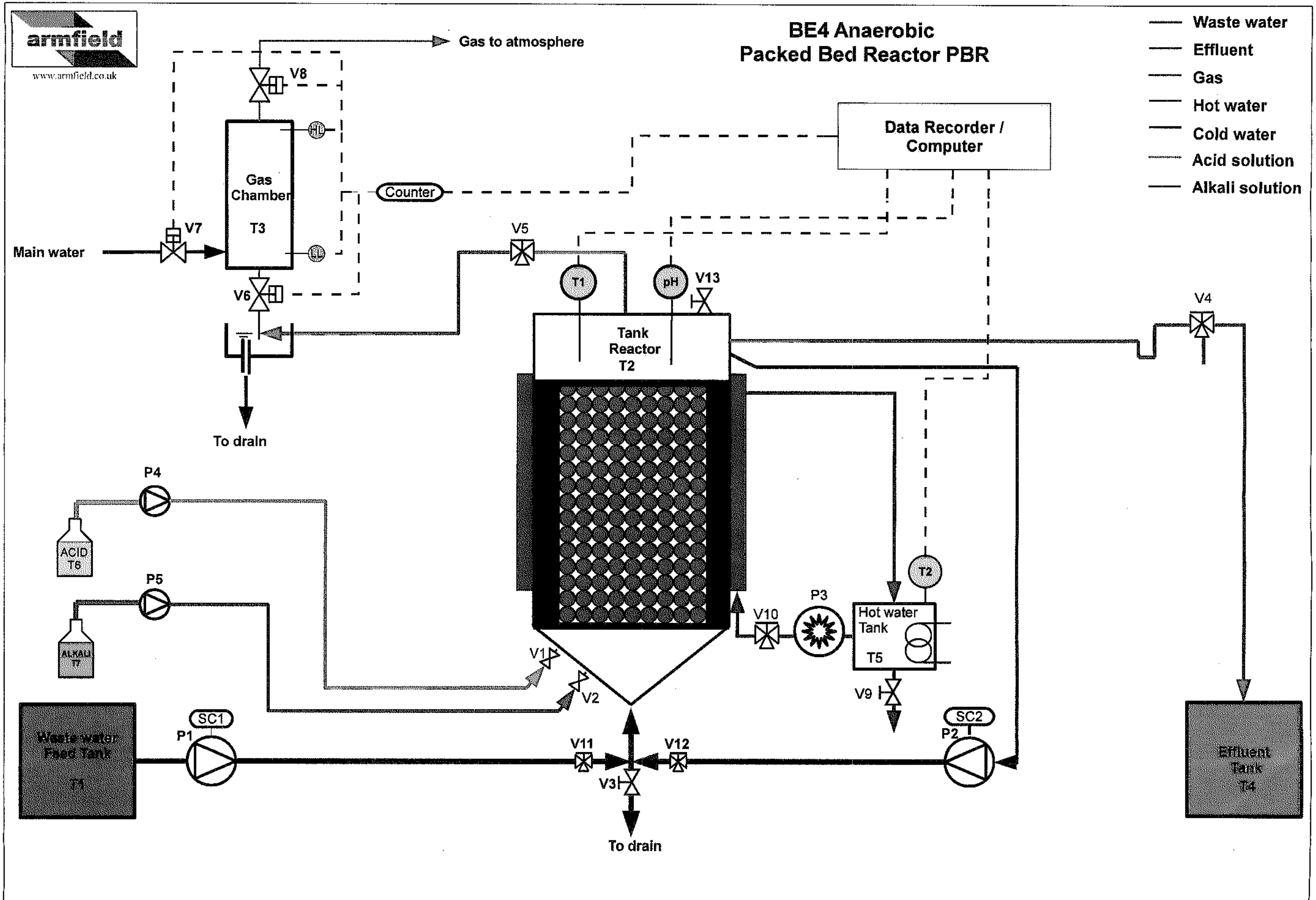
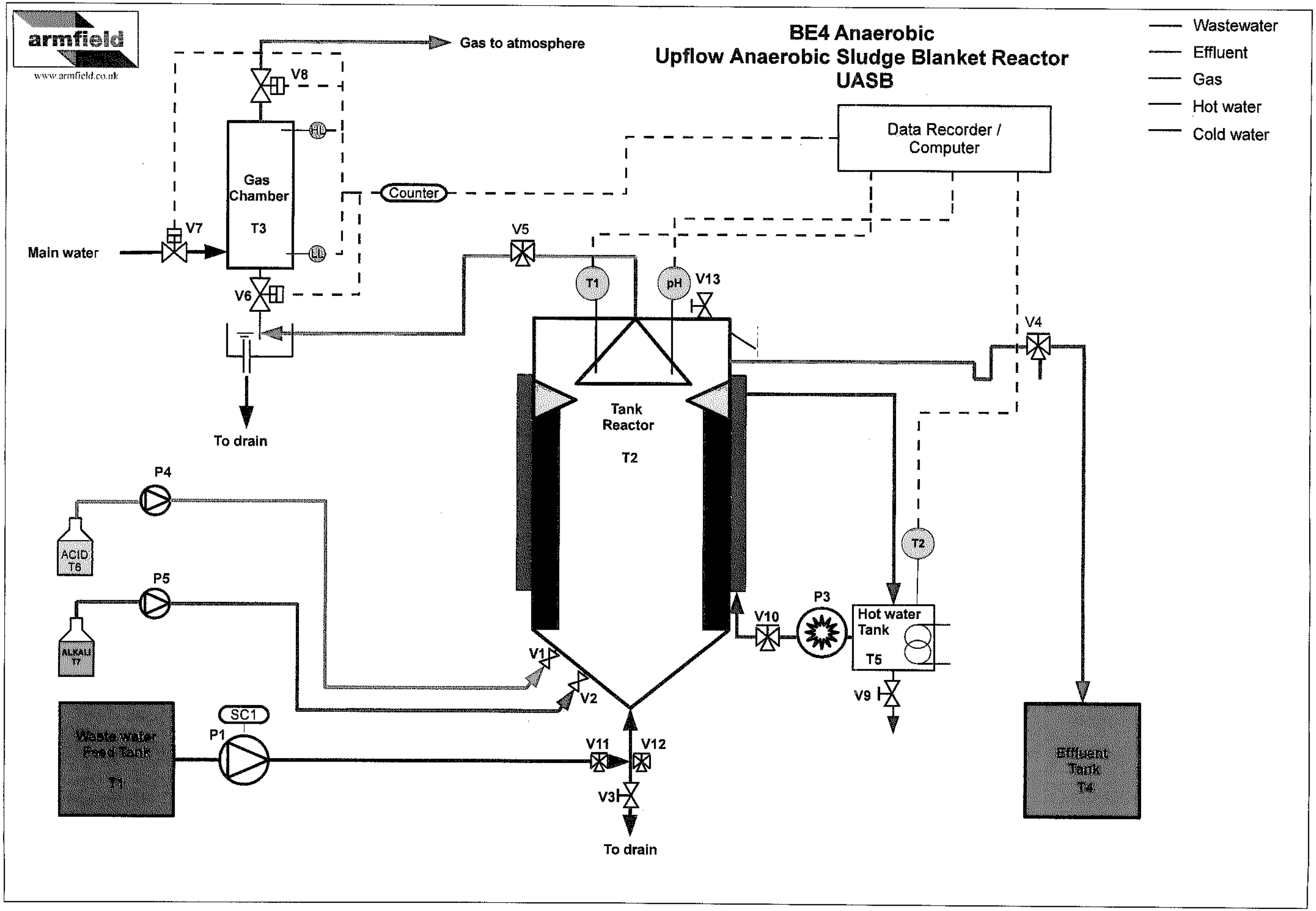


BE4 Anaerobic
CSTR with Optional Settler (BE4-1)
armfield
www.armfield.co.uk
Waste water
Effluent
Gas
Hot water
Cold water
Acid solution
Alkali solution
Gas to atmosphere
V8
Gas Chamber T3
Counter
V7
Main water
V6
To drain
Data Recorder / Computer
V5
SC3
M1
T1
pH
V13
V14
Settler T5
V4
Tank Reactor T2
P4
ACID T6
P5
ALKALI T7
Waste water Feed Tank T1
SC1
P1
V1
V2
V10
P3
T2
Hot water Tank T5
V9
V15
V11
V12
V3
To drain
SC2
P2
Effluent Tank T4



BE4 Anaerobic
Packed Bed Reactor PBR
Waste water
Effluent
Gas
Hot water
Cold water
Acid solution
Alkali solution
armfield
www.armfield.co.uk
Gas to atmosphere
V8
Gas Chamber
T3
HL
LL
Counter
Data Recorder / Computer
Main water
V7
V6
V5
To drain
T1
pH
V13
V4
Tank Reactor T2
P4
ACID T6
P5
ALKALI T7
V1
V2
V10
P3
Hot water Tank
T5
T2
V9
Waste water Feed Tank
T1
SC1
P1
V11
V12
V3
SC2
P2
To drain
Effluent Tank
T4


armfield
www.armfield.co.uk
BE4 Anaerobic
Upflow Anaerobic Sludge Blanket Reactor
UASB
Wastewater
Effluent
Gas
Hot water
Cold water
Gas to atmosphere
Data Recorder / Computer
Gas Chamber
T3
V8
V7
V6
Main water
Counter
To drain
V5
T1
pH
V13
V4
Tank Reactor
T2
P4
ACID T6
P5
ALKALI T7
V1
V2
Waste water Feed Tank
T1
SC1
P1
V11
V12
V3
To drain
V10
P3
Hot water Tank
T5
V9
T2
Effluent Tank
T4