For up to date publications, please go to our website www.CambridgeReactorDesign.com

Cambridge Reactor Design
Unit D2
Brookfield Business Centre
Twentypence Road, Cottenham
Cambridge, CB24 8PS

T +44 (0) 1954 252522
F +44 (0) 1954 252566
E sales@crduk.com
W www.crduk.com

Gastropod – For Gas Liquid Reactions

Gastropod - Gas Introduction Module

Part number **25620**

Gastropod - Gas Reaction Module

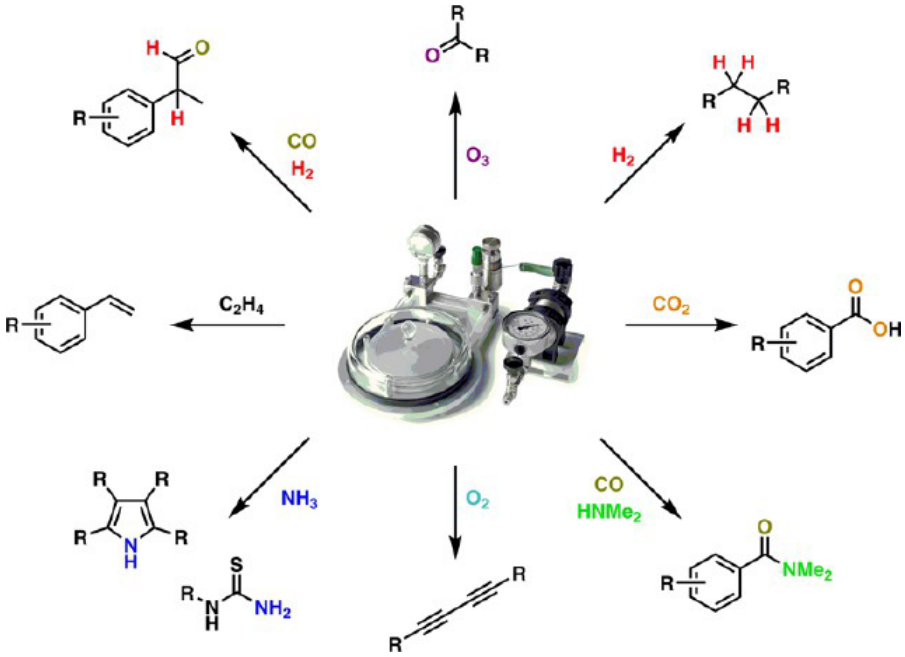
Part number **46820**

Content

Introduction	3
Features	4
Description	5
Operating Instructions	6
Important Safety Notes	6
Gas Introduction Module	8
Step by Step Guide - generating a gas saturated solution	9
Gas Reaction Module	10
Gas Reservoir Option	12
Pressure Declaration	14
Tubing Kits	15

Introduction

Reactive gases are valuable reagents for a multitude of chemical transformations and serve as critical feedstocks for pharmaceuticals, crop-enhancing additives, polymers, and advanced materials. Gases are ideal reagents because reaction products can often be isolated by simply venting excess gas from the reaction vessel. Raising the pressure to provide a stoichiometric excess of reagent offers a simple means of driving a reaction to completion, with the low cost of gases readily enabling such an approach. High-pressure reactions often necessitate expensive specialized equipment or purpose built facilities and additional safety precautions, while the use of toxic, flammable, and corrosive gases generates significant hazards that are intensified by scale.



Flow Chemistry: Intelligent Processing of Gas–LiquidTransformations Using a Tube-in-Tube Reactor
Martin Brzozowski, Matthew O'Brien,§ Steven V. Ley, and Anastasios Polyzos

Features

Gastropod - Fast, efficient and controllable gas-liquid reactions in flow

The Gas Liquid Module provides a safe and efficient means of performing gas-liquid reactions under continuous flow-through conditions. Based on an ingenious 'tube-in-tube' design developed by scientists at Cambridge University in the UK1, it promotes rapid diffusion of pressurised gas through gas-permeable tubing to quickly create a gas saturated solvent stream in typically less than 10 seconds.

Liquid (usually in the form of an organic solvent) is passed through a gas-permeable inner tube which is nested inside a closed, thick-walled outer tube filled under pressure with a reactive gas. The gas is able to diffuse across the membrane into the liquid phase, but the liquid cannot move in the opposite direction.

The Gas Liquid Module is compatible with a wide range of reactive gases (e.g. CO, CO2, H2, D2, ethene, ethyne, SO2) and organic solvents (e.g. THF, MeCN, MeOH, PrOH) and is designed to be connected in-line with any continuous flow reactor. Its primary purpose is to provide a solvent feed stream pre-saturated with gas, but it can also be used as a reactor in its own right.

M. O'Brien, I. R. Baxendale and S. V. Ley; Org.Lett. 2010, 1596-1598.

- Add to any existing or other continuous flow reactor system
- Rapidly generate a continuous gas-saturated solvent stream - no undissolved gas bubbles to disrupt control of pressure and residence time
- Effortlessly perform heterogeneous and homogeneous gas-liquid reactions - hydrogenation, ozonolysis, carbonylation, and direct synthesis of carboxylic acids
- Choose the convenient optional Portable Gas Reservoir and avoid the need to bring bulky pressurised gas cylinders into the lab
- Safe operation ensured by integral safety features (safety cover and gas pressure release valve) and the use of small gas volumes

Description

The Gastropod Gas Introduction Module is a 'Tube-in-Tube' reactor, with a gas-permeable Teflon AF-2400 membrane as the inner tube set within a Tefzel outer tube.

There are two configurations.

In the Gas Addition Module, the liquid feed flows through the inner tube whilst reactive gas fills the annular area. This pre-dissolves the gas into one of the reagent streams. It is then taken into the main reactor downstream

In the Gas Reaction Module, the gas fills the inner tube and the liquid flows along the annular path so it is easy to conduct heat in and out of the flowing liquid. The advantage of this approach is that gas can be supplied during the course of a reaction - the gas is consumed, and the solubility of the gas need not be a limitation. *For maximum flexibility, Gas Reaction Module is based upon the Polar Bear Plus – Flow Synthesizer coil mandrel.*

Where hazardous gases such as hydrogen are employed, the safety profile of these reactions is improved due to the low volumes of gas in use. Teflon AF-2400, which is a copolymer of tetrafluoroethylene, is an ideal choice of material for the purposes of gas-liquid contact. It combines extremely high levels of gas permeability for a wide variety of gases with practically zero liquid permeability and a broad chemical resistance commonly associated with perfluorinated polymers. The Gastropod is offered with a range of customization and scalable options.

Operating Instructions

The basic reactor apparatus is shown in Figure 1a.

IMPORTANT NOTES

All experiments using flammable or toxic gas under pressure should be carried out only following proper safety assessment and with adequate ventilation and fire prevention facilities in place, which are capable of handling a sudden mechanical failure and auto-ignition. Only qualified individuals should operate the apparatus.

The low volume of (reactive) gas contained within the Gas Liquid Module (1.2 ml/m) offers improved safety in comparison to conventional batch reactors.

The Gas Liquid Module must only be connected to a gas cylinder fitted with a suitable pressure regulator. A dual stage regulator compatible with the gas in use should be used. The outlet pressure should be limited to less than 30 bar. For applications where the gas pressure does not exceed 35 bar, the regulator can be safely and conveniently attached to the Gas Liquid Module using the 1/8" x 1/16" Tefzel tubing supplied (other suitable gas transfer tubing may also be used). An optional gas reservoir is available to avoid the necessity to attach to a large gas cylinder in the lab.

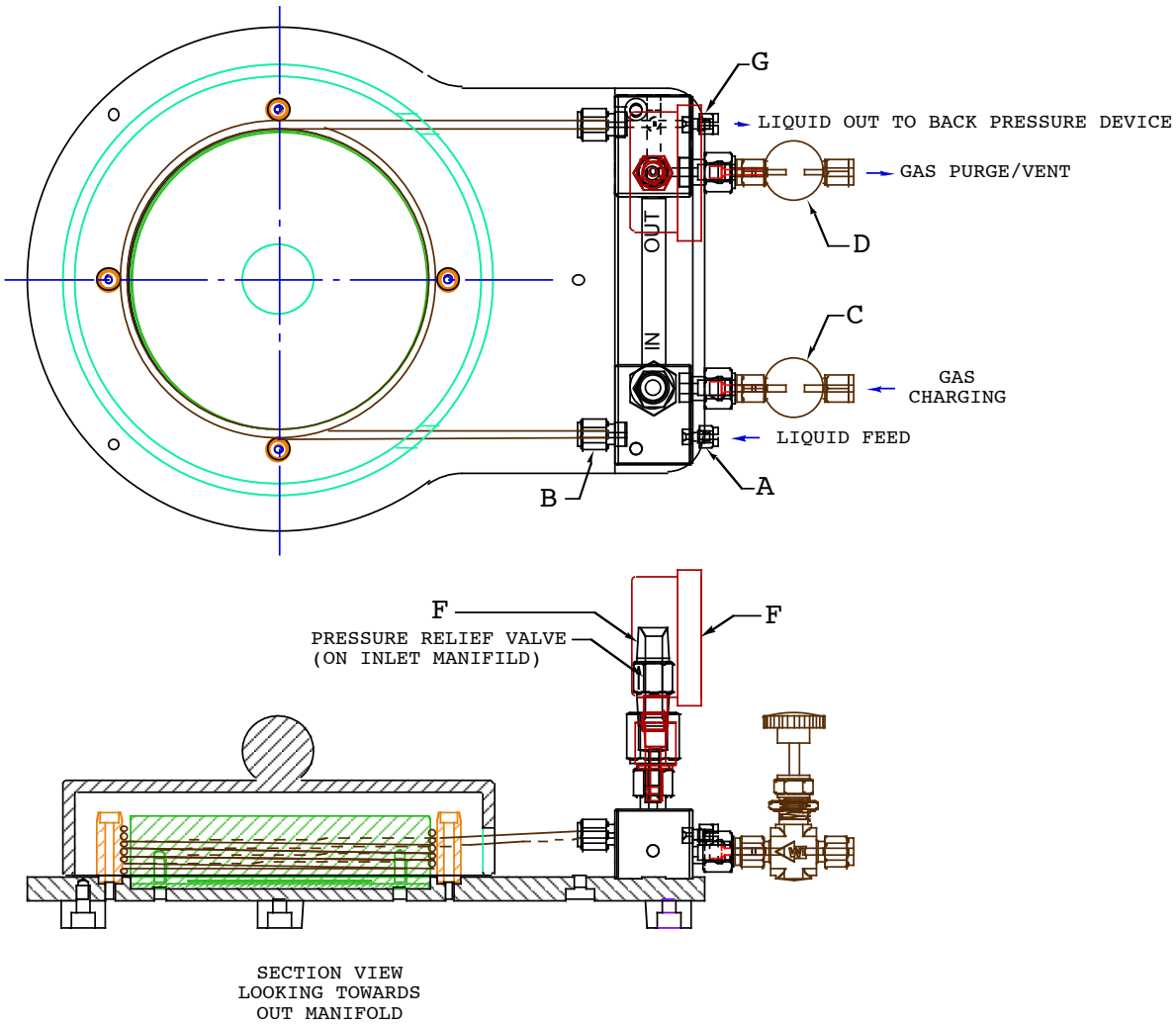
At room temperature Teflon AF-2400 should not be exposed to an internal differential pressure of >35 bar otherwise it may rupture. An external pressure differential of >30 bar may cause the AF-2400 to irreversibly collapse (*test performed with new tubing*). The basic apparatus is supplied with a safety pressure relief valve set to 26 bar break pressure on the gas inlet manifold.

A protective glass cover is available to cover the pressurized tube-in–a-tube assembly.

The Gastropod is suitable for use with many gases (CO, H_2, ethene, ethyne, SO_2, CO_2, ozone, oxygen and ammonia have been used to date) and is compatible with a wide range of solvents (eg: MeOH, MeCN, EtOH, THF, CH_2Cl_2). Please note that the tubing is NOT compatible with fluorous solvents.

The high gas concentration gradient between the two tubes ensures that a gas saturated liquid phase is attained rapidly in only 5-10 seconds residence times at only moderate differential pressures (typically 2-20 bar). Thus, as supplied, a flow rate of up to 2 ml/min will produce a gas saturated solvent stream using the standard 1 m long tube-in-tube reactor.

Figure 1a. Gastropod – Gas Introduction Module

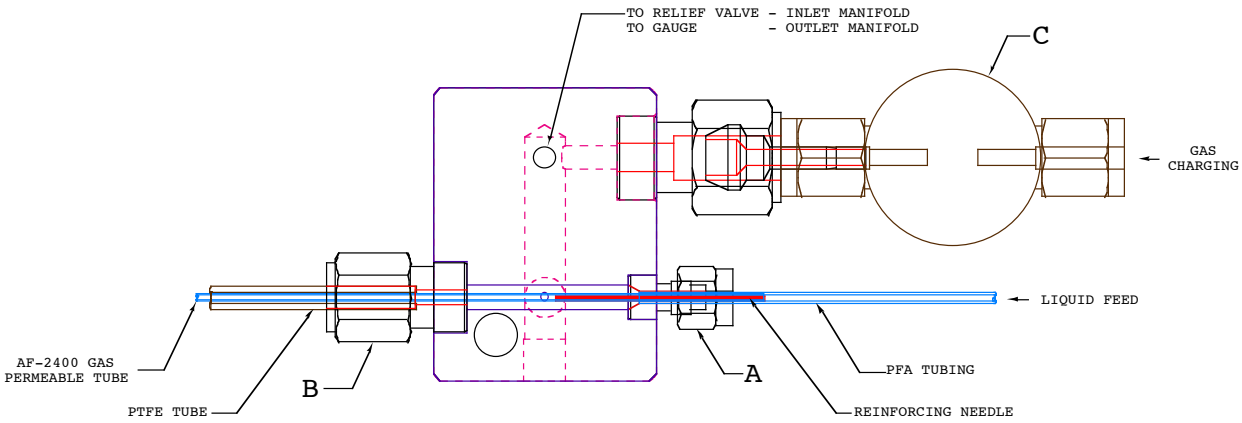


Gas Introduction Module

The liquid is introduced into the apparatus via the attached PTFE tube and 1/16" connection (A) on the IN manifold, where it enters the inner AF-2400 tubing through a reinforced swaged seal. The means of introducing the solution (e.g. syringe pump, HPLC pump) is not included as part of the basic Gastropod Gas Introduction Module.

The AF-2400 tube exits the manifold block through the 1/8"connection (B) where it runs into the 1/8" OD Tefzel outer tube connected at this point. These connections can be seen in the enlarged view of the IN MANIFOLD.

The gas permeable AF-2400 tube is located inside the Tefzel outer tube, providing the annulus where the gas resides. The tube in a tube construction is coiled round the boss and the connections are made to the OUT manifold through a 1/8th connection in a similar manner.



The gas enters the apparatus via the needle valve (C) on the IN manifold, the needle valve (D) on the OUT manifold allows the apparatus to be purged prior to pressurization and vented at the end of the process. On closing the OUT valve (D) the apparatus can be brought to the desired pressure using valve (C), on the IN manifold, and the gauge (E),on the OUT manifold. The gas enters the annulus through channels in the blocks as shown in figure 2. The residual gas pressure can be monitored using the gauge (E). A safety pressure relief valve (F) on the IN manifold, is set to a pressure below the collapse pressure of new AF-2400 tube. The safety pressure relief valve supplied with the unit is set at 26 bar unless otherwise specified.

Gas permeates into the liquid during residence within the Tube- in-Tube contactor resulting in a solution saturated with the appropriate gas, which exits the apparatus via the 1/16" connection (G) on the OUT manifold (Figure 1).
NB. Only the inner tube of the Tube-in-Tube reactor is made of Teflon AF-2400, At all other times the solution passes through standard PTFE tubing.

It should be noted that any drop in pressure downstream of the apparatus will lead to some of the gas coming out of solution which will make the flow erratic as bubbling occurs. Therefore it is important the system in which the apparatus is used should incorporate a backpressure control device. These back-pressure devices may be purchased from CRD or are available from companies e.g. Upchurch Scientific.

The apparatus is supplied with approximately 1m of AF-2400tubing and the corresponding length of 1/8" tubing. If desired the apparatus can be configured with a greater length of tubing, which can be purchased

separately from CRD. Each additional coil round the boss is increases the length by 403mm.

The gas enters the apparatus via the needle valve (C) on the IN manifold, the needle valve (D) on the OUT manifold allows the apparatus to be purged prior to pressurization and vented at the end of the process. On closing the OUT valve (D) the apparatus can be brought to the desired pressure using valve (C), on the IN manifold, and the gauge (E),on the OUT manifold. The gas enters the annulus through channels in the blocks as shown in figure 2. The residual gas pressure can be monitored using the gauge (E). A safety pressure relief valve (F) on the IN manifold, is set to a pressure below the collapse pressure of new AF-2400 tube. The safety pressure relief valve supplied with the unit is set at 26 bar unless otherwise specified.

Gas permeates into the liquid during residence within the Tube- in-Tube contactor resulting in a solution saturated with the appropriate gas, which exits the apparatus via the 1/16" connection (G) on the OUT manifold (Figure 1).

NB. Only the inner tube of the Tube-in-Tube reactor is made of Teflon AF-2400, At all other times the solution passes through standard Tefzel tubing.

It should be noted that any drop in pressure downstream of the apparatus will lead to some of the gas coming out of solution which will make the flow erratic as bubbling occurs. Therefore it is important the system in which the apparatus is used should incorporate a backpressure control device. These backpressure devices may be purchased from CRD or are available from companies e.g. Upchurch Scientific.

The apparatus is supplied with approximately 1m of AF-2400tubing and the corresponding length of 1/8" tubing. If desired the apparatus can be configured with a greater length of tubing, which can be purchased separately from CRD. Each additional coil round the boss is increases the length by 403mm. An instructional video is available to demonstrate how the tubing may be changed.

Step by Step Guide to Generating a Gas Saturated Solution

Step 1: With the main gas cylinder valve closed, wind the gas cylinder pressure regulator fully out to reduce the outlet pressure at the cylinder to zero.

Step 2: Open both inlet (C) and outlet (D) valves on the Gas Addition Module.

Step 3: Start and prime the flow reactor tubing with system solvent and allow it to pressurise and the pressure to become stable (determined by the back pressure regulator (BPR) fitted to the outlet).

Step 4: Open the gas cylinder main valve, then close the Gas Addition Module outlet valve (D).

Step 5: Slowly wind in the gas cylinder regulator valve until the desired cylinder outlet pressure is reached (< 25 bar).

Purging: Purge the connecting tubing and Gas Addition Module by alternatively closing the cylinder main valve and opening the Gas Addition Module outlet valve (D), then closing outlet valve (D) and opening the cylinder main valve. Three times is usually adequate.

When correctly configured no excess gas bubbles should be visible in the flow reactor tubing until after the final BPR when natural outgassing of excess gas will occur. (The GAS ADDITION MODULE can also be used as a degasser if required. In this case a diaphragm vacuum pump is connected in place of the gas cylinder).

Gas Reaction Module

In the Gas Reaction Module, the gas fills the inner tube and the liquid flows along the annular path so it is easy to conduct heat in and out of the flowing liquid. The advantage of this approach is that gas can be supplied during the course of a reaction - the gas is consumed, and the solubility of the gas need not be a limitation.

The Gas Reaction Module is designed to fit our Polar Bear Plus – Flow Synthesiser. It is also compatible with Uniqsis Flow Syn. Our Polar Bear product allows the temperature of the module to be adjusted from -40 to 150 C. This wide range in temperature allows a variety of experiments for example to control the permeability of the AF2400 material.

As standard, the Gas Reaction Module comes with 1 m of AF2400 permeable tube. A purpose-manufactured mandrel has been designed with the purpose of providing additional clamping points so longer lengths of AF2400 tube may be used if longer residence times are needed.

The Gas Reaction Module also comes with a gas manifold. This allows the gas pressure in the AF2400 tube to be controlled to a set pressure. A relief valve protects the AF2400 tube in the event of an overpressure situation.

Figure 1a. Gastropod – Gas Reaction Module

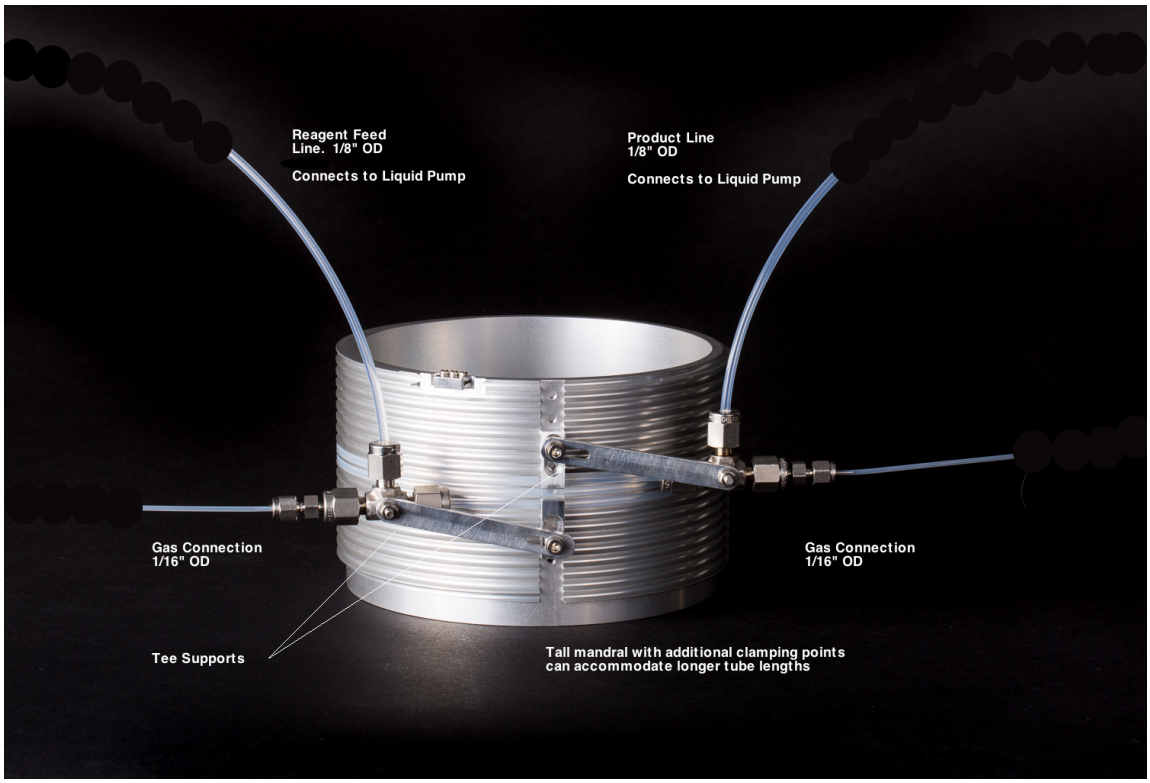


Figure 1b. Gastropod – Gas Manifold

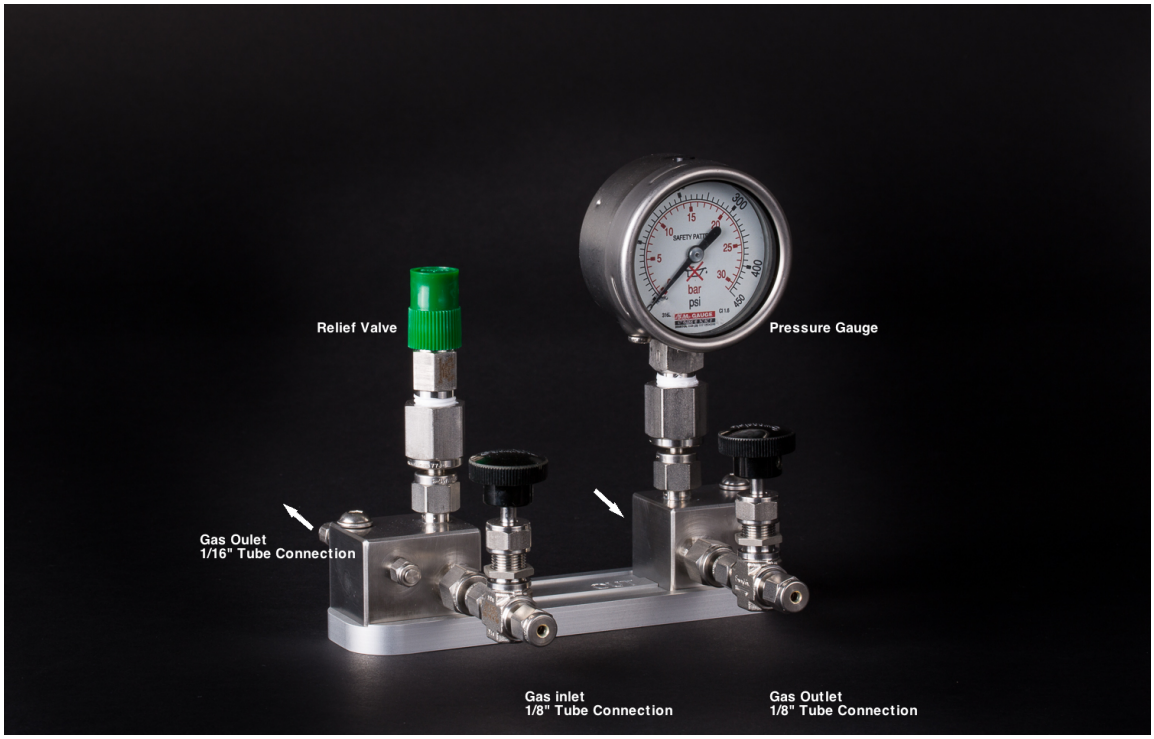
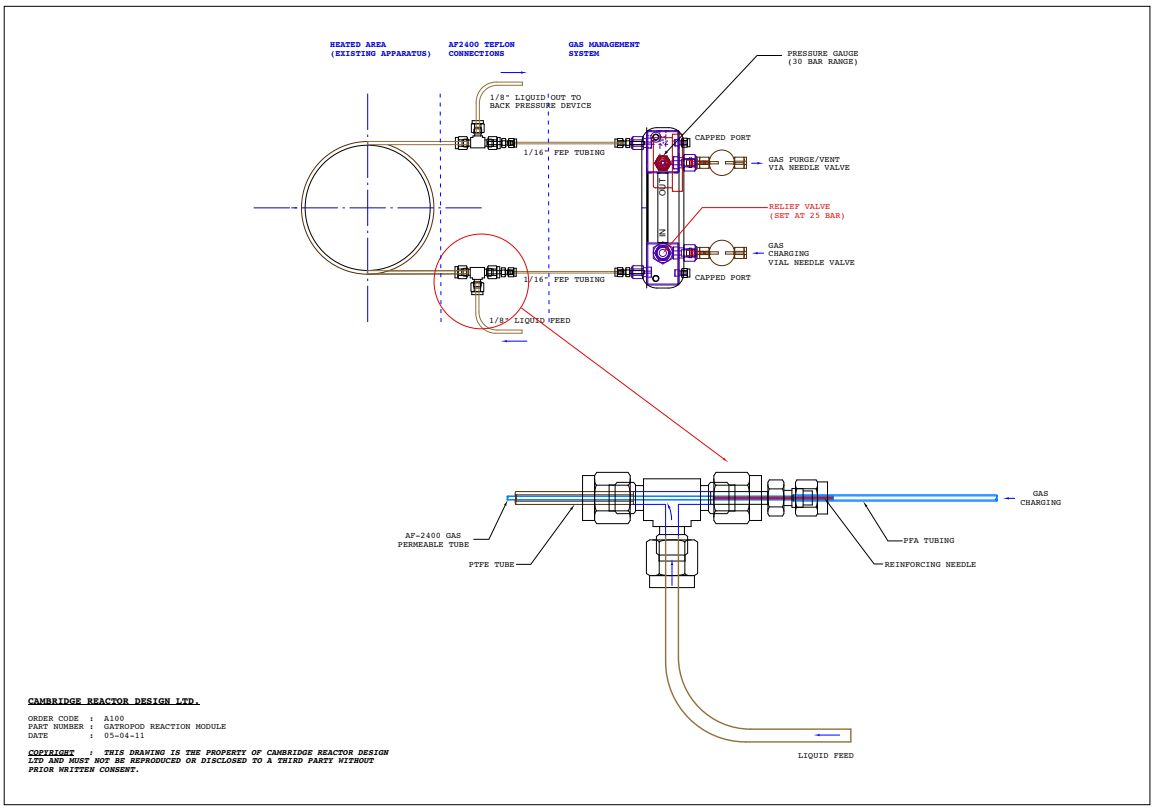


Figure 1c. Schematic of the Gas Reaction and Gas Manifold System



Gas Reservoir Option

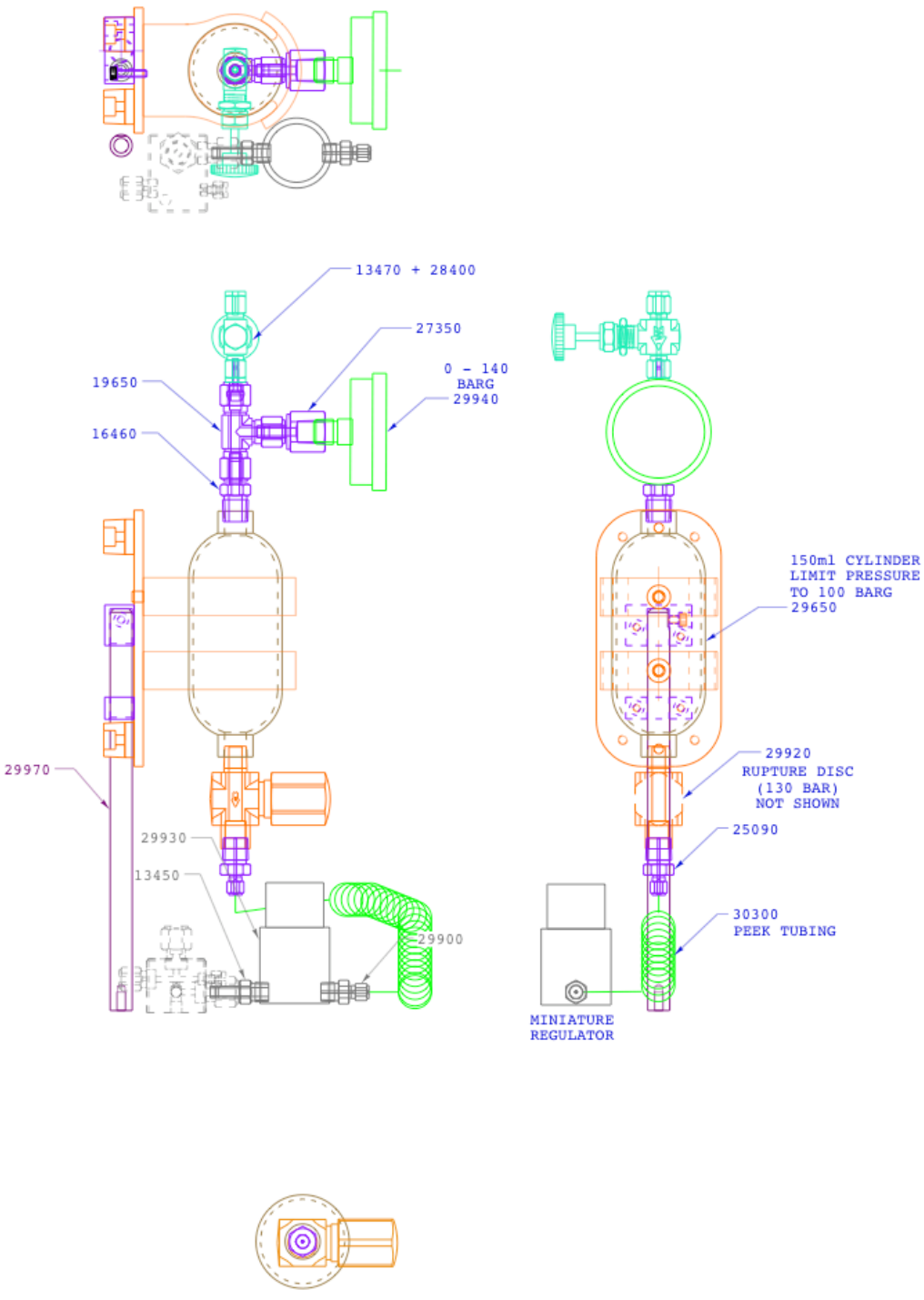
(Illustrated connected to the Gastropod Gas Introduction Module)

To avoid the necessity of bringing a large gas cylinder to the apparatus a portable reservoir option is available. This comprises a 150ml/100bar cylinder with appropriate gauge, valves and safety rupture disc.

The needle valve on the IN manifold is replaced with a miniature regulator, the needle valve being moved to the inlet port of the cylinder.

The pressure in the apparatus is set using the mini regulator and gauge (F). The residual pressure in the reservoir is monitored on its gauge.

Figure 2. Reservoir assembly



Pressure Declaration

Cylinder air was used to perform these tests at room temperature.

The gastropod tube in a tube reactor consists of a stainless steel manifold, 1/8 and 1/16" tubes.

Stainless steel manifolds are leak checked at 30±2 bar pressure and room temperature

The gastropod assembly is leak checked during assembly and is leak tight at 5 bar total pressure.

Maximum pressure rating for polymer tubing can be downloaded from
http://www.upchurch.com/PDF/Lit/Tubing.pdf

All fittings are Swagelok
http://www.swagelok.com/

Suppliment 1. Tubing Kits

1. Gastropod – Gas Introduction Module

Tubing Kit consist of

1083 ±1 mm AF2400 permeable tubing
1003 ±1 mm 1/8" FEP (or equivalent) (1.6 or 2.4 mm bore) tubing
255 ± 5mm 1/16 FEP (1mm Bore) Tubing
2 off thin wall tube inserts
2 off 1/16" Swagelok ferrules
2 off 1/8" Swagelok ferrules

These assembly instructions are a supplement to the Video demonstration

1. Cut tubes to length
2. Push Stainless steel inserts into the ends of the permeable tube until they are fully inserted.
3. While holding the 1/8" tube as straight as possible, gently feed the AF2400 tube through.
4. While holding the Needle insert, feed the 1/16" tube over the permeable tube until it is covering the insert by about ¾. (The end of the 1/16" tube may have to be gently warmed).
5. Feed on a 1/8" nut and ferrules onto the 1/8" tube
6. Carefully feed one of the 1/16" tubes through the inlet manifold block - care not to buckle the AF2400 tube.
7. Locate 1/8" tube and swage the swagelok fitting ¾ turn from finger tight, making sure that the insert is visible.
8. Wrap the 1/8" tube around the central boss 1 turn and locate inside the pillars.
9. Feed on the other 1/8" nut and ferrules.
10. Feed the outlet end through the manifold block and secure 1/8" fitting as above.
11. Adjust the position of the 1/16" tubes so that the inserts are level and partly inside the 1/16" fittings.
12. Feed on the 1/16" ferrules and nuts and do up ¾ turn from finger tight.

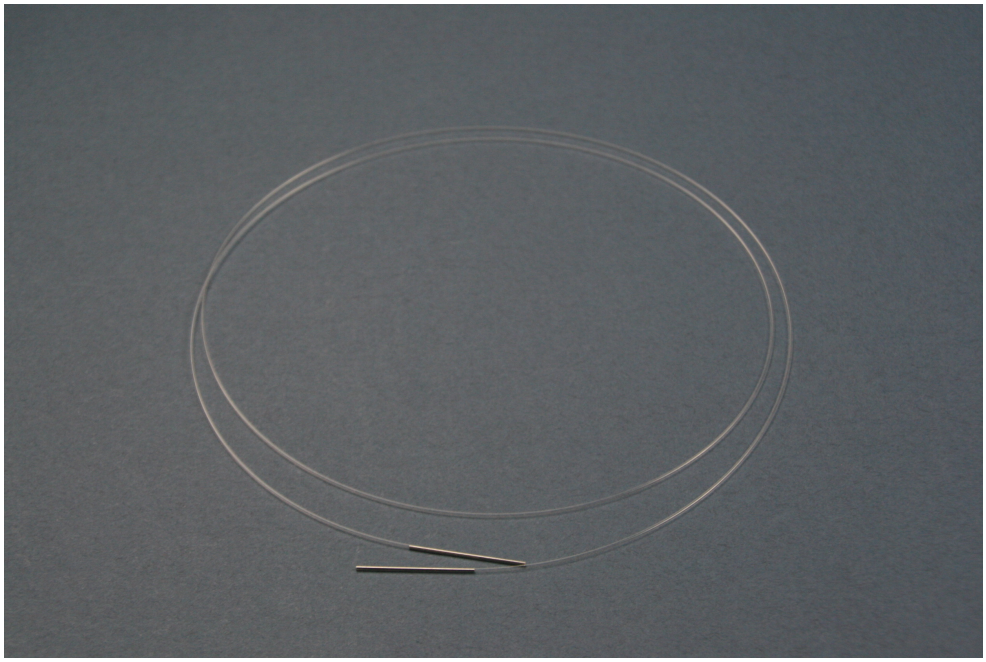
2. Gastropod – Gas Reaction Module

Tubing Kit consist of

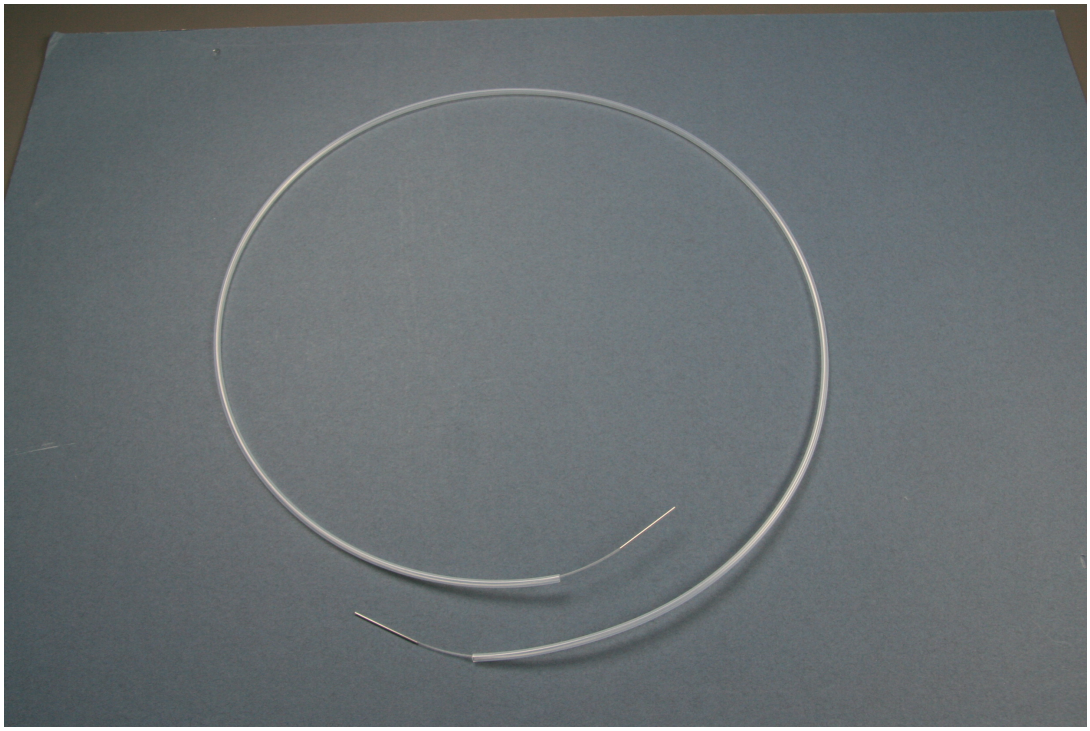
1059±1 mm AF2400 permeable tubing
949±1 mm 1/8" FEP (or equivalent) (1.6 or 2.4mm bore) tubing,
2 x 1250 ± 5mm 1/16 FEP (1mm Bore) Tubing,
2 x 1250 ± 5mm 1/8" FEP (or equivalent) (1.6 or 2.4mm bore) tubing
2 off thin wall tube inserts,
2 off 1/16" Swagelok ferrules,
2 off 1/8" Swagelok ferrules

Assembly instructions

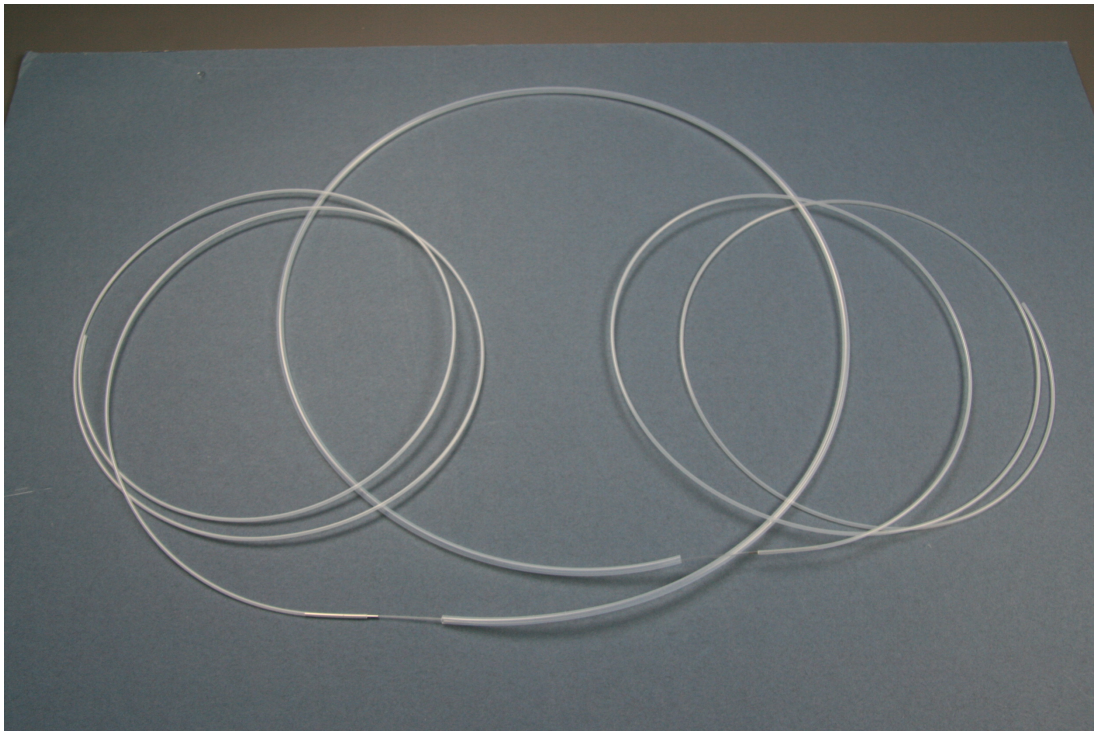
1. Cut tubes to length
2. Push Needle inserts into the ends of the AS2400 tube until fully inserted.



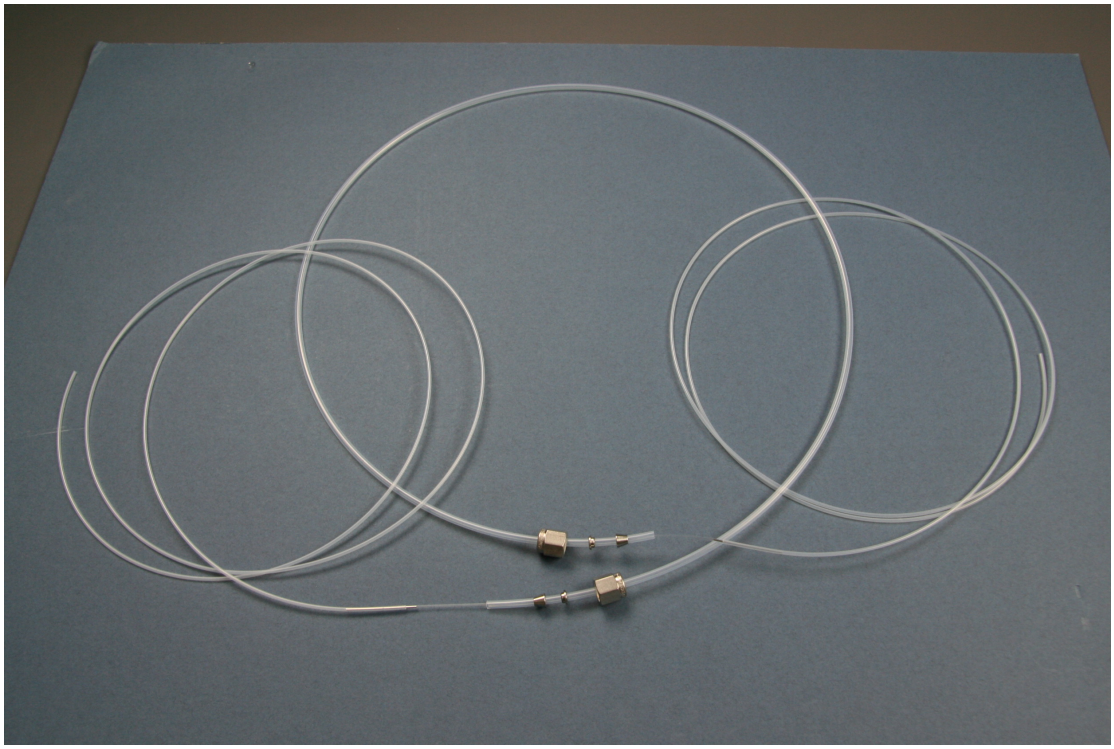
3. While holding the 1/8” tube as straight as possible, gently feed the permeable tube through.



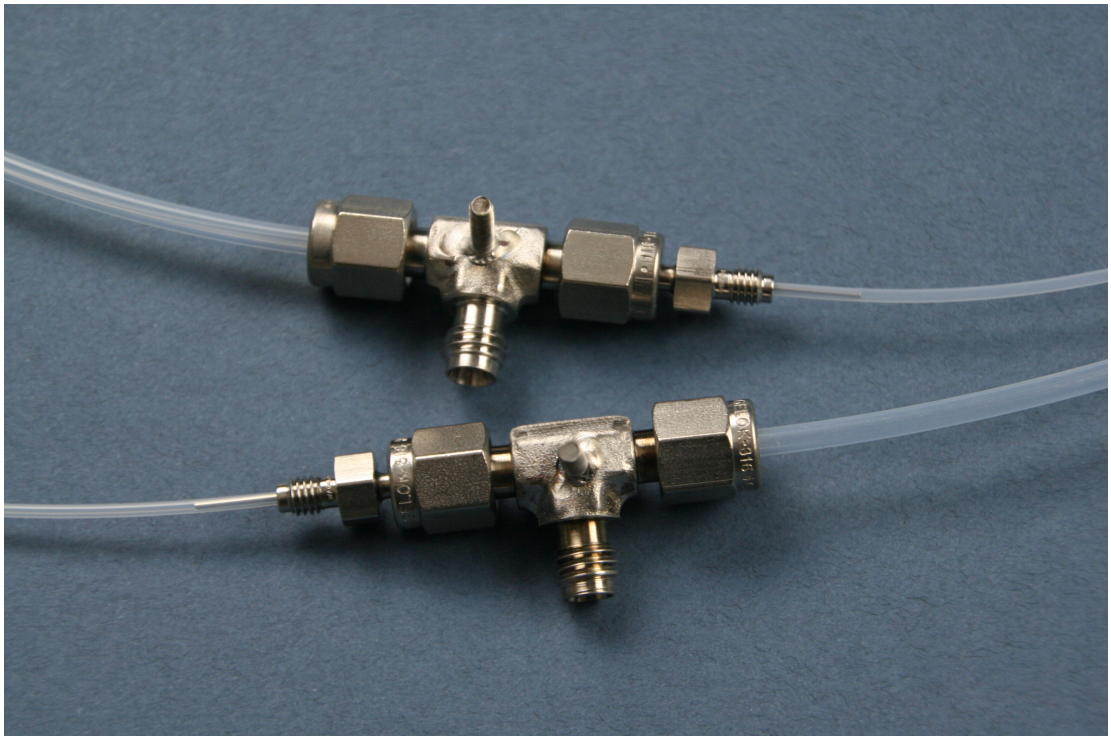
4. While holding the stainless steel insert, feed the 1/16” tube over the permeable tube until it is covering the insert by 3/4 minimum. (The end of the 1/16” tube may have to be gently heated).



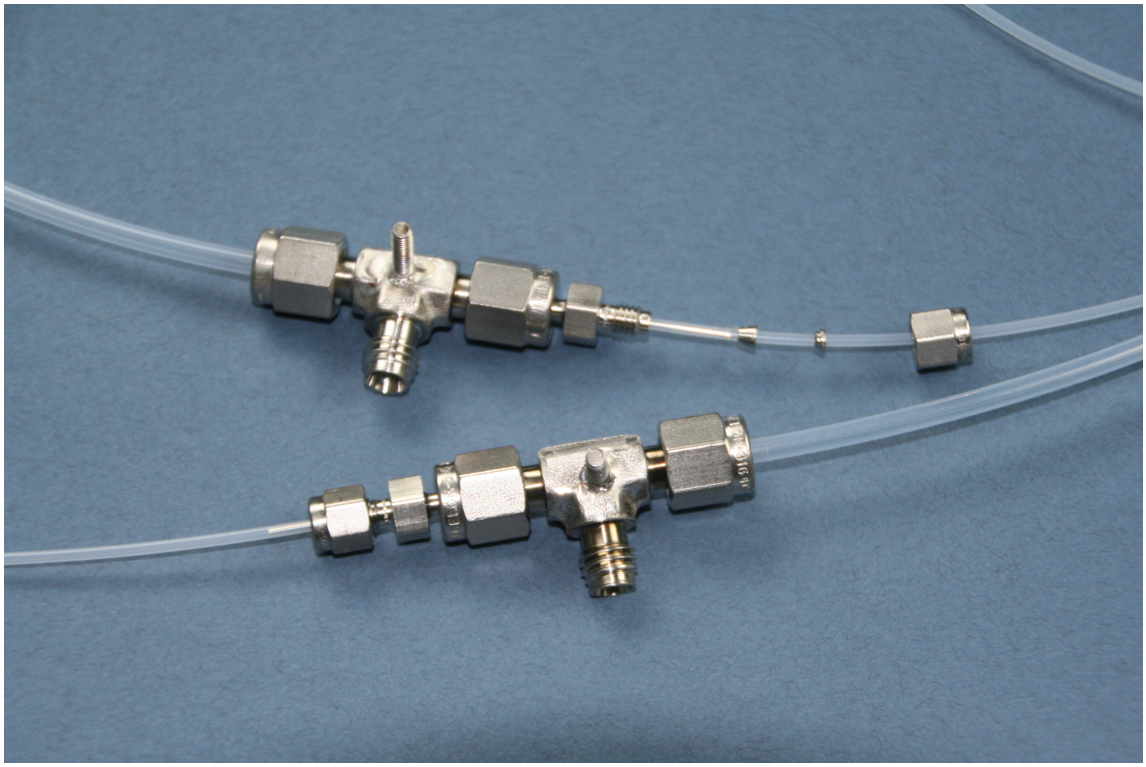
5. Feed on a 1/8" nuts and ferrules onto the 1/8" tube



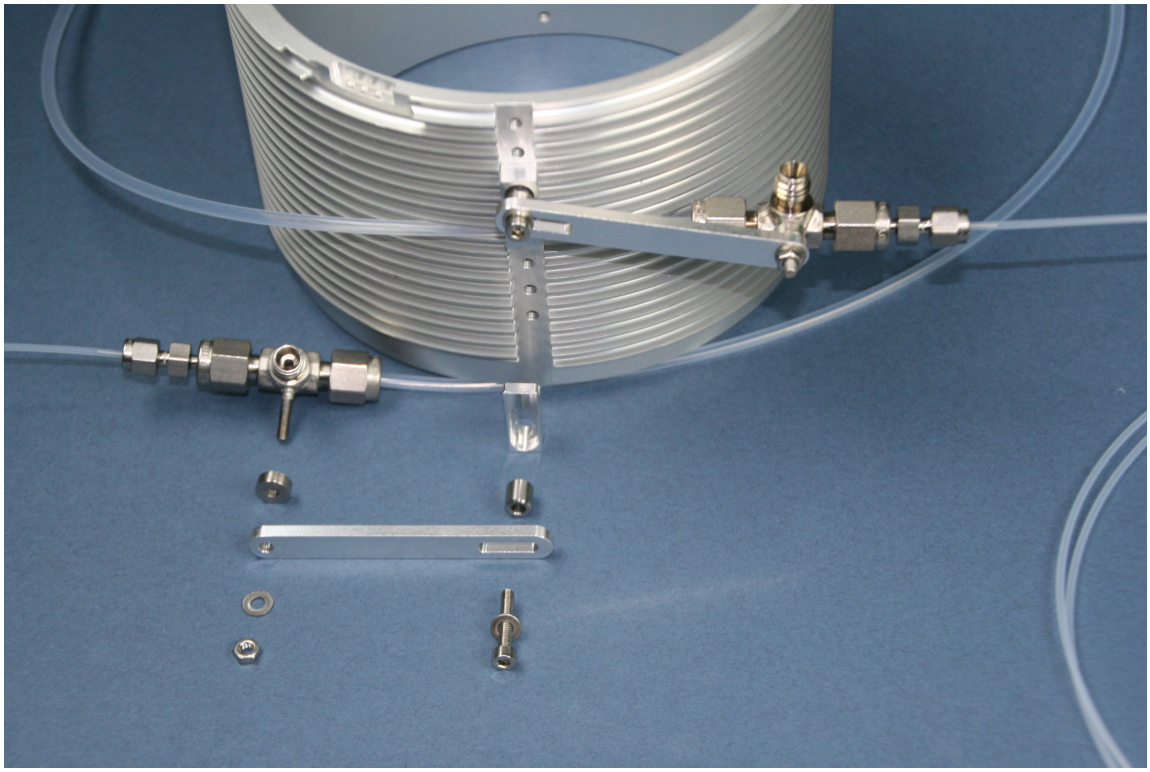
6. Carefully feed the 1/16" tubes through the 1/8" Tee assemblies taking care not to buckle the AF2400 tube and tighten the 1/8" fittings 3/4 turn from finger tight, making sure that the insert is visible.

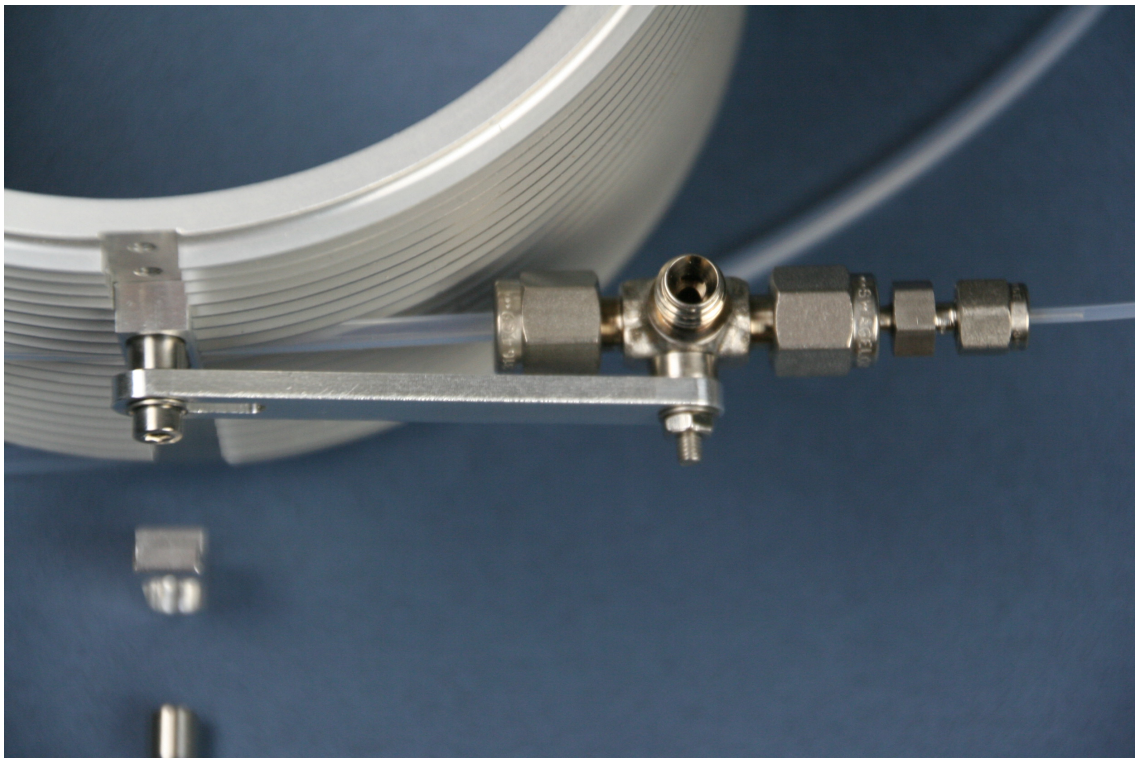


7. Adjust the position of the 1/16” tubes so that the inserts are level and partly inside the 1/16” fittings. Feed on the 1/16” ferrules and nuts and do up 3/4 turn from finger tight.

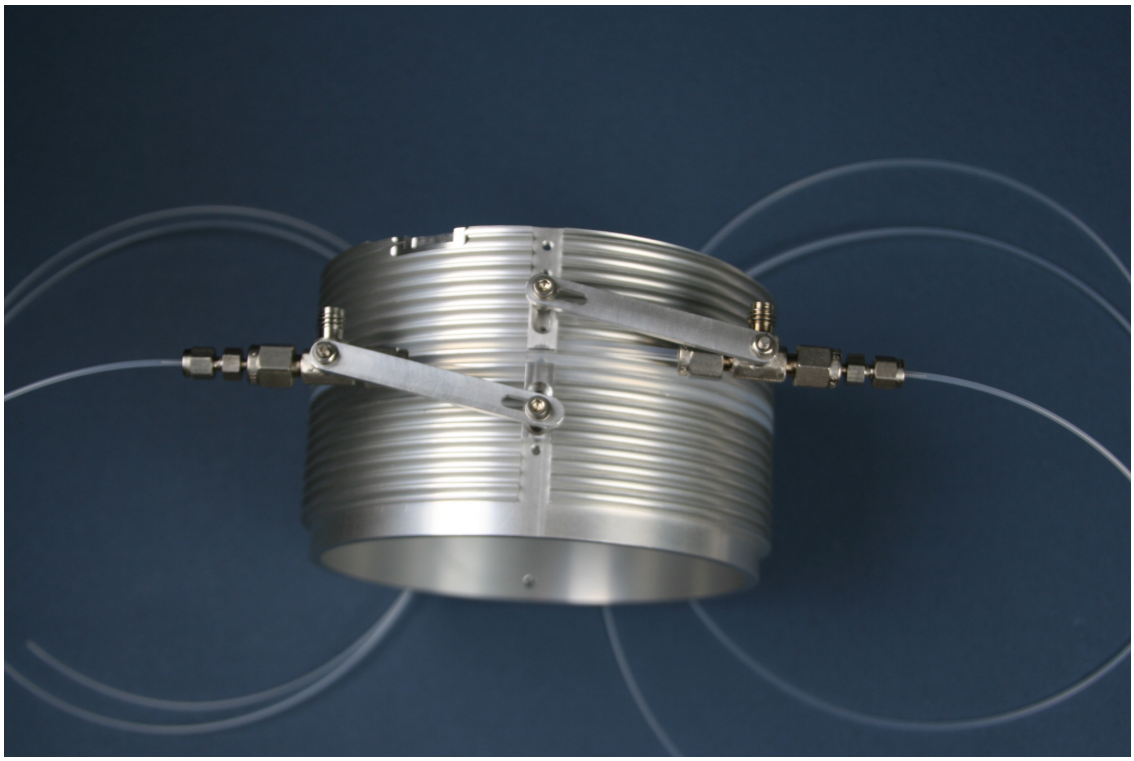


8. Secure one of the tee assemblies into the support bar, locating the tube clamp over the 1/8” tube.





10. Wrap the tube around the mandrel and secure the other end as before.



11. Make sure that the screws and nuts on the assembly are secure.

12. Assemble 1/8” tubes for liquid feeds.