



Series 5400 Continuous Flow Tubular Reactor Systems

Series Number:

5400

Type:

**Bench Top, Cart,
or Floor Stand**

Vessel Sizes, mL:

15 mL - 300 mL

Standard Pressure Rating
MAWP, psi (bar):

**3000 (200) or
5000 (345)**

Maximum Operating
Temperature, °C:

350 or 550

Tubular reactors are always used in a continuous flow mode with reagents flowing in and products being removed. They can be the simplest of all reactor designs. Tubular reactors are often referred to by other names:

- Pipe reactors
- Packed-bed reactors
- Trickle-bed reactors
- Bubble-column reactors
- Ebulating-bed reactors

Single-phase flow in a tubular reactor can be upward or downward. Two-phase flow can be co-current up-flow, counter-current (liquid down, gas up) or, most commonly, co-current down-flow.

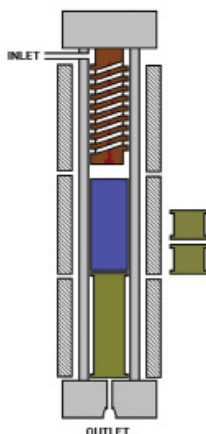
Tubular reactors can have a single wall and be heated with an external furnace or they can be jacketed for heating or cooling with a circulating heat transfer fluid. External furnaces can be rigid, split-tube heaters or be flexible mantle heaters. Tubular reactors are used in a variety of industries:

- Petroleum
- Petrochemical
- Polymer
- Pharmaceutical
- Waste Treatment
- Specialty Chemical
- Alternative Energy

Tubular reactors are used in a variety of applications:

- Carbonylation
- Dehydrogenation
- Hydrogenation
- Hydrocracking
- Hydroformulation
- Oxidative decomposition
- Partial oxidation
- Polymerization
- Reforming

Tubular reactors may be empty for homogenous reactions or packed with catalyst particles for heterogeneous reactions. Packed reactors require upper and lower supports to hold particles in place. Uppermost packing is often of inert material to serve as a pre-heat section. Pre-heating can also be done with an internal spiral channel to keep incoming reagents close to the heated wall during entry, as shown above.



Model 5403 with a 1" inside dia. x 24" length, 3-zone clam shell heater with gas & liquid feed system.

It is often desirable to size a tubular reactor to be large enough to fit 8 to 10 catalyst particles across the diameter and be at least 40-50 particle diameters long. The length to diameter ratio can be varied to study the effect of catalyst loading by equipping the reactor with "spools" to change this ratio.

Temperature is typically controlled by thermocouples located on the outer wall of an externally heated tubular reactor. A moveable internal thermocouple is often employed to observe the temperature changes occurring as the reaction proceeds through the reactor.

Tubular reactor systems are highly customizable and can be made to various lengths and diameters and engineered for various pressures and temperatures.

We provide a split-tube furnace for heating these vessels. Insulation is provided at each end so that the end caps are not heated to the same



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Open 3-Zone Split Tube Furnace with 1" I.D. Tubular Reactor.

temperature as the core of the reactor. The heater length is normally divided into one, two, or three separate heating zones, although it can be split into as many zones as required.

We can furnish either a fixed internal thermocouple in each zone or a single movable thermocouple that can be used to measure the temperature at points along the catalyst bed. External thermocouples are typically provided for control of each zone of the heater.

Gas Feed Systems

Various gas feeds can be set up and operated from a **Gas Distribution Panel**. In order to deliver a constant flow of gas to a reactor, it is necessary to provide gas at a constant pressure to an electronic **Mass Flow Controller**. This instrument will compare the actual flow rate delivered to the set point chosen by the user, and automatically adjust an integral control valve to assure a constant flow. Care must be taken to size these controllers for the specific gas, the flow rate, and the pressure of operation. A mass flow controller needs a power supply and read-out device, as well as a means of introducing the desired set point.

Series 5400 Tubular Reactor System Specifications				
Shaded bar indicates specifications that change within series.				
Model Number	5401	5402	5403	5404
Sizes	3/8 in.	1/2 in.	1.0 in.	1.5 in.
O.D. / I.D. (in.)	0.38 / 0.28	0.50 / 0.37	1.9 / 1.0	2.0 / 1.5
O.D. / I.D. (mm)	9.5 / 7.0	13 / 9.4	48 / 25	51 / 38
Heated Length (in.)	6, 12, 24		12, 24, 36	
Max. Pressure (psi)	3000		5000	3000
Max. Temperature	550		550	350
Support Spools	No		Yes	
Spiral Pre-Heat	No		Yes	
No. Ports in Top Head	1		4	
No. Ports in Bottom Head	1		4	
Internal Thermocouple	Yes			

When ordering mass flow controllers, you will need to specify:

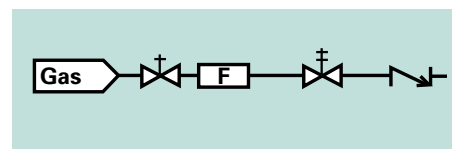
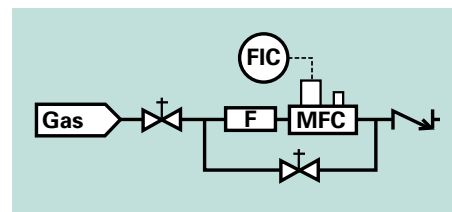
1. Type of gas to be metered (e.g. N₂, H₂, CH₄)
2. Maximum operating pressure of the gas (100 or 300 bar)
3. Maximum flow rate range in standard cc's per minute (sccm)
4. Pressure for calibration of the instrument

Mass flow controllers are available for use to 1500 psi and to 4500 psi. Considerable savings can be obtained if the mass flow controller is to be used only to 1500 psi.

The schematic at right depicts the installation of a mass flow controller for the introduction of gas to a continuous-flow reaction system. Such installations are enhanced with the addition of a by-pass valve for rapid filling.

A purge line can also be added. It is typically used for feeding nitrogen or helium to remove air before reaction or to remove reactive gases before opening the reactor at the end of a run. The purge line includes a shut-off valve, metering valve, and a reverse-flow check valve.

Shut-off valves can be automated when using a 4871 Control system.



Liquid Metering Pumps

High pressure piston pumps are most often used to inject liquids into a pressurized reactor operating in a continuous-flow mode. For low flow rates, HPLC pumps, many of which are rated for 5000 psig, are excellent choices.

Series 5400 Continuous Flow Tubular Reactor Systems



Tubular Reactor System on Floor Stand with 3-zone Flexible Mantle Heater, one Mass Flow Controller, one Liquid Pump, and a High Pressure Gas/Liquid Separator.



Tubular Reactor System on Cart with Flexible Mantle Heater, two Mass Flow Controllers, one Liquid Pump, and Manual Back Pressure Regulator.

Typical flow rates for pumps of this type range up to 10 or 40 mL per minute. Pumps are available to accommodate manual control from their digital faceplate or computer-control from a 4871 Process Controller.

Chemical feed pumps are our recommendation for continuous feeding of liquids when the desired flow rate is greater than 2 liters per hour. Parr can assist with the feed pump selection. We will need to know the type of liquid; the minimum, typical, and maximum desired feed rate; the maximum operating pressure; and any special operating considerations such as explosion proof operation or corrosion possibilities.

Back Pressure Regulators

In addition to supplying gases to a reaction through electronic mass flow controllers, the reactor is kept at a constant pressure by installing a Back Pressure Regulator (BPR) downstream of the reactor. This style of regulator will release products only when the reactor pressure exceeds a preset value.

When a BPR is used in conjunction with mass flow controllers, the user is assured that a constant flow of gas is passing through a reactor, which is being held at a constant pressure. This provides for the highest degree of control and reproducibility in a continuous-flow reactor system.

Cooling Condensers

It is often desired to cool the products of the reaction prior to handling them. For this purpose, tube-and-shell heat exchangers are available to act as the cooling condensers. An adaptation of our standard condensers provides an excellent design. Descriptions and available sizes are found in Chapter 5 of this catalog on page 109.

Gas/Liquid Separators

Tubular reactors operating in continuous-flow mode with both gas and liquid products will also require a Gas/Liquid Separator for smooth operation. The separator is placed downstream



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of the reactor, often separated from the reactor by a cooling condenser. In the separator vessel, liquids are condensed and collected in the bottom of the vessel. Gases and non-condensed vapors are allowed to leave the top of the vessel and pass to the back pressure regulator. It is important to operate the BPR with a single fluid phase to prevent oscillation of the reactor pressure.

The gas/liquid separator can be sized large enough to act as a liquid product receiver that can be manually drained periodically. Many of the non-stirred pressure vessels made by Parr are ideally suited for use as gas/liquid separators. Vessels of 300, 600, 1000, or 2000 mL are commonly chosen.

Control and Data Acquisition Systems

A variety of solutions exist to meet the needs of system operators. System accessories such as heaters, mass flow controllers, and pumps can be obtained with individual control packages to create a manual, Distributed Control System (DCS).

As the number of channels to be controlled increases, economics and convenience will often dictate that the distributed system of individual controllers should be replaced with the computer-based Model 4871 Process Controller (PCC). The 4871 Process Controller is described in detail in Chapter 4 of this catalog beginning on page 95.



This Continuous Flow Stirred Reactor System is on a Cart with our new Modular Frame System. This modular frame allows for easy access and flexibility in hook-ups, accessories, and flow.



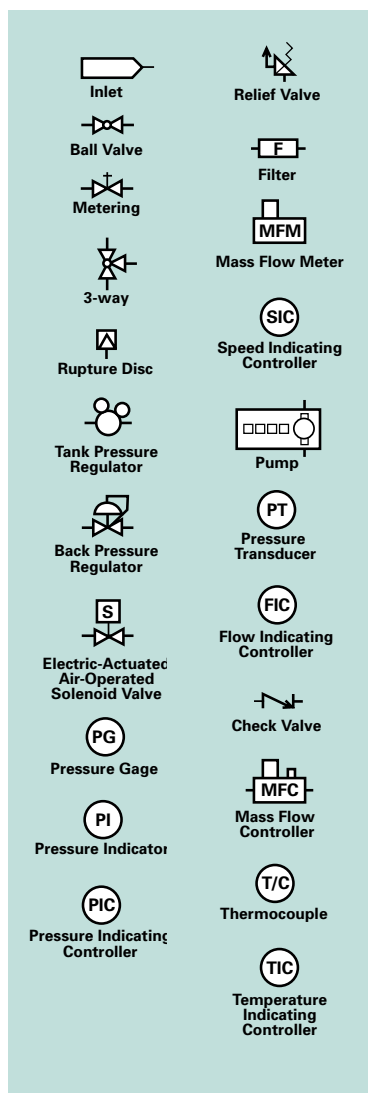
This Tubular Reactor System can be used with its three reactors configured for series or parallel operations.



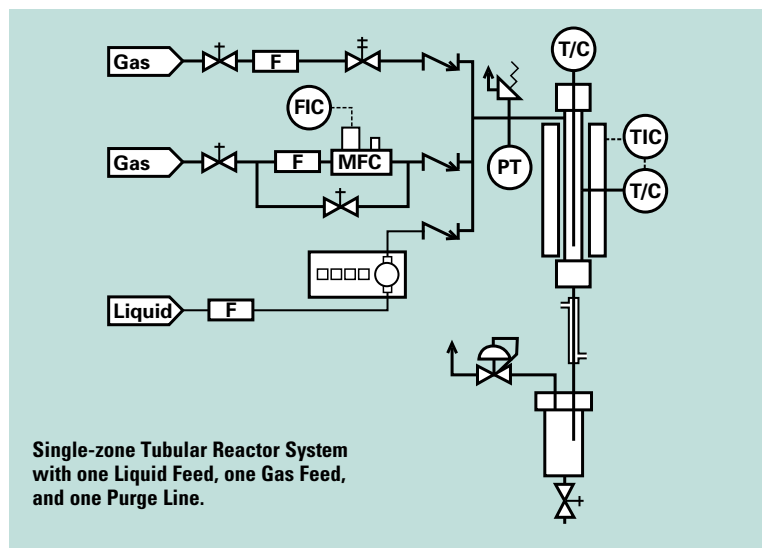
Series 5400 Continuous Flow Tubular Reactors

On this page are schematic representations of typical tubular reactor systems, along with a symbols chart to facilitate understanding. We have provided an ordering number for each of these examples.

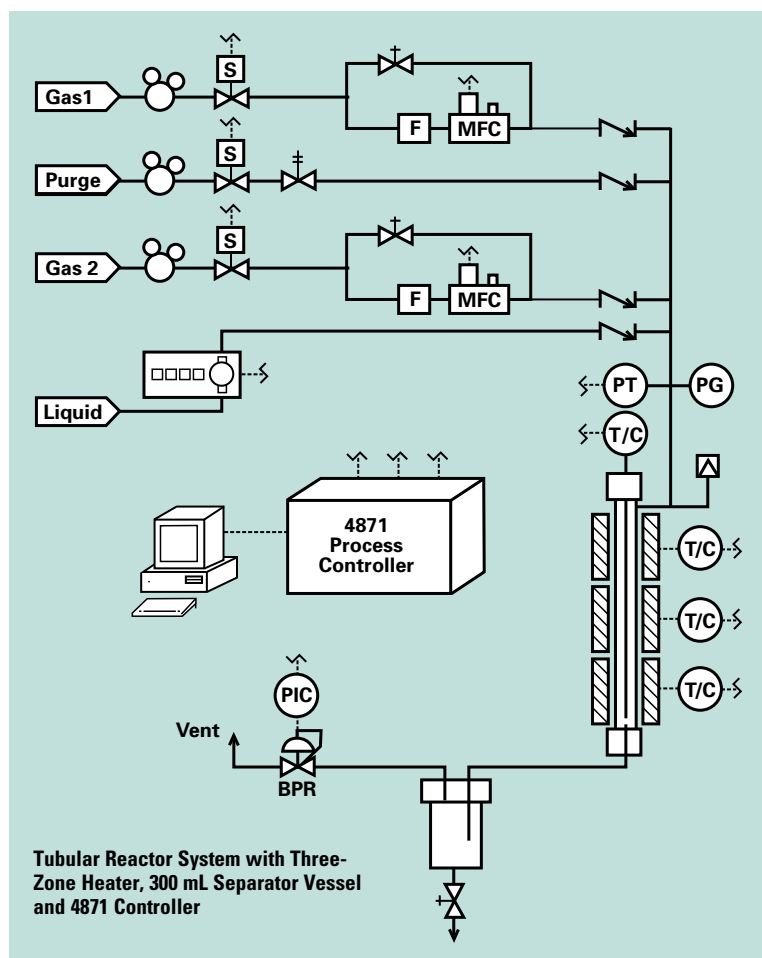
Key to Symbols



Order No. for this system would be:
5402C-SS-115-FM-1500-DCS-GF(1)-PL-LF(1)-ITW-CHX-GLS(300)



Order No. for this system would be:
5403F-SS-230-ST3(24)-3000-PCC-GF(2)-PL-LF(1)-ISP-CSS-ITW-GLS(600)-TR(3)-AP-ASV





Series 5400 Ordering Guide

The Order No. for the Base System is: **5402C-SS-115-ST3(24)-3000-DCS-GF2-LF1-ITW-GLS1000**

A composite identification number to be used when ordering a 5400 Series Reactor can be developed by combining individual symbols from the separate sections below. For more information on how to use this ordering guide, please see page 27.

A Base Model

Model No.	Size
5401	3/8 in.
5402	1/2 in.
5403	1.0 in.
5404	1.5 in.

Add suffix F for Floor Stand mounting
Add suffix B for Bench Top mounting
Add suffix C for Cart mounting

B Materials of Construction

-SS	T316 Stainless Steel
-HC	Alloy C-276
-TI	Titanium
-IN	Alloy 600
-MO	Alloy 400

C Electrical Supply

-115	115 VAC
-230	230 VAC

D Heater Options

-ST1(#)	Split Tube, 1-Zone
-ST3(#)	Split Tube, 3-Zone
-FM(#)	Flexible Mantle
-WJ(#)	Welded Jacket

Add suffix (6), (12), (24), (36) for heated length in inches.

E Maximum Operating Pressure

-1500	1500 psi / 100 bar
-3000	3000 psi / 200 bar
-4500	4500 psi / 300 bar

F Controller

-PCC	PC-based Process Control (4871-style)
-DCS	Distributed Control System

G Custom Options

-GF(#)	Number of Gas Feeds
-PL	Purge Gas Feed Line
-LF(#)	Number of Liquid Feeds
-ISP	Internal Pre-heat Spiral (5403/5404 only)
-CSS	Catalyst Support Spools (5403/5404 only)
-ITW	Internal Thermowell, with T/C
-CHX	Cooling Heat Exchanger
-GLS(#)	Gas/Liquid Separator, Volume (300), (600), (1000), (2000) in mL.
-SPH	Separator Heater
-TR(#)	Number of Gas Tank Regulators
-AP*	Automated Pressure Control
-ASV*	Automated Shut-off Valves

*Available only with 4871 Process Control

H Certifications

-No Symbol	No Certification
-ASME	ASME Certification
-CE/PED	European Community Certification/Pressure
-P	Parr Certification