Chapter 3
Specialty & Custom Reactors

Inside this chapter you will find:

Specialty & Custom Reactor Systems

Parr Instrument Company designs and builds a number of Reactor Series that fall under the category of Specialty Reactors. These reactor systems embody the spirit of innovation that has made Parr the world leader in laboratory pressure apparatus.

Series 5000 Multiple Reactor System (MRS)

The Parr Series 5000 Multiple Reactor System has been designed to provide an integrated system for running multiple reactions simultaneously and applying the principles of high throughput experimentation to reactions conducted at elevated temperatures and pressures.

Series 5400 Tubular Reactor Systems

For continuous flow systems, Parr Tubular Reactors have been developed with continuous reactant feed, a variety of pre-heat and heating options with sample collection systems and product handling. Varying degrees of automation and data collection are available.

Custom-designed Stirred Reactor System for a proprietary process.

Series 5000 Multiple Reactor System (MRS)

Parr Fluidized Bed Tubular Reactor with dual zone Mantle Heater.

Parr Tubular Reactor with single zone Mantle Heater.

Pressure vessel with multiple 1-inch diameter windows installed.

Specialty & Custom Reactor Systems

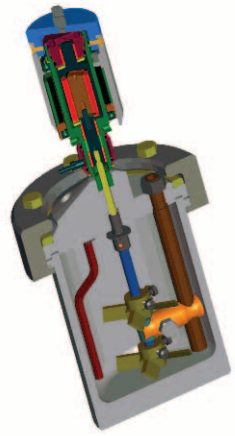
Parr Instrument Company has invested heavily in new technology, new machinery and new software. We have created a "mass customization" process that allows us to progress from a new design to manufacture with a high degree of speed, automation and economy.

Mass Customization

Most of our customers have unique needs, proprietary processes and in some cases, design constraints. Our standard products come with a large variety of options and accessories to help meet those needs. But if you need a higher pressure, higher temperature or a different volume, we can usually do that too. We are very experienced at combining feed systems with batch or continuous flow reactors, adding product handling options and a variety of detectors for analysis of the results. Our controllers can automate the process, control individual components, datalog and archive the data. This is called mass customization.

3-D CAD System

This system allows us to create new designs or modify existing ones with speed and accuracy. You can "see" what the product will look like, rotate it, see inside and check for clearances. It is a virtual prototype.



State of the Art Mill/Turn Machining Centers

CAD designs can be automatically translated into machine language in our machine shop to make the item. This saves time and allows our machinists to begin the process of making the product immediately. All of the machining operations are computer controlled, including the selection of tools for all six axis of work.

New Software

We use the same software to make reactors that Boeing® uses to make airplanes. We constantly update, modify and purchase new programs to keep pace with changing needs, improve turn-around times and manage our resources efficiently.

Custom-designed Valve Heating Oven.

Parr utilizes the latest technology in milling and manufacturing techniques to produce your custom system to the highest level of precision possible in the field today.

5000 Multiple Reactor System (MRS)

Series Number:
5000

Type:
Multiple Vessel

Stand:
Bench Top

Vessel Mounting:
Moveable

Vessel Sizes, mL:
45 and 75

Standard Pressure MAWP, psi (bar):
3000 (200)

Standard Maximum Operating Temp., °C:
225 w/ FKM O-ring
275 w/ FFKM O-ring
300 w/ PTFE Flat Gasket

Model 5000 Multiple Reactor System, six 75 mL Vessels with Flat-Gaskets and Head-Mounted Valves, shown with included 4871 Process Controller.

The Parr Series 5000 Multiple Reactor System has been designed to provide an integrated system for running multiple reactions simultaneously and applying the principles of high throughput experimentation to reactions conducted at elevated temperatures and pressures.

The principle features of the new instrument include:

- Six reactors with internal stirring.
- Operating pressures to 3000 psi.
- Operating temperatures to 300 °C.
- Individual temperature control.
- Continuous individual pressure monitoring.
- Computer control and data logging
- Manifold system for rapid turn around and to allow two different input gases.
- Volumes and reactor geometry designed for three phase reactions.
- Flexible Control Software.

Stirred Batch Reaction Vessel

This multiple reaction system has been designed around a vessel with 75 mL total volume. This will accommodate between 15 and 40 mL of liquid reactants which is close to the minimum volume appropriate for heterogeneous catalytic reactions.

The vessel valves and accessories are designed for maximum operating pressures up to 3000 psi at operating temperatures up to 300 °C. A system with 45 mL vessels is also available.

Stirring System

All six vessels are stirred with a single magnetic stirrer system specifically designed and built for this application. The magnetic drives and fields are focused on the stirrer bars within each vessel. High strength compact magnets are used to provide coupling forces which will operate through the heaters and vessels. The stirring speed of the stirrer bar is variable from 0-1200 rpm. All vessels will have the same stirring speed during a single run of the apparatus. This arrangement ensures that the difference in reaction rates between vessels run in parallel are due to set conditions other than variations in stirrer speed.

Heaters

The external heaters surround the vessel walls for rapid and uniform heating and temperature control. Each vessel is individually temperature controlled. The 250-watt heater used on each vessel produce heating rates up to 15 °C per minute.

5000 Multiple Reactor System (MRS)

Series 5000 Pressure Reactor System Specifications				
Shaded bar indicates specifications that change within series.				
Model Number	**5000**			
Sizes, mL	45	75		
No. of Reaction Vessels	6			
Maximum Pressure	3000 psi (200 bar)			
Maximum Temperature				
with FKM O-ring	225 °C			
with FFKM O-ring	275 °C			
with PTFE Flat Gasket	300 °C			
Closure				
with O-ring	Screw Cap			
with Flat Gasket	Screw Cap (6 Cap Screws)			
Material of Construction	T316SS			
Process Controller	Model 4871			
Analog Inputs	6 Temperature			
	6 Pressure			
	1 Motor Speed			
Analog Outputs	1 Stirrer Speed (Optional)			
Digital Outputs	6 PID Temperature Control			
Temperature Measurement	6 Thermowells			
Heater Style	6 Band Heaters, Aluminum Block			
Heater Power Watts	250W Per Station, 1500W Total			
Stirrer Motor Type	Manual or Computer Controlled			
Stirrer Style	PTFE- or Glass- Coated Magnetic Stirrer Bar			
Electrical Supply				
Volts, AC	115 or 230			
Maximum Load, amps	15 / 7.5			
Vessel Dimensions				
Inside Diameter, inches	1.2		1.5	
Inside Depth, inches	2.69 Flat Gasket, 2.50 O-ring			
Weight of Vessel, pounds	3 (w/ Panel-mounted valves)		6 (w/ Head-mounted Valves)	
Dimensions	Width, in.	Depth, in.	Height, in.	Weight, lb.
Heater	25.75	9.25	2.875	31
Stirrer	28	9.5	7.625	12
4871 Controller	13	11	15	14
Manifold, Remote	26.5	9.0	15	36
Manifold, Head Mount	26.5	9.0	15	18
Other options available. See Ordering Guide, visit www.parrinst.com, or call for more information.				

Operating Modes

The Series 5000 Multiple Reaction System provides an apparatus for running up to six reactions in parallel to build a database for comparing and optimizing operating conditions. The user can design experiments to:

- Run all reactions at the same temperature and pressure while varying catalyst loading or reactant concentrations to optimize these parameters.
- Run all reactors with identical loads varying pressures at a common temperature to study the effect of pressure on reaction rates.
- Run individual reactors with individual loading and temperature and pressure to screen multiple options for activity.

A comparison of the plots of pressure drop versus time within the reactors running under parallel conditions will usually be the most useful means of measuring reaction rates and comparing operating conditions. The internal thermocouple also provides a means of detecting temperature changes due to exothermic reactions.

Reactor Options

As Parr customers have come to expect with our line of laboratory pressure reactor equipment, these reactors are offered with a number of options which permit the user to configure the system to their reactions and intended operating conditions. These options include:

O-ring or Flat Gasket Seals. Vessels with O-ring seals are closed by simply tightening the screw cap down hand tight. The maximum operating temperature will depend upon the O-ring material. When equipped with FKM (Viton®) O-rings operating temperatures up to 225 °C are permitted. By substituting FFKM (Kalrez®) O-rings this limit can be raised to 275 °C. Careful consideration of chemical compatibility must also be given when selecting O-ring materials. PTFE gaskets can be used to temperatures up to 300 °C and offer virtually universal chemical compatibility. Six cap screws are used to develop the sealing forces on the PTFE gaskets in this design.

5000 Multiple Reactor System (MRS)

MRS with individually controlled Gas Burettes.

Head Configuration. Each reaction vessel is equipped with an inlet valve, exhaust valve, safety rupture disc, and pressure transducer in addition to an internal thermocouple. The user can choose to have the valves, transducer and rupture disc mounted on a gage block connected directly to the vessel head, or remotely mounted on the back panel and connected to the valve with a quick coupling flexible high pressure hose. The head mounted design makes it possible to remove pressurized vessels from the heater/stirrer assembly or to prefill the vessels in a remote location. The remote panel mounted arrangement connects all of the pressure inlets/outlets to each vessel with a single flexible connection for the greatest ease of handling.

The heads of these vessels can also be modified to include a dip tube for liquid sampling, or a cold finger for cooling.

Materials of Construction. Type 316 Stainless Steel is the standard material of construction for both the vessel with its wetted parts and the gage block assemblies exposed to vapors. For investigators working with systems containing strong mineral acids or other more corrosive systems these vessels can be made of most of the Parr standard materials of construction.

Stirrer Configuration. Stirring is accomplished by use of either PTFE coated or glass coated magnetic stirrer bars.

Thermocouple Configuration. Thermocouples are mounted inside the vessel for the best temperature monitoring and control. The thermocouples are protected by stainless steel sheaths which are inserted into a protective thermowell. These thermowells make it easy to install and remove thermocouples from the vessels, and also provide additional chemical and mechanical protection for the thermocouple.

RTD temperature sensors can be substituted for users who prefer this method of temperature measurement.

We also offer a redundant thermocouple option with the thermocouple positioned in contact with the heater.

Gas Manifold. The gas inlet manifold can be designed to handle both a purge gas, usually nitrogen, and a reactant gas, usually hydrogen. This can be set up to automatically fill each vessel to the same initial pressure or to manually fill each vessel to a unique operating pressure.

4871 Process Controller

The Series 5000 Multiple Reaction System is controlled by a dedicated Parr 4871 Process Controller. A detailed description of this controller is found in Chapter 4 of this catalog, pages 95-100.

For this application the controller is set up to provide:

- Temperature monitoring and PID control of each individual reactor.
- Pressure monitoring of each individual reactor.
- Data logging of temperature and pressure in each reactor.
- Control and logging of the common stirring speed of the reactors.

The controller provides Ramp & Soak programming for individual reaction vessels, digital inputs and outputs for interlocks, alarms or other safety features, and additional analog and digital inputs and outputs to control flow meters or other accessories which might be added at some future date. The user's control station is a PC running any current Windows operating system. A simplified graphical user interface has been designed for the control and monitoring of the Series 5000 Multiple Reaction System. The PC is used strictly as the user interface and data logging module. All control actions are generated in the 4871 Process Controller (not the PC).

5000 Ordering Guide

The Order No. for the Base System is: **5000-T-SS-115-P-MV-2000-MB-CC**

A composite identification number to be used when ordering a 5000 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
5000	45 or 75 mL

B Gasket / Maximum Temperature

-JV	FKM O-ring, 225 °C
-JK	FFKM O-ring, 275 °C
-T	PTFE Flat Gasket, 300 °C

C Materials of Construction

-SS	T316 Stainless Steel
-MO	Alloy 400
-IN	Alloy 600
-HB	Alloy B-2
-HC	Alloy C-276
-CS	Alloy 20
-TI2	Titanium Grade 2
-ZI	Zirconium Grade 702 of Grade 705

D Electrical Supply

-115	115 VAC
-230	230 VAC

E Thermocouple

-No Symbol	Type J (Std.)
-K	Type K
-RTD	RTD

F Valve Mounting

-H	On Head
-P	On Manifold Panel

G Inlet Valve

-AC	Automatic Check Valve
-MV	Manual Valve

H Transducer Range

-1000	0-1000 psi
-2000	0-2000 psi
-3000	0-3000 psi

I Stirrer Type

-MB	Magnetic Bar Stirrer, PTFE
-GB	Magnetic Bar Stirrer, Glass

J Stirring Control

-M	Manual
-CC	Computer Controlled
-RPM	Digital RPM Display

K Certifications

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

L Options

-SV	Dip Tube with Sampling Valve
-CF	Cold Finger
-MPG	Manifold Pressure Gage
-FMH	Flexible SS Hoses
-R-TC	Redundant Thermocouples
-RCS	Reactor Cooling Support

Other Available Options

Glass Liner
PTFE Liner

M Spare Parts Kit

-5009	Spare Parts Kit for 5000 Series

Parr also designs and builds a wide range of multiple reactor systems with overhead magnetic drive stirrers. These have been based upon our Series 4590 Micro Reactors, Series 4560 Mini Reactors, and our Series 5500 High Pressure Compact Reactors. Please see page 87 of this catalog for examples. Contact our Customer Service Department for details and proposals for custom systems.

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

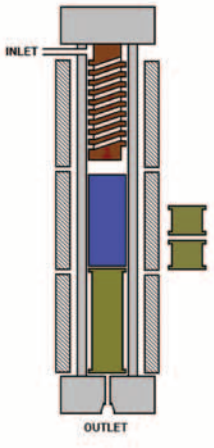
Single-phase flow in a tubular reactor can be upward or downward. Two-phase flow can be co-current up-flow, counter-current (liquid down, gas up) or, most commonly, co-current down-flow.

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

Series 5400 Continuous Flow Tubular Reactor Systems

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

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			

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

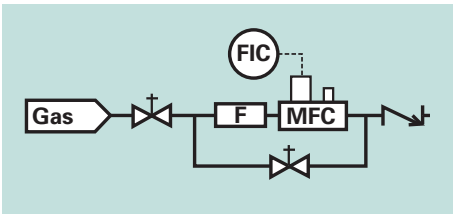
Various gas feeds can be set up and operated from a **Gas Distribution Panel**. In order to deliver a constant flow of gas to a reactor, it is necessary to provide gas at a constant pressure to an electronic **Mass Flow Controller**. This instrument will compare the actual flow rate delivered to the 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.

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

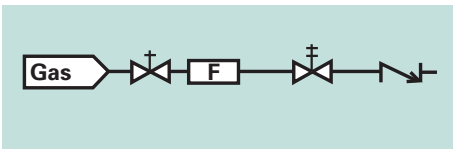
1. Type of gas to be metered (e.g. N2, H2, CH4)
2. Maximum operating pressure of the gas (100 or 300 bar)
3. Maximum flow rate range in standard cc's per minute (sccm)
4. Pressure for calibration of the instrument

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

Series 5400 Continuous Flow Tubular Reactor Systems

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.

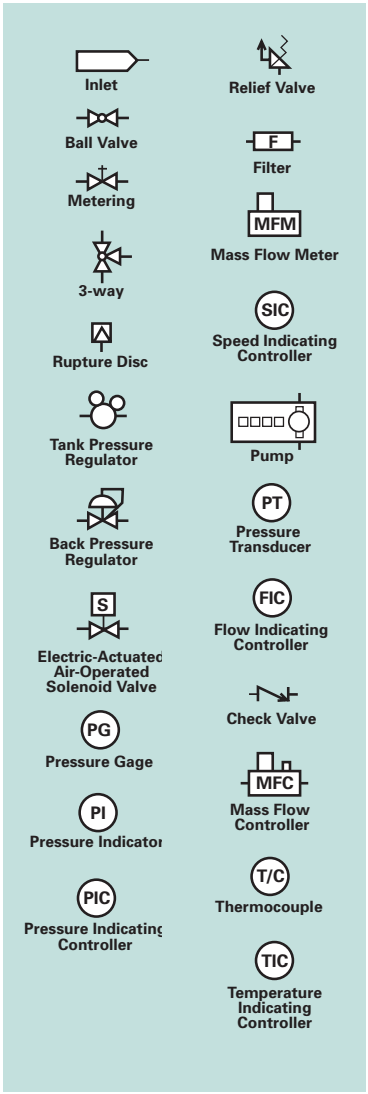
This Continuous Flow Stirred Reactor System is on a Cart with with our new Modular Frame System. This modular frame allows for easy access and flexibility in hook-ups, accessories, and flow.

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

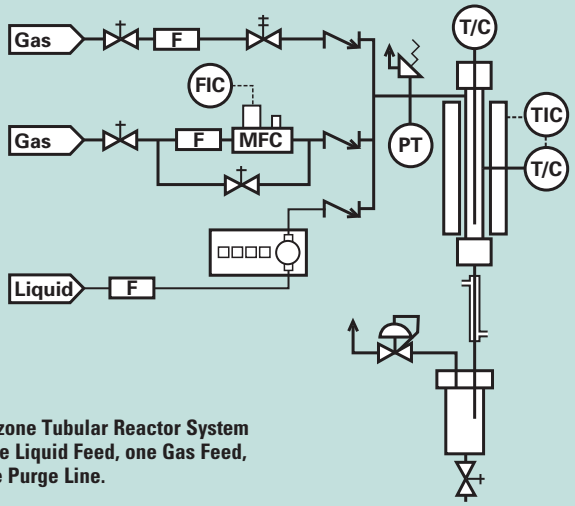
Series 5400 Continuous Flow Tubular Reactors

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

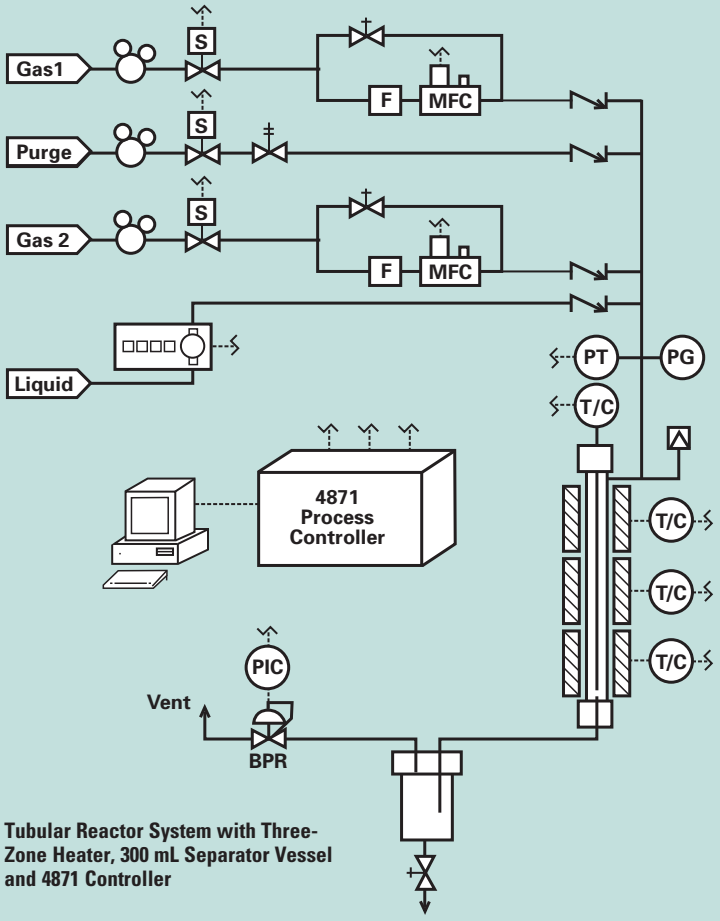


Order No. for this system would be:
5402C-SS-115-FM-1500-DCS-GF(1)-PL-LF(1)-ITW-CHX-GLS(300)



Single-zone Tubular Reactor System with one Liquid Feed, one Gas Feed, and one Purge Line.

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



Tubular Reactor System with Three-Zone Heater, 300 mL Separator Vessel and 4871 Controller

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

Fluidized Bed Reactors

Parr Fluidized Bed Reactors are used extensively in the chemical process industries. The distinguishing feature of a fluidized bed reactor is that the solids bed or catalytic particles are supported by an up flow of gas. This reactor provides easy loading and removing of catalyst. This is advantageous when the solids bed must be removed and replaced frequently. A high conversion with a large throughput is possible with this style of reactor. Such reactors inherently possess excellent heat transfer and mixing characteristics.

Fluidized beds have been significantly utilized in chemical processes, in which parameters such as diffusion or heat transfer are the major design parameters. Compared to packed bed, a fluidized bed has notable advantages such as better control of temperature, no hot spot in the bed, uniform catalyst distribution and longer life of the catalyst. The desirability of using fluidized beds is dependent on achieving good mixing between the solids and the suspending fluid.

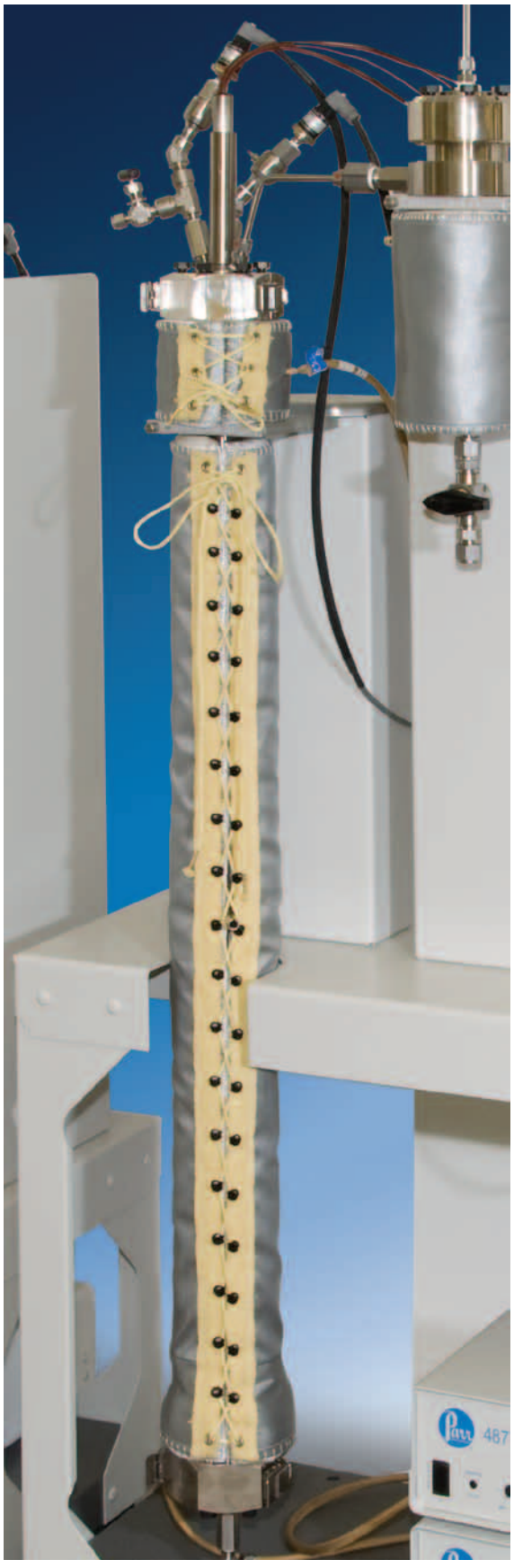
Nearly all the significant commercial applications of fluidized bed technology concern gas-solid systems. Applications of fluidized bed reactors include but are not limited to Fisher-Tropsch synthesis, catalytic cracking of hydrocarbons and related high molecular weight petroleum fractions. Gasification in a fluidized bed can be utilized to convert coal, biomass and other waste materials into synthesis gas.

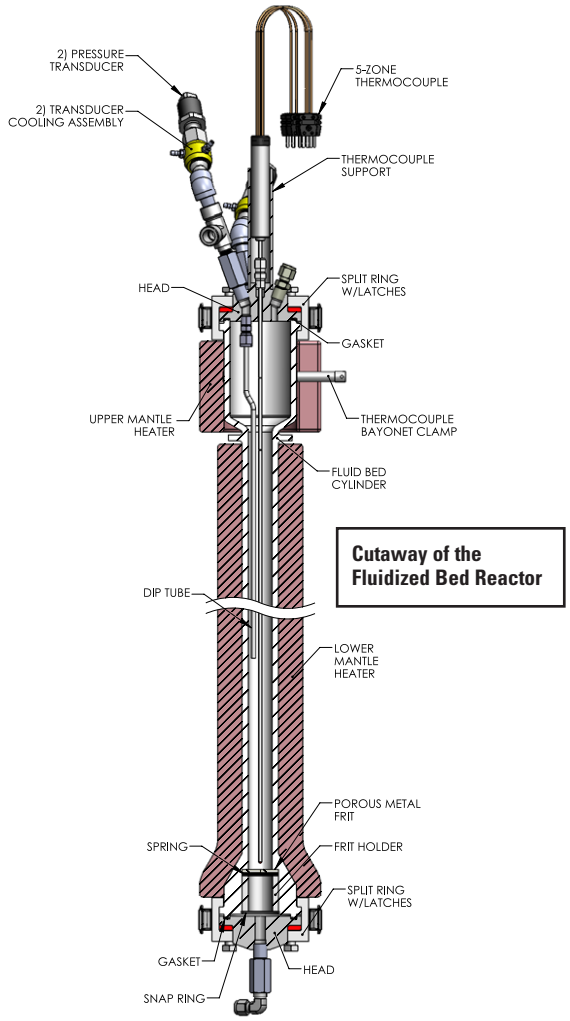
The Parr Fluidized Bed Reactor features the Reactor (A), a Heated Cyclone Separator (B), a Cooling Condenser (C), and a 600 mL Product Receiver (D).

The reactor system pictured on this page includes the following key components:

- A gas handling and mixing sub-system used to blend and regulate the flow of reactant gas to the bottom of the reactor.
- The reactor is roughly one meter long with a 2.5 cm ID. The lower portion of the reactor incorporates an easily replaced porous metal gas diffusion plate and the top of the reactor widens abruptly to form a disengaging zone for the fluidized bed. Separate heaters are provided for both the main reactor and disengaging zone. A multipoint thermocouple is provided for monitoring the internal reactor temperature distribution.
- A heated cyclone separator or filter is provided immediately downstream of the reactor to capture the fines resulting from particle attrition.
- The reaction products are then cooled by a condenser and collected in a 600 mL product receiver.
- The system pressure is maintained by a dome loaded back pressure regulator.
- All system functions and parameters are monitored and maintained by a Parr 4871 Process Controller (not shown, see Chapter 4, page 95).

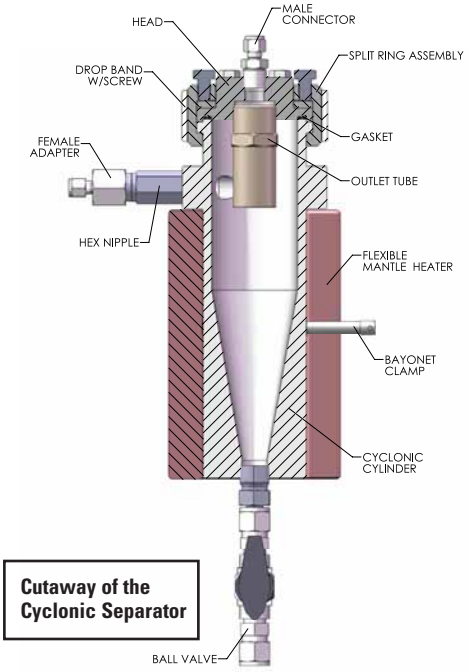
Fluidized Bed Reactors





Cutaway of the Fluidized Bed Reactor

The Flexible Mantle Heater attaches in two pieces and provides even heating to the entire length of the reactor.



Cutaway of the Cyclonic Separator

Bio-Fuels and Alternative Fuels Research Systems

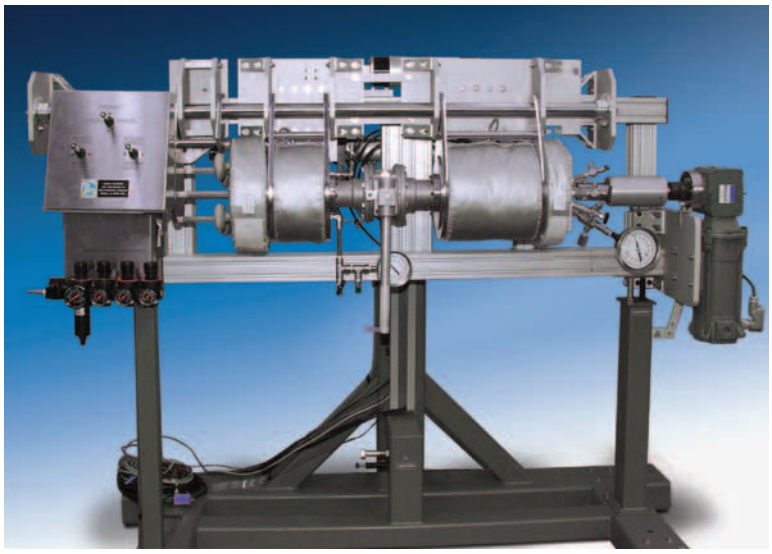
Custom Reactor Systems like the above Bio-Fuels Research System are a product of collaboration between the researchers and the Engineers at Parr Instrument Company.

Parr Instrument Company manufactures non-stirred vessels for the decomposition of biomass in ammonia and steam. Parr stirred reactors, including a new horizontal reactor technology, have been designed for research processes that include hydrogenation, isomerization, and metathesis reactions. In addition, fully customizable continuous-flow tubular reactor systems have been developed with continuous reactant feed and product handling capabilities.

The above photo illustrates a complete pilot scale plant used for hydrogenating feedstock that originates from a proprietary fermentation process. The system is used to develop and optimize the process conditions necessary for a much larger demonstration-scale system, ultimately leading to full-scale production of renewable fuels.

The system is comprised of five major subsystems: from left to right, a gas and liquid feed system, the jacketed tubular reactor module including a reactant pre-heater and circulating bath, product recovery and backpressure control, an auto-sampler and a Parr 4871 Control System (not pictured). The system is completely automated and includes an auto-sampling subsystem that periodically samples the reactor output stream in order to accurately monitor product quality.

Bio-Fuels and Alternative Fuels Research Systems



The reactor shown in the two images above and right has a five gallon capacity, and is used for stirring horizontally. Pneumatic controls on the left can tilt the system upright to open the bottom drain valve. The product is filtered and collected in the lower heated sample collection vessel. This system is used for making fabric from biomass. Most synthetic fabric is made from oil.

Horizontal Reactors

Stirring biomass such as straw or grasses is not easy to do in a vertical reactor. A new technology has been developed to do it horizontally. In the system pictured to the right, a 1 liter reactor can be disconnected to tilt vertically for loading or tilt horizontally for stirring. A heavy-duty stirring motor and double anchor stirrers are used. Another option would be to tilt upside down for discharge. A 4848 controller monitors the temperature and pressure and controls the stirring speed. A flexible mantle heater (not pictured) is used to obtain temperatures up to 350 °C. Maximum pressure is 1900 psig for this system.

Parr Horizontal Stirred Reactor System, 1 liter Fixed Head Vessel, shown with 4848 Reactor Controller with optional expansion modules.

GTO (Gas-To-Oil) System

Parr GTO System

This system incorporates three tubular reactors that can be configured as required to operate in a strictly parallel fashion or in a cascade arrangement where the products from one reactor are immediately directed to a second reactor. This type of system can support reaction schemes including but not limited to the Fisher-Tropsch process, methanation reactions, steam reforming and other similar processes.

The Fisher-Tropsch process converts carbon monoxide and hydrogen into oils or fuels that can substitute for petroleum products. The reaction uses a catalyst based on iron or cobalt and is fueled by the partial oxidation of coal or wood-based materials such as ethanol, methanol, or syngas. This reaction scheme offers a promising route to producing economical renewable transportation fuels. By carefully controlling the temperature and oxygen content, resulting products can range from syngas to "green diesel".

One of the unique features of this system is a gas blending subsystem capable of mixing up to four reactant gases followed by a controlled delivery of this blended mixture to each of the three reactors via dedicated mass flow controllers.

Downstream components for each reactor include a heat exchanger/condenser, a gas/liquid separator (product receiver) and a fully automated back pressure regulator. The system includes support for introducing liquid reactants via a high pressure metering pump. The system comes completely automated with the addition of the highly versatile 4871 Process Controller (not pictured, see chapter 4, page 95).

Combinatory Chemistry & High-Throughput Screening

16 Station Multiple Reactor System

This system is a combination of sixteen standard 4560 Mini Reactors with heaters, valves, pressure gage and rupture disc assemblies and two 4871 Process Controllers with sixteen 4875 Power Controllers. It allows the user to run multiple reactions simultaneously, applying the principles of high-throughput experimentation. Individual variables that can be controlled are gas mixtures, liquids, catalysts or other solids, stirring speed, temperature, pressure and time.

12 Station HPCL System

This system makes use of the lower cost 5500 High Pressure Compact Lab Reactors that feature a modified stand, aluminum block heaters, removable vessels and a standard gage block assembly. A control system (not pictured) automates the process, monitors the parameters and collects the data. Parr also provides a standard Multi Reactor System in the 5000 MRS pictured below.

5000 Multiple Reactor System (MRS)

The 5000 MRS comes standard with six reactors, a gas distribution panel, magnetic stirring motor and stirring bars, and a 4871 Controller to monitor and control the parameters. For more information on the 5000 MRS see page 72.

Supercritical CO2

A supercritical fluid is any substance at a temperature and pressure above its critical point. It can diffuse through solids like a gas and dissolve materials like a liquid. Near the critical point, small changes in pressure or temperature result in large changes in density, allowing many properties of a supercritical fluid to be "fine-tuned". Supercritical fluids are suitable as a substitute for organic solvents in a range of industrial and laboratory processes. Carbon dioxide is one of the many commonly used supercritical fluids. Applications that involve supercritical fluids include extractions, nano particle and nano structured film formation, supercritical drying, carbon capture and storage, as well as enhanced oil recovery studies. Parr has provided systems at one time or another for all the aforementioned applications.

The supercritical fluid extraction system pictured to the right and diagramed below incorporates a 1.2 liter vessel rated for use at 4300 psig (300 bar) at temperatures to 300 °C. The system includes an automated inlet valve and an air piloted back pressure regulator which is used to facilitate a controlled pressure release at the end of the test. The vessel is heated with a 1500W flexible mantle heater. The feed system (not pictured) includes a pump capable of delivering up to 1.5 gallons per minute (5.7 lpm) of liquid carbon dioxide at pressures up to 4000 psig (275 bar).

Supercritical CO2 System shown with automated control features.