Stirred Reactors and Pressure Vessels

Designing and Building Quality Pressure Apparatus for Over 100 Years

Chapter Four

This pdf is just one chapter from our Catalog 4500. Please refer to all eight chapters to make the proper equipment choice for your needs.
Chapter 4
Tubular Reactor Systems

Inside this chapter you will find:
5400 TUBULAR REACTOR SYSTEMS
FLUIDIZED BED REACTOR SYSTEMS
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 a variety of 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.

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.

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 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.
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. 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 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. Cooling condensers are available for this purpose. An adaptation of our standard condensers provides an excellent design.
**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 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) based on our 4838 and 4848 Controllers.

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).
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**

- **Inlet**
- **Relief Valve**
- **Ball Valve**
- **Filter**
- **Needle Valve**
- **Metering**
- **3-way**
- **Rupture Disc**
- **Mass Flow Meter**
- **Pressure Gage**
- **Mass Flow Controller**
- Electric-Actuated Air-Operated Solenoid Valve
- **Pressure Indicating Controller**
- **Speed Indicating Controller**
- **Tank Pressure Regulator**
- **Back Pressure Regulator**
- **Mass Flow Meter**
- **Flow Indicating Controller**
- **Pump**
- **Pressure Transducer**
- **Thermocouple**
- **Pressure Indicating Controller**
- **Temperature Indicating Controller**
- **Check Valve**
- **Process Controller**
- **Vent**
- **BPR**

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

Order No. for this system would be:
5402B-SS-115-ST1(6)-1500-DCS-GF(1)-PL-LF(1)-ITW-CCD-GLS(300)-MPC

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

<table>
<thead>
<tr>
<th>Model No.</th>
<th>Size (O.D. / I.D.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5401</td>
<td>3/8 in. (0.38” / 0.28”)</td>
</tr>
<tr>
<td>5402</td>
<td>1/2 in. (0.50” / 0.37”)</td>
</tr>
<tr>
<td>5403</td>
<td>1.0 in. (1.9” / 1.0”)</td>
</tr>
<tr>
<td>5404</td>
<td>1.5 in. (2.0” / 1.5”)</td>
</tr>
</tbody>
</table>

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

**B** Materials of Construction

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

**C** Electrical Supply

- 115: 115 VA, 50/60Hz
- 230: 230 VAC, 50/60Hz

**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.]

**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 (4838-style)

**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 Movable T/C
- IZT: Internal, Zoned, Fixed T/Cs
- CCD: Cooling Condenser
- GLS(#) Gas/Liquid Separator (300, 600, 1000, 2000 mL)
- SPH: Separator Heater
- MPC: Manual Pressure Control
- APC* Automated Pressure Control
- ASV(#) Automated Shut-off Valves (1-12)

*Available only with 4871 Process Control (PCC)

**H** Certifications

- No Symbol: No Certification Required
- PARR: Parr Certification
- ASME: ASME Certification
- PED: PED Certification
- C: China
Fluidized Bed Reactors are used extensively in the chemical process industries. The distinguishing feature of a fluidized bed reactor is that the bed of solid particles or catalyst is 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 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 6, page 101).
The Flexible Mantle Heater attaches in two pieces and provides even heating to the entire length of the reactor.

Flexible Mantle Heaters are wrapped around this 30”-long Fluidized Bed Reactor and the Cyclonic Separator to maintain temperatures to 350 °C. This system is also equipped with two gas feeds with automated shut-off valves, automated pressure control, and a Model 4871 Process Controller (not shown).