

A. Design and specification of Bench-scale Low-cost Reactor (BLR)

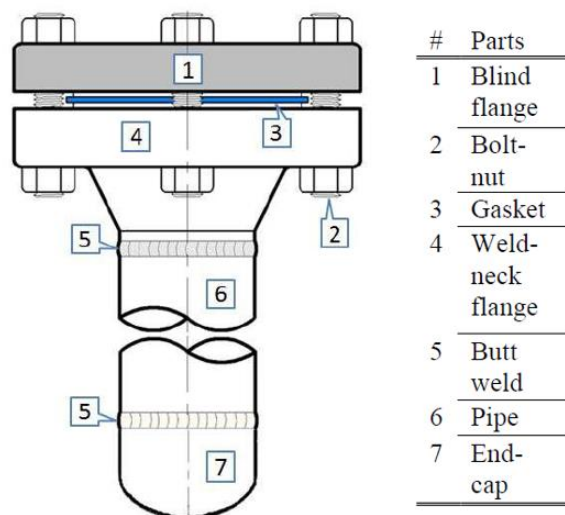


Figure 1. Structure of a low-cost HTC reactor

Table 1. Specification of the BLR

General	Value
Operational Temperature	200 °C
Pressure limit	25 bar
Material	Stainless Steel 1.4404 (316L)
Tentative Dimension of Body	
Size	DN 100
Length (pipe + weld neck flange)	180.00 mm
Outer Diameter	114.30 mm
Wall Thickness (10S)	3.05 mm
Inner Diameter	108.20 mm
Inner volume of main body	1.64 L
Inner volume of end cap	0.33 L
Total volume	1.97 L

Figure 1. shows the structure of the BLR. The specifications of the reactor are shown in Table 1. Allowable working pressure of the proposed material (1.4404 – 10S) ranges from 55 bar at 50 °C to 38 bar at 500 °C. Below are some comments to be noted.

1. The main body of the reactor will be constructed by circumferential welding of pipe-fitting materials: weld neck flange, pipe and endcap.

2. The reactor has a volume of 2 L. The length of the reactor given in Table 1 can be modified according to the volume of an endcap.

3. Overpressure valve, pressure gauge, temperature gauge, rupture disc and steam drain valve will be installed to the blind flange (see Figure 2). Specifications of these instruments and estimated price can be found in the **Appendix**.

4. To avoid over-heating of the pressure gauge and the over pressure valve, they will be installed through a T-fitting and a cooling element.

5. The temperature gauge (face - stem) will be installed using a compression fitting (sliding on stem) or a thermowell, and it is positioned to have: i) approximately 100 mm distance between the gauge face and the blind flange, to avoid over-heating and ii) at least 180 mm of stem length below the blind flange, to immerse the minimum insertion length of 120 mm (gauge-specific vale, provided in technical data sheet) in the target media for temperature monitoring. The stem length of 290 mm is designed to cover 10 mm - thick blind flange and 50 mm - depth end cap.

6. A thread type rupture disc will be installed. In case that the blind flange cannot accommodate all equipment, the rupture disc will be installed together with the steam drain valve using a T-fitting.

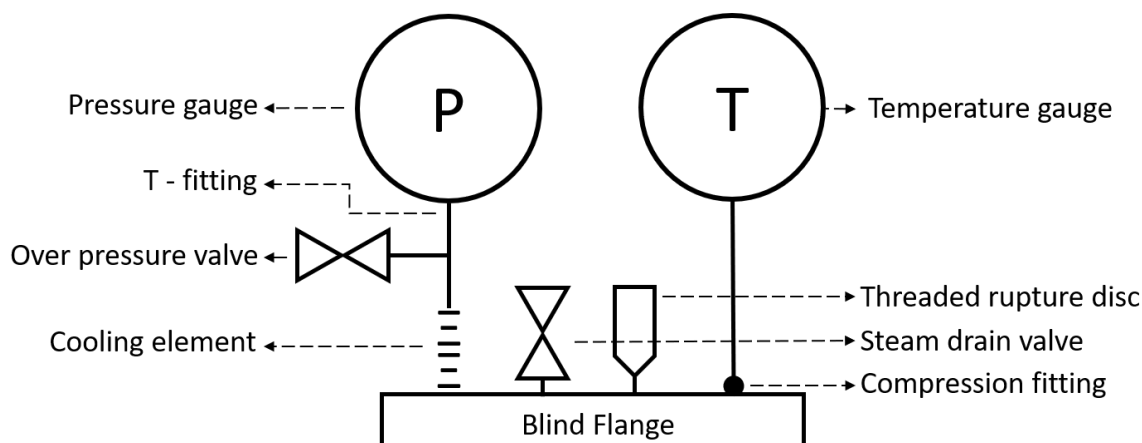


Figure 2. Installation of equipment to the reactor

- The connection method for equipment installation can be selected by manufacture (e.g. size and type of thread, welding).

B. Design and specification of Pilot-scale Low-cost Reactor (PLR)

Table 1. Specification of the PLR

General	Value
Operational Temperature	200 °C
Pressure limit	20 bar
Material	Stainless Steel 1.4404 (316L)
Tentative Dimension of Body	
Size	DN 150
Length (pipe + weld neck flange)	500.00 mm
Outer Diameter	168.28 mm
Wall Thickness (10S)	3.40 mm
Inner Diameter	161.48 mm
Inner volume of main body	10.23 L
Inner volume of end cap	1.10 L
Total volume	11.33 L

The PLR has a similar structure and function to the BLR in a scaled-up volume around 10 L. Specification of PLR is given in Table 2. Allowable working pressure of the proposed material (1.4404 – 10S, DN 150) ranges from 41 bar at 50 °C to 29 bar at 500 °C. Below are some comments to be noted.

- The main body of the reactor will be constructed by circumferential welding of pipe-fitting materials: weld neck flange, pipe and endcap.
- The same equipment designed in BLR will be installed to PLR except following three aspects: i) the overpressure valve for PLR has 20 bar limits, ii) the rupture disc has 30 bar of bursting pressure (specified in the appendix) and iii) the stem of the temperature gauge for PLR has 470 mm length.
- The reactor will be certified according to the relevant safety regulation (PED 2014/68/EU).
- The connection method for equipment installation can be selected by manufacture (e.g. size and type of thread, welding).

Appendix

1. Temperature gauge

Provider: Wika

Bimetal thermometer, stainless steel version

Specifications according to data sheet: TM 55.01

Case: stainless steel

Stem material: stainless steel

Model: R 5526, nominal size 63, location of stem radial

Connection design: 4, compression fitting, sliding on stem

Unit: °C

Scale range: 0 °C ... 300 °C

Process connection: G 1/2 B

Stem diameter: 8 mm

Insertion length L1: 290 mm

Window: polycarbonate

Connector location: radial bottom

Manufacturer logo: *WIKA*

Accuracy class: class 1 per EN 13190

serial number on dial: Serial number *...*

Order code: R5526 -4-C1N-GD-C290EZZ-ZZZZ TB FZZZESZSVID-AZ1ZZZZZ1ZZZZ

Estimated price without VAT – CHF 231

https://www.wika.co.uk/55_en_co.WIKA?ProductGroup=72403

2. Pressure gauge

Provider: Wika
Bourdon Tube Pressure Gauges, Safety Pattern
Series EN 837-1
Model: 232.30
Specifications according to data sheet: PM 02.04
Measuring system: stainless steel
Case filling: without
Nominal size: 063 mm
Measuring range: gauge pressure range
Scale range: 0...40 bar
Process connection: G 1/2 B
Connector location: lower mount
Window: polycarbonate
Pointer: standard pointer
Accuracy class: class 1.6
Material pressure element: Measuring System 316 SS
Ingress protection: IP 65
Permissible medium temperature: + 200 °C
Permissible ambient temperature: -40 ... +60 °C
Pressure Gauge Standard: International (standard Europe)
Manufacturer logo: *WIKA*
stop pin on dial: at zero
with Serial number
Permissible ambient temperature: -40 ... +60 °C
Order code: 232.30-C-BG440Z-GD-UZEZCZZ-ZZZZ 313D41ZI3W0ZZ2Z-IZZZZZZ121ZZ
Article No.: 14281288
Estimated price without VAT – CHF 170
https://www.wika.co.uk/232_30_233_30_en_co.WIKA?ProductGroup=72390

3. Over pressure valve

Provider: FRANZ GYSI GZ
Safety valve "GYSI-GZ" serie 851
in gunmetal, angle type, spring loaded,
with open spring housing, seal in PTFE,
Process connection: male thread DN 1/2" and outlet female threaded outlet DN 1"
Type BSP-P according ISI 228/1,
Set pressure: **25 bar** for BLR and **20 bar** for PLR
Article No: 901015
Estimated price without VAT – CHF 270
<https://fgysi.ch/sortiment/gysi-gz-typ-851-ptfe-d-g-f-f-k-s>

4. Steam drain valve

Provider: Swagelok
Bleed Valve
Material 316 SS (stainless steel)
Process connection: 1/2" ISO (G 1/2 B) male thread
Fluorocarbon FKM O-ring
Pressure-temperature rating: 419 bar at 454 °C
Ordering code: BVM8RT-SH
Estimated price without VAT – CHF 90
<https://www.swagelok.com/de-DE/product/valves/bleed-and-purge>

5. Cooling element

Provider: Wika

Cooling element for pressure measuring instruments

Model 910.32, for threaded attachment Connections for G ½ B (EN 837)

5 Cooling fins

Article No: 14109815

Estimated price without VAT – CHF 220

https://www.wika.co.uk/910_32_en_co.WIKA?ProductGroup=72400

6. Thermowell (optional)

Provider: Wika

Thermowell to accommodate the stem of the Temperature gauge

TW55-6 Form 4 F2=26 mm L=280 mm

Connection [N]: G 1/2

Total length [L]: 280 mm

Installation length [U1]: variable

Cone length [U]: 125 mm

Tip diameter [V or F3]: 12,5 mm

Bore [B or d1]: 7,0 mm

Technical data according to data sheet: TW 95.55

https://www.wika.co.uk/tw55_en_co.WIKA?ProductGroup=72411

7. Threaded rupture disc

For **BLR**

Provider: SITEC

Article number of the safety head (disc holder): 720.5032

Process connection: 1/4" - M16 x 1.5

Rupture disc bursting pressure: 50 bar (at ambient temperature)

Expected bursting pressure in operational temperature range around 200 °C: 36 bar

Estimated price without VAT – CHF 245 (for both holder and disc)

For **PLR**

Provider: Büchiglas

Bursting disc assembly 30 bar DN 6, 1/4" Ga, UKB

Article number: 46.40046

Bursting pressure at 200 °C: 30 bar

Estimated price without VAT – 1160 CHF

* In case of malfunctioning of the over pressure valve (OPV), the rupture disc will burst and release pressure to avoid damaging the reactor and surrounding. The bursting pressure of rupture disc is selected to be higher than the set pressure of the OPV and lower than the pressure rating of reactor at a given temperature range. Detailed values are provided in Table 3.

Table 3. Bursting pressure of rupture disc and pressure rating (maximum operational pressure) of reactor

Temperature (°C)	Theoretical water vapor pressure (bar)	BLR (OPV set pressure 25 bar)		PLR (OPV set pressure 20 bar)	
		Bursting pressure of rupture disc (bar)	Pressure rating of reactor (bar)	Bursting pressure of rupture disc (bar)	Pressure rating of reactor (bar)
200	14.9 - 18.4	36.0	52	30	39
210	18.1 - 23.1	35.5			
220	21.8 - 28.7	35.0			
230	26.0 - 35.3	34.5			
240	30.7 - 43.0	34.0			
250	36.0 - 52.1	33.5	48		34

The theoretical water vapor pressure will exceed the pressure limit of rupture discs for both BLR and PLR in the range of 230-240 (°C). This temperature range can be considered as conservative limit for safety assurance. Inclusion of dry material in the feedstock for hydrothermal carbonization would induce rapid pressure development, and the safety devices react in lower temperature range.