Design and manufacture of an 8 kg sodium alanate hydrogen storage

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Contents

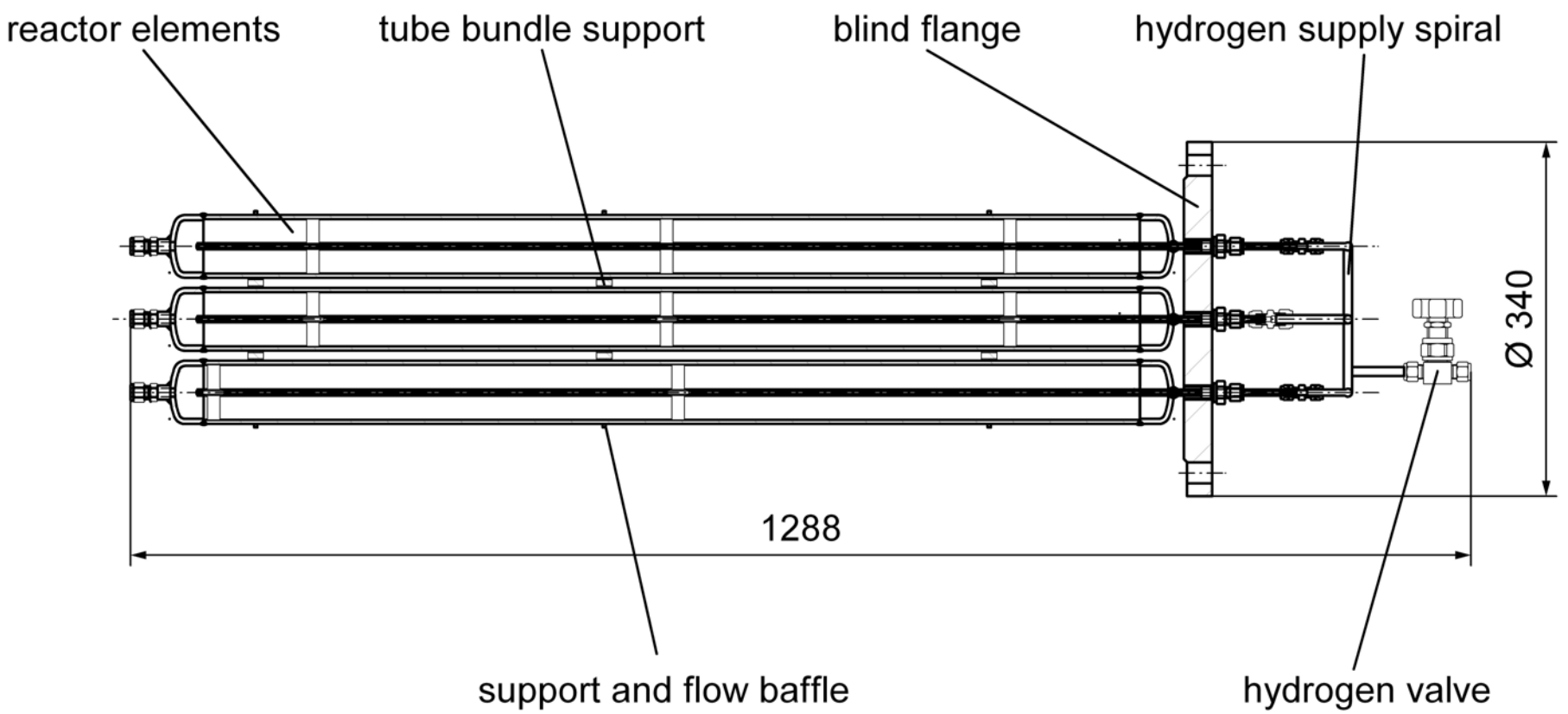
- Selected features of the storage design
- Masses and costs of the components of the storage
- Assembly of the storage
- Predicted performance data of the storage

Considered geometries

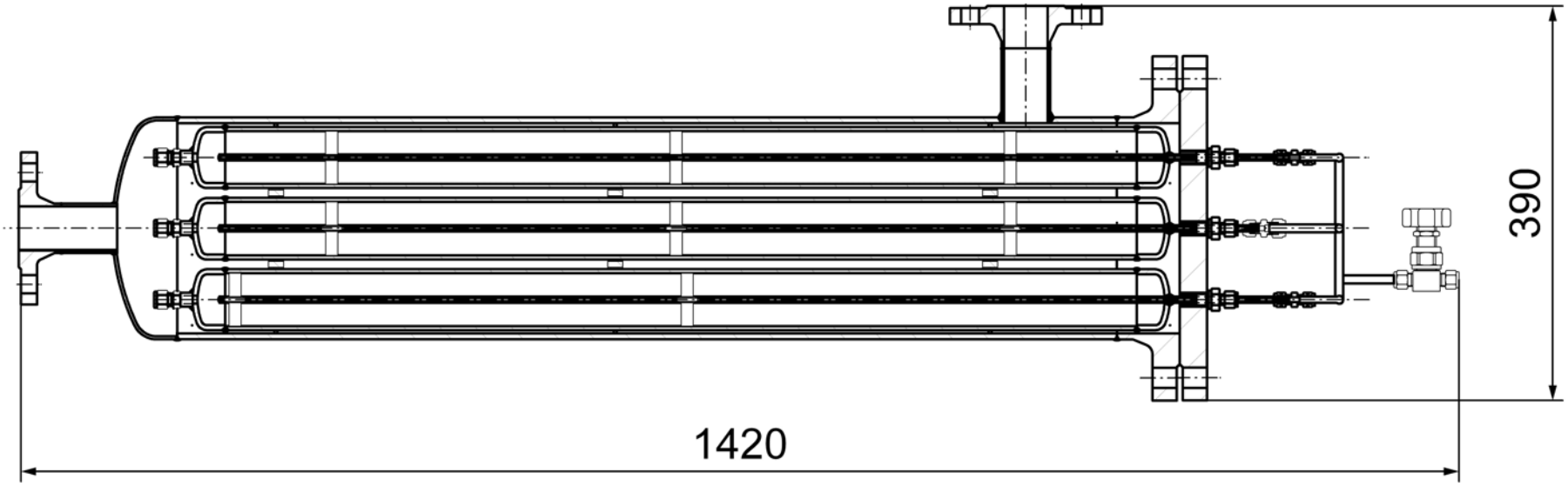
- Tubular reactors with metal hydride inside tubes including investigation of different flow patterns on the cooling oil side:
  - single-pass
  - single-pass with displacement bodies
  - multi-pass
- Directly cooled reactor bed
- Reactors of plate heat exchanger type

- Taking also into account aspects like available production facilities and measures in case of repair we selected:
- **Bundle of 7 tubular reactors with metal hydride inside tubes and single pass on the cooling oil side.**

Hydrogen side (Glove box parts)

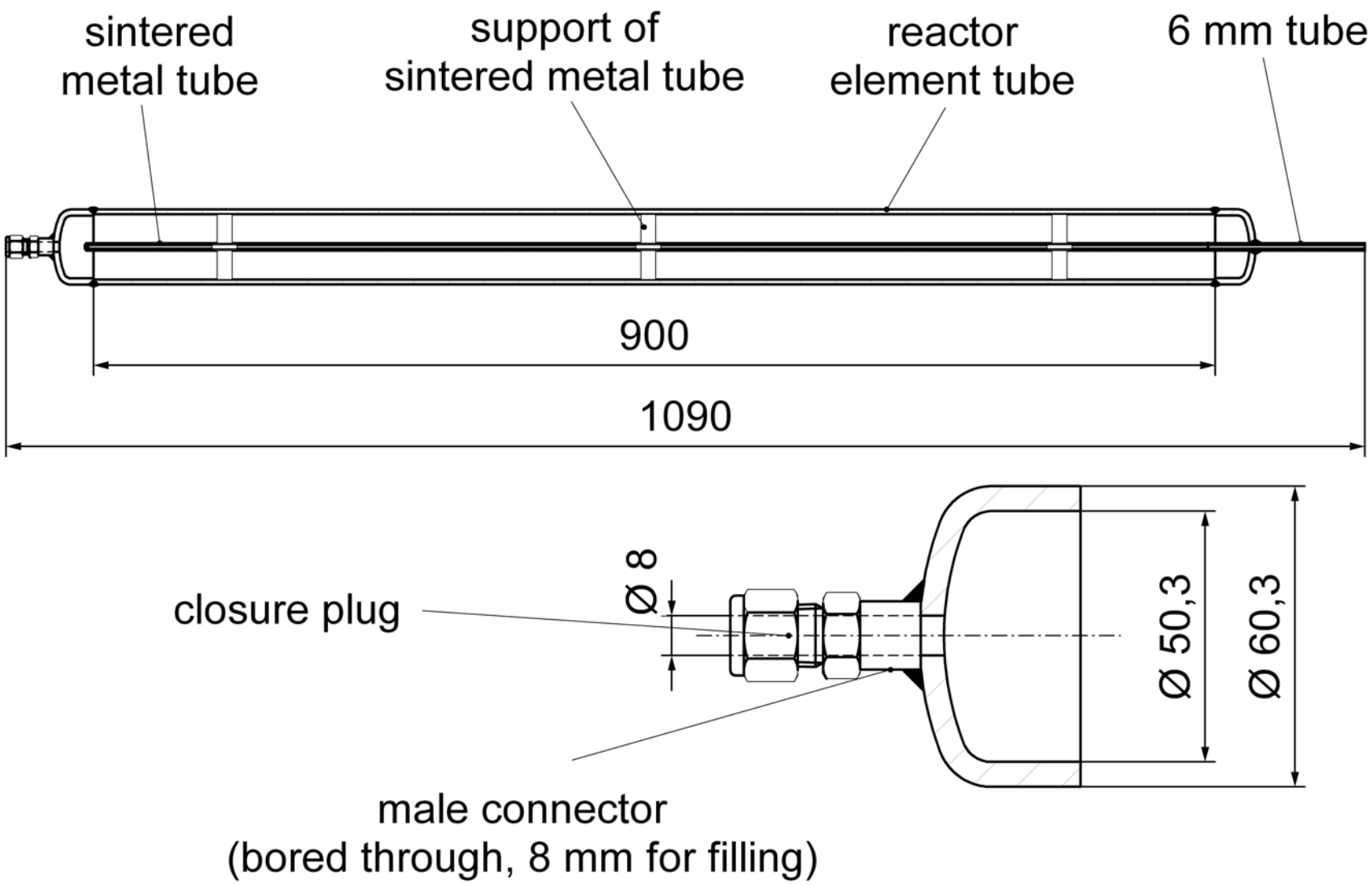


General arrangement drawing

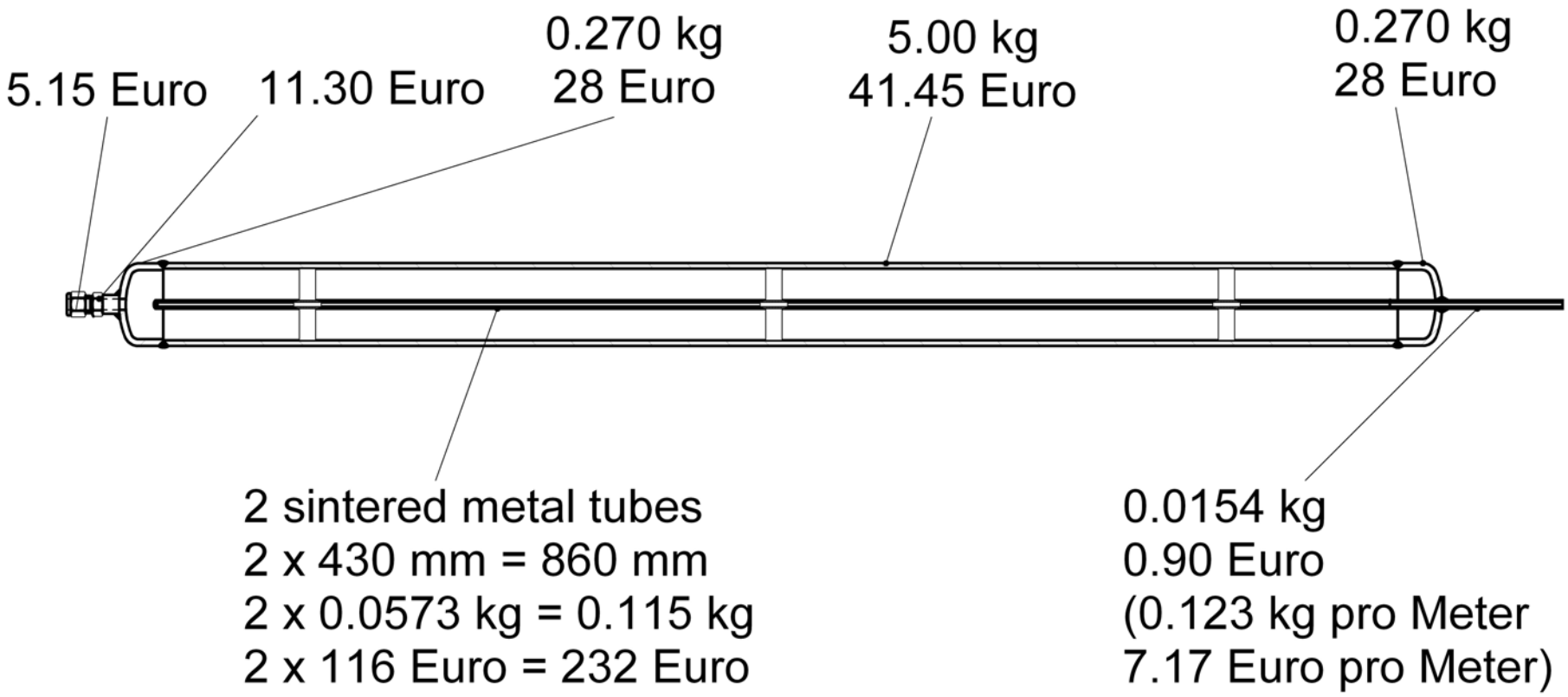


- Enveloping box: 1420 mm x 390 mm x 340 mm
- Hydrogen: 400 g, 200 mol, 4.5 m^3_N
- Active Material: 8 kg, 13.3 l
- Heat transfer oil (Marlotherm X): 12 kg, 15 l

Single reactor element (Filling and proof test)



Single reactor element (masses and costs)



One reactor element has a mass of 5.74 kg and costs 346.80 €.

Storage densities of single reactor element

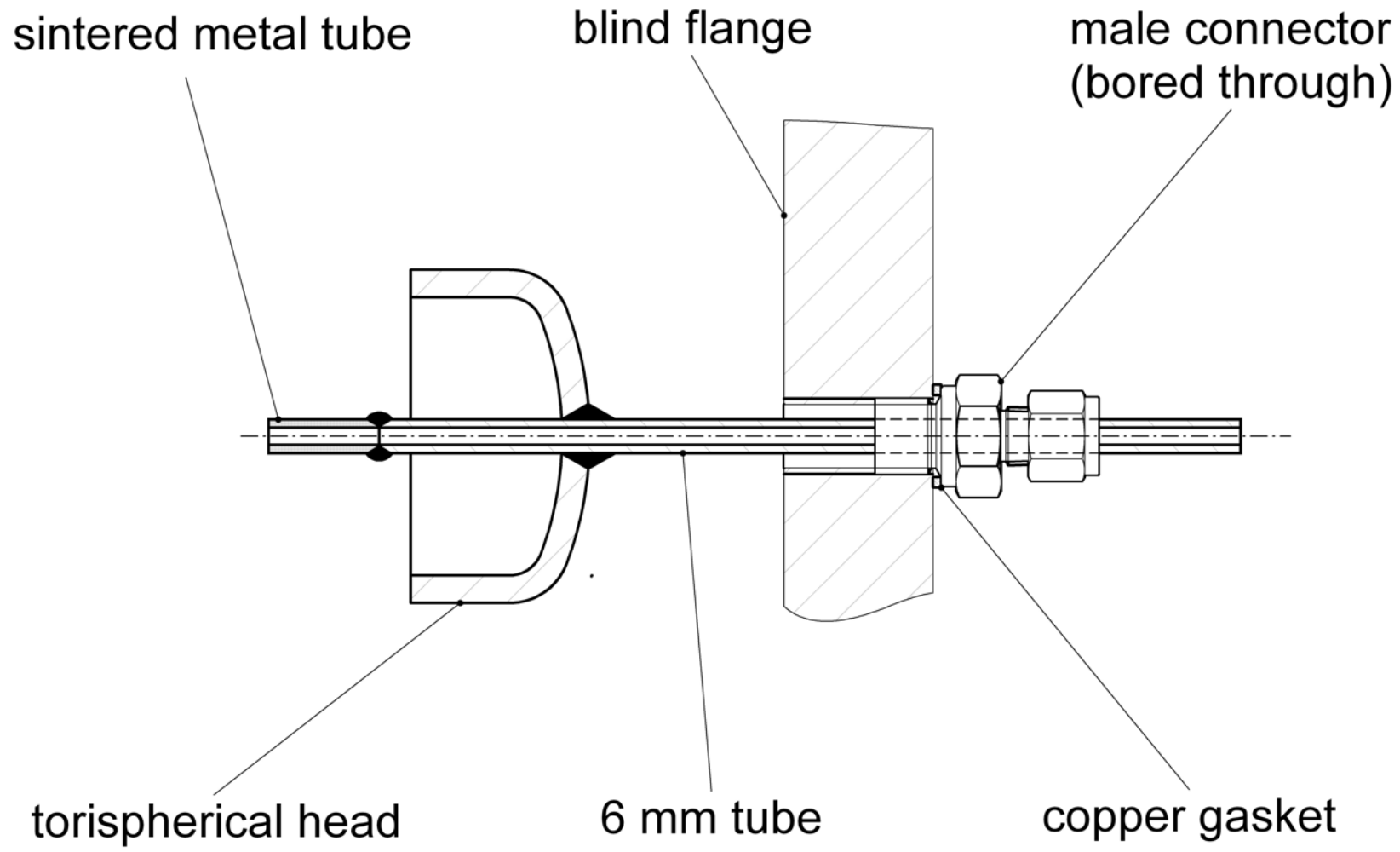
$$\frac{m_{H_2}}{m_{reactor} + m_{MeH}} = \frac{60g}{5740g + 1200g} = 0.865\%$$

Material: 5%, DOE 2010: 6%

$$\frac{m_{H_2}}{V_{reactor}} = \frac{60g}{2.86l} = 21\frac{kg}{m^3}$$

Material: 30 kg/m^3, DOE 2010: 45 kg/m^3

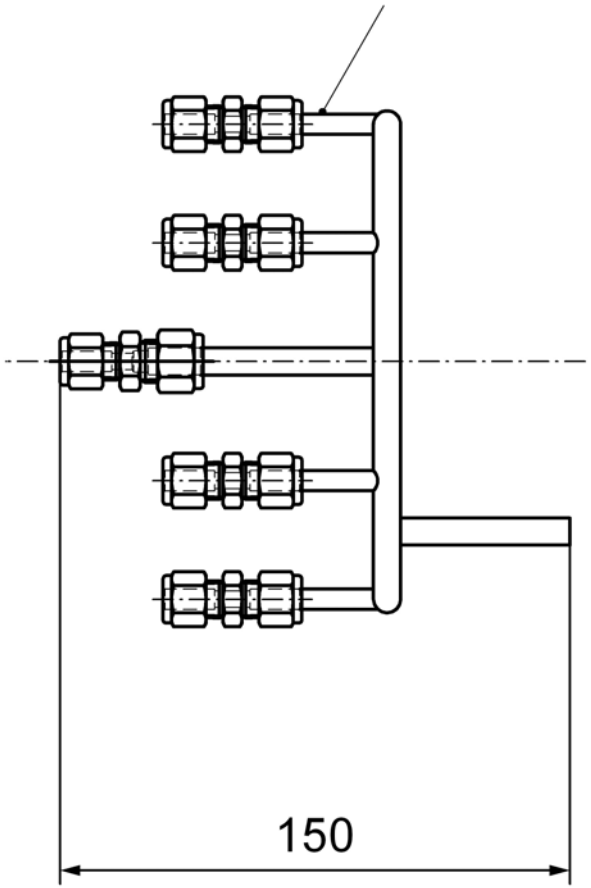
Realisation of reactor element feedthrough

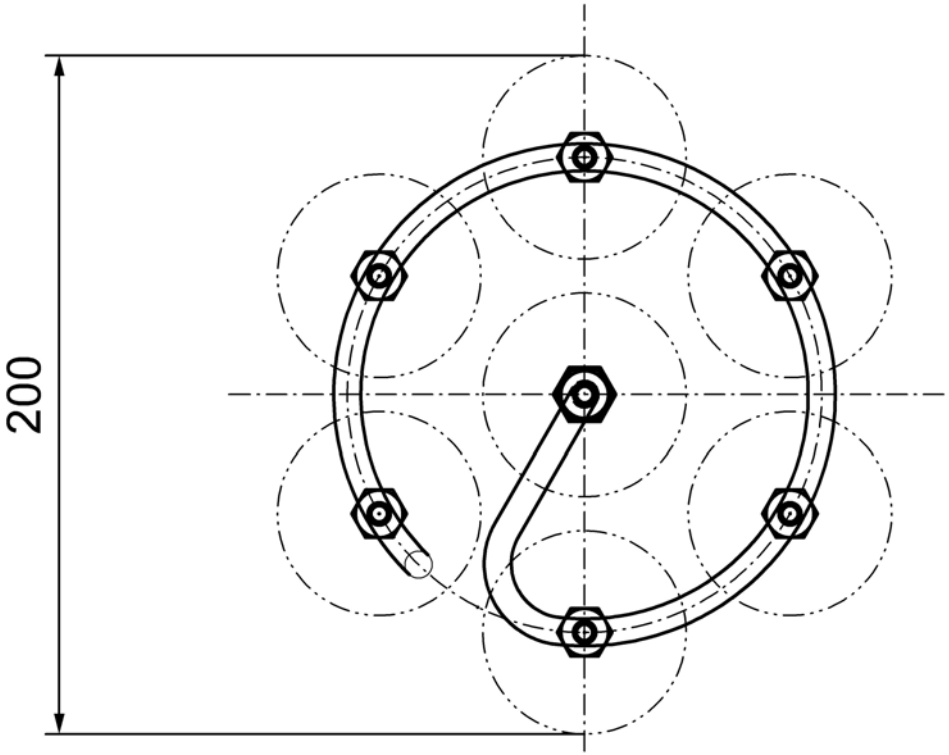


Tube fittings consist of fitting body, nut, front ferrule, back ferrule and tube. Once the nut is tightened the ferrules are connected to the tube and cannot be removed.

Hydrogen supply spiral

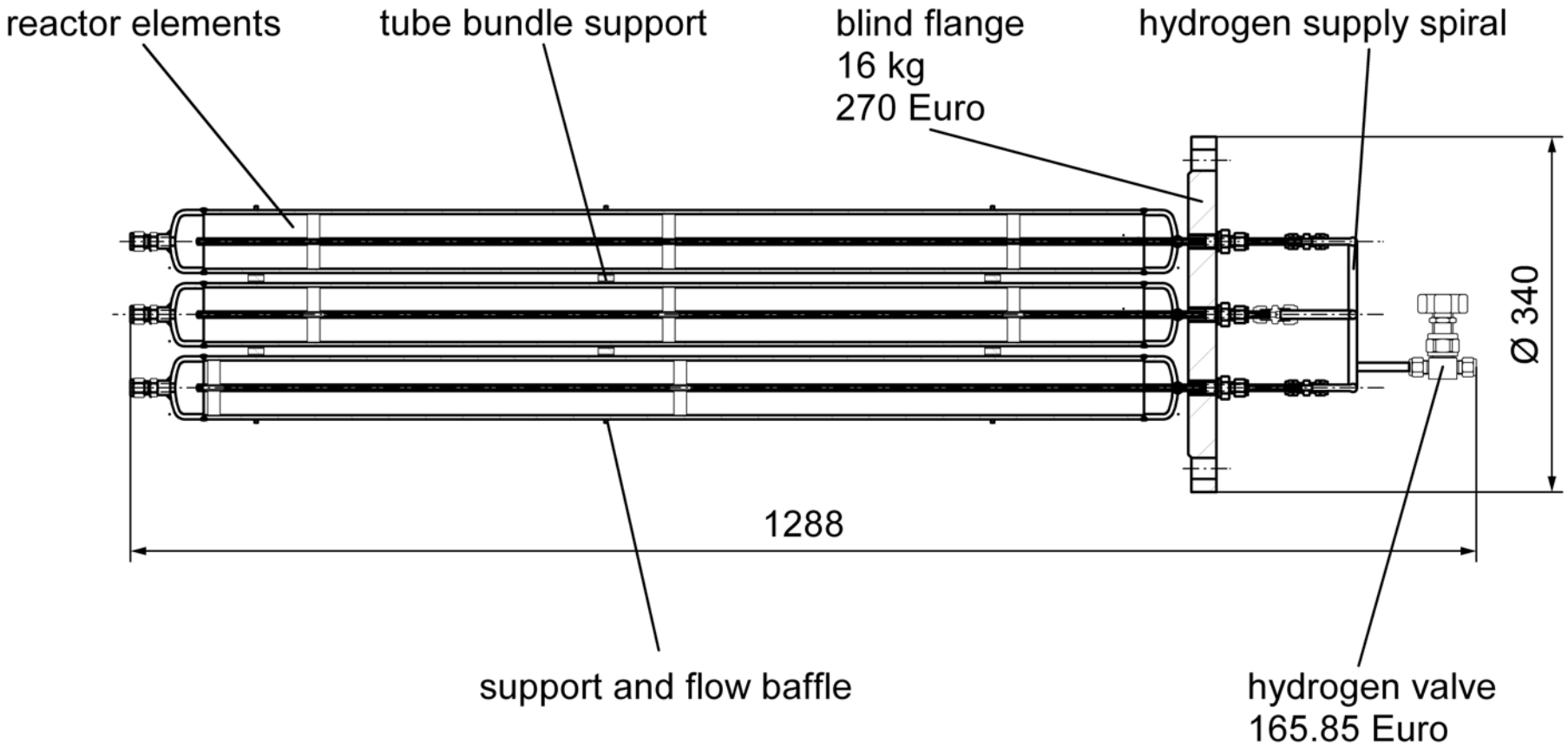
hydrogen supply spiral
0.456 kg
77.50 Euro



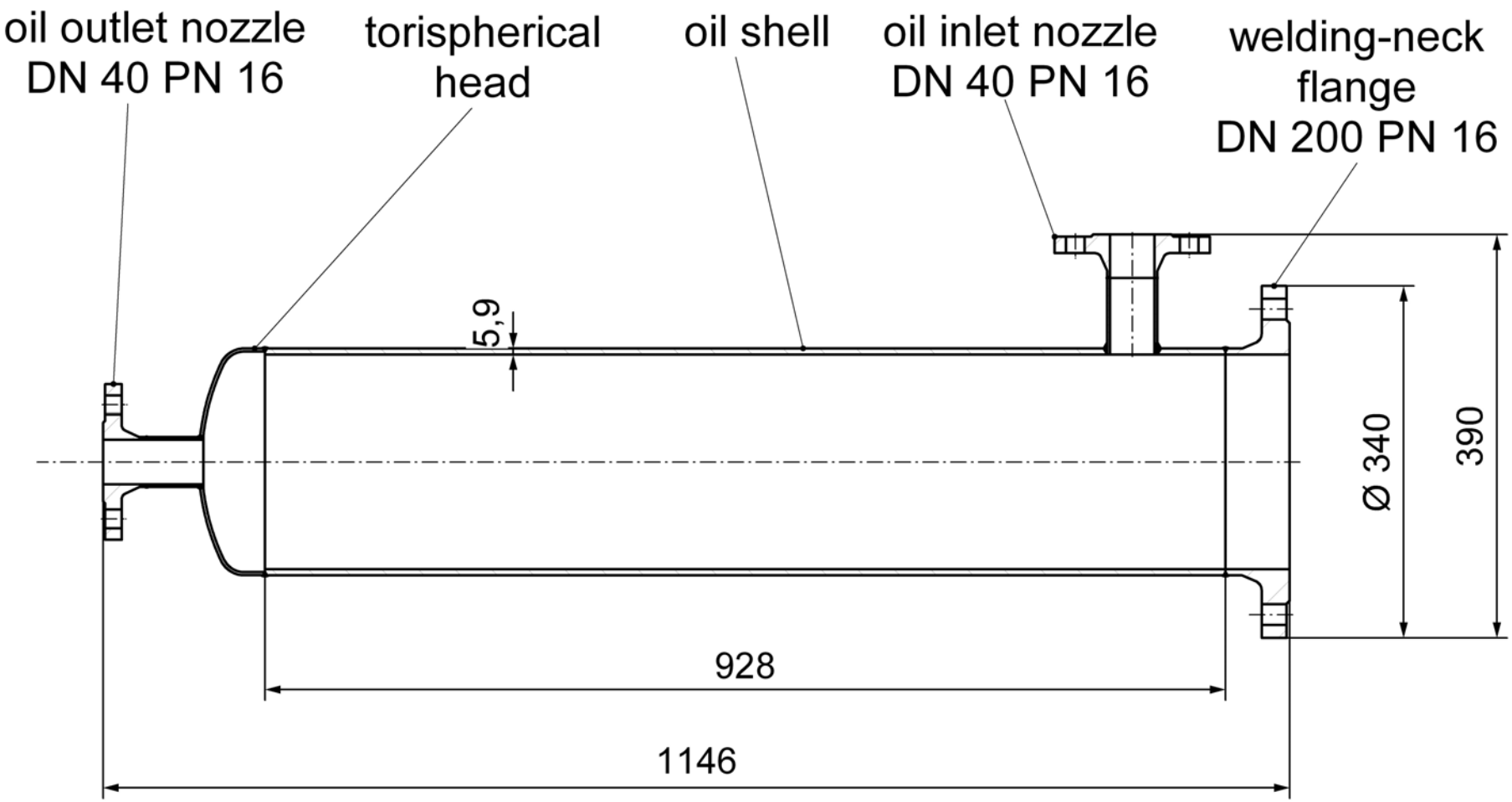


8 mm tube: 0.173 kg / Meter, 8.96 Euro / Meter
6 mm tube: 0.123 kg / Meter, 7.17 Euro / Meter
Each fitting. approximately 45 g, 10 Euro

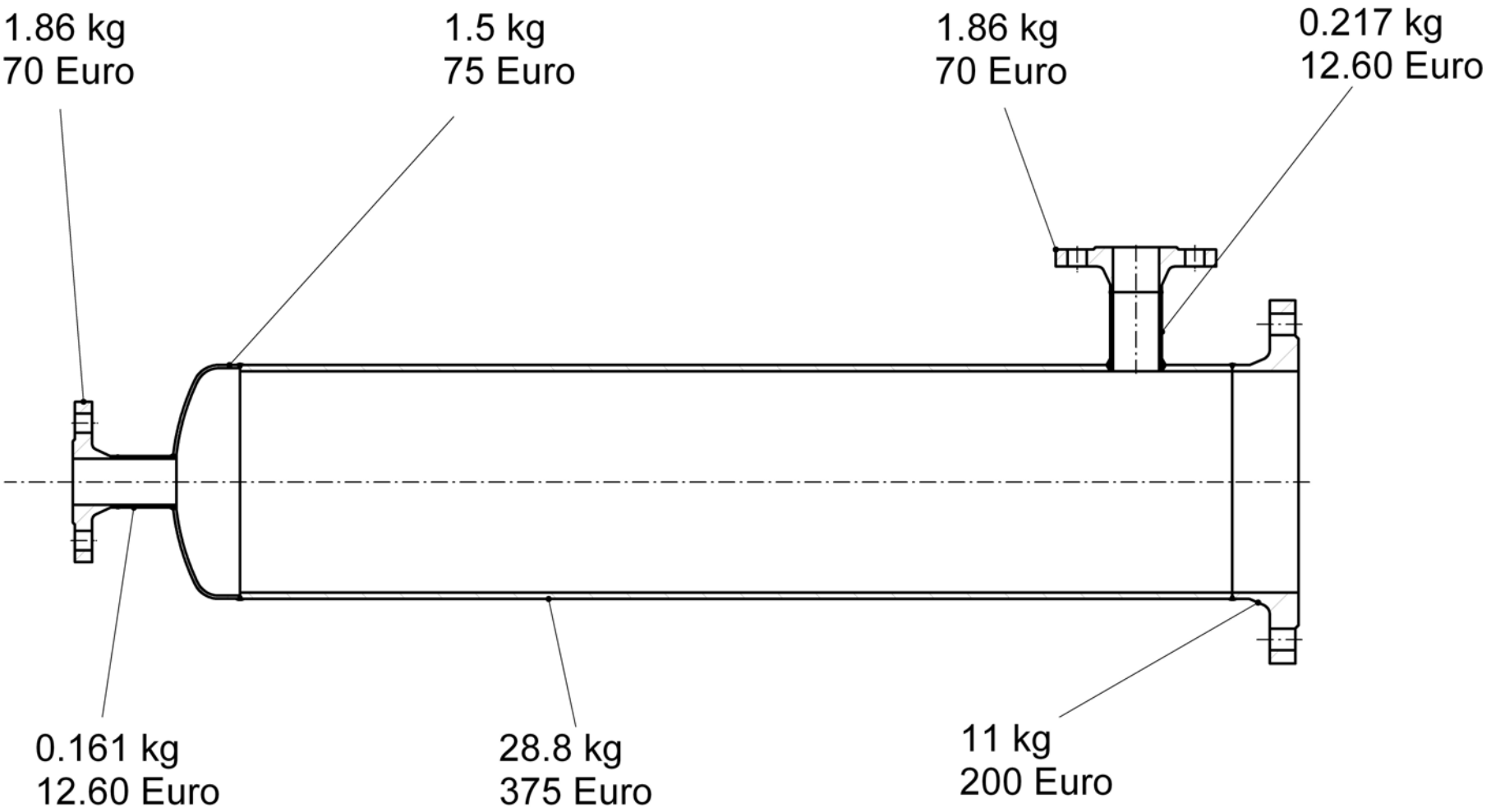
Blind flange and hydrogen valve



Oil side

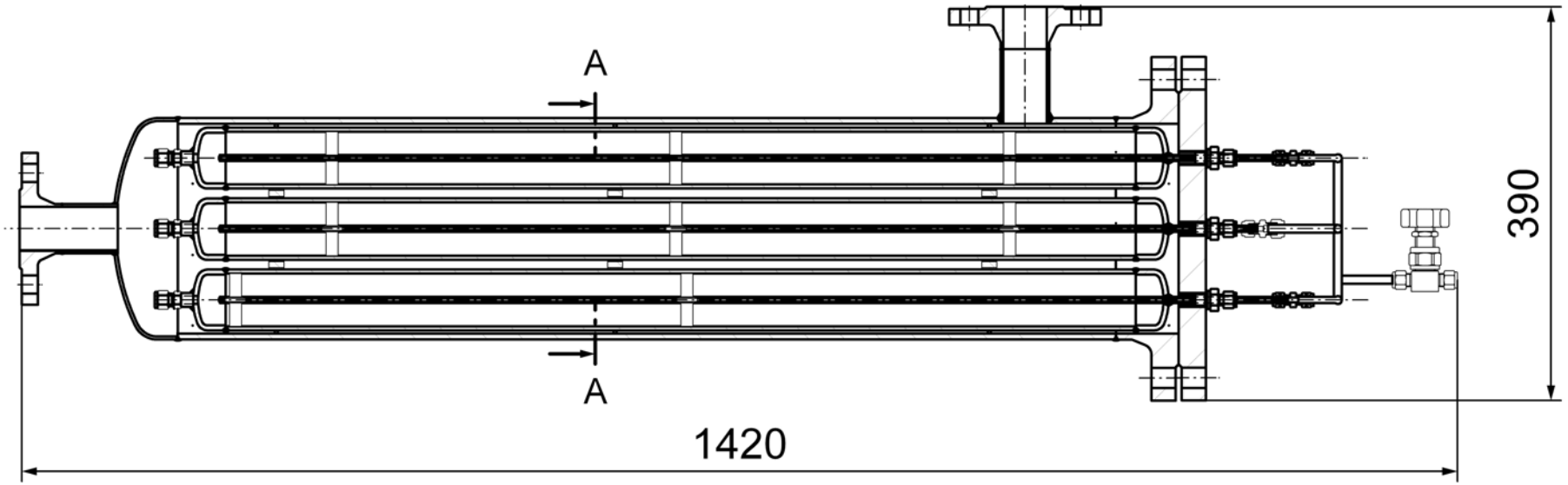

oil outlet nozzle
DN 40 PN 16
torispherical
head
oil shell
oil inlet nozzle
DN 40 PN 16
welding-neck
flange
DN 200 PN 16
5,9
Ø 340
390
928
1146

Oils side (masses and costs)

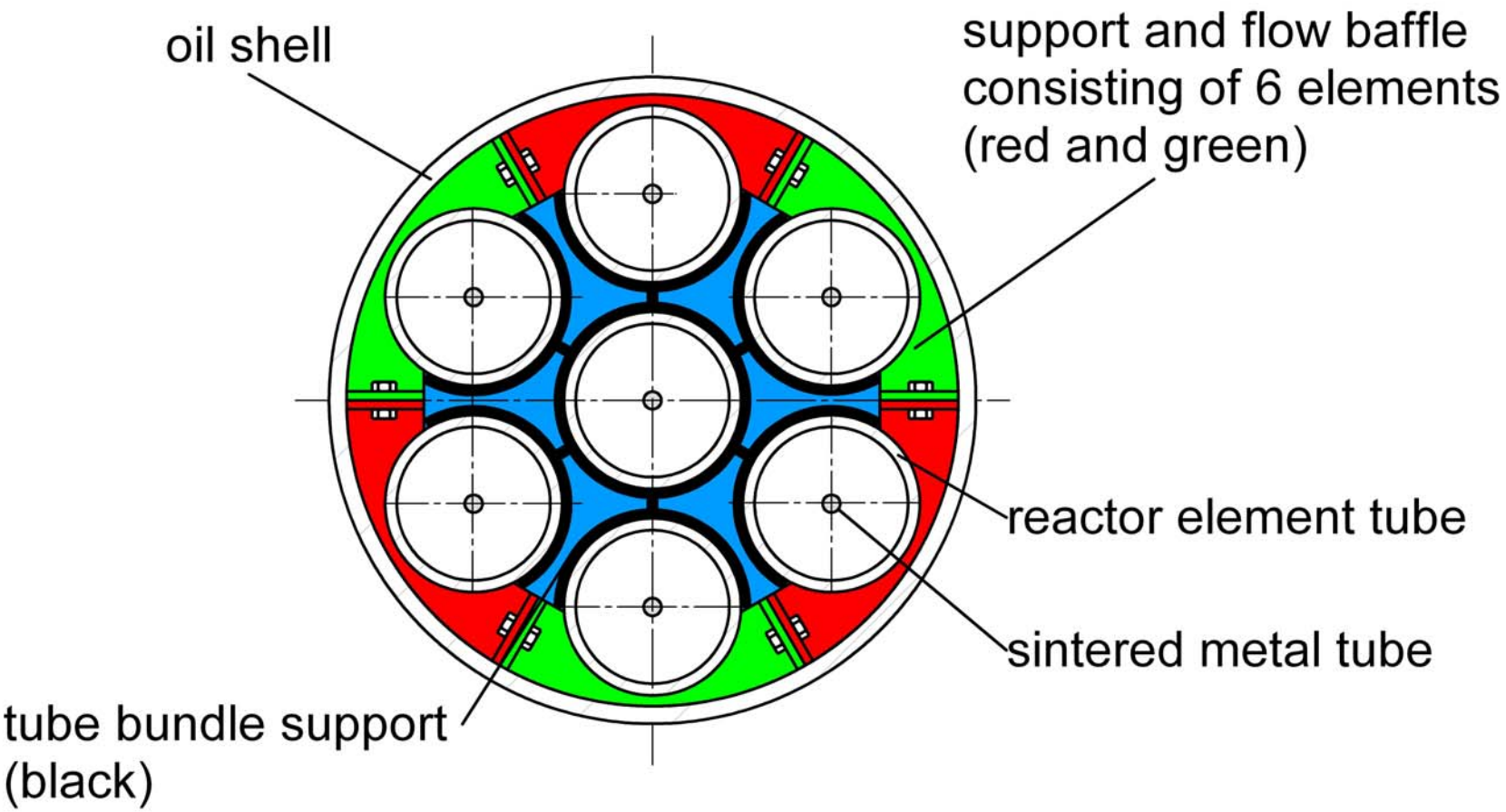


The mass of the oil shell is 45.4 kg and the costs are 815.20 €.

Sectional view: Support and flow baffles

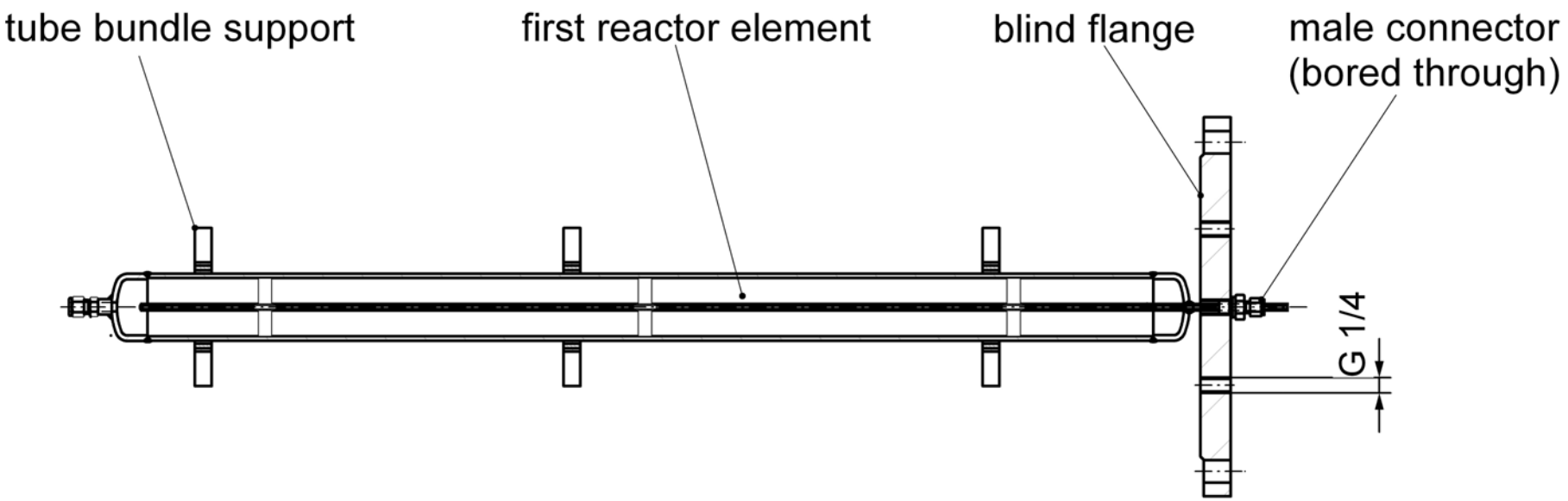


Sectional view: Support and flow baffles



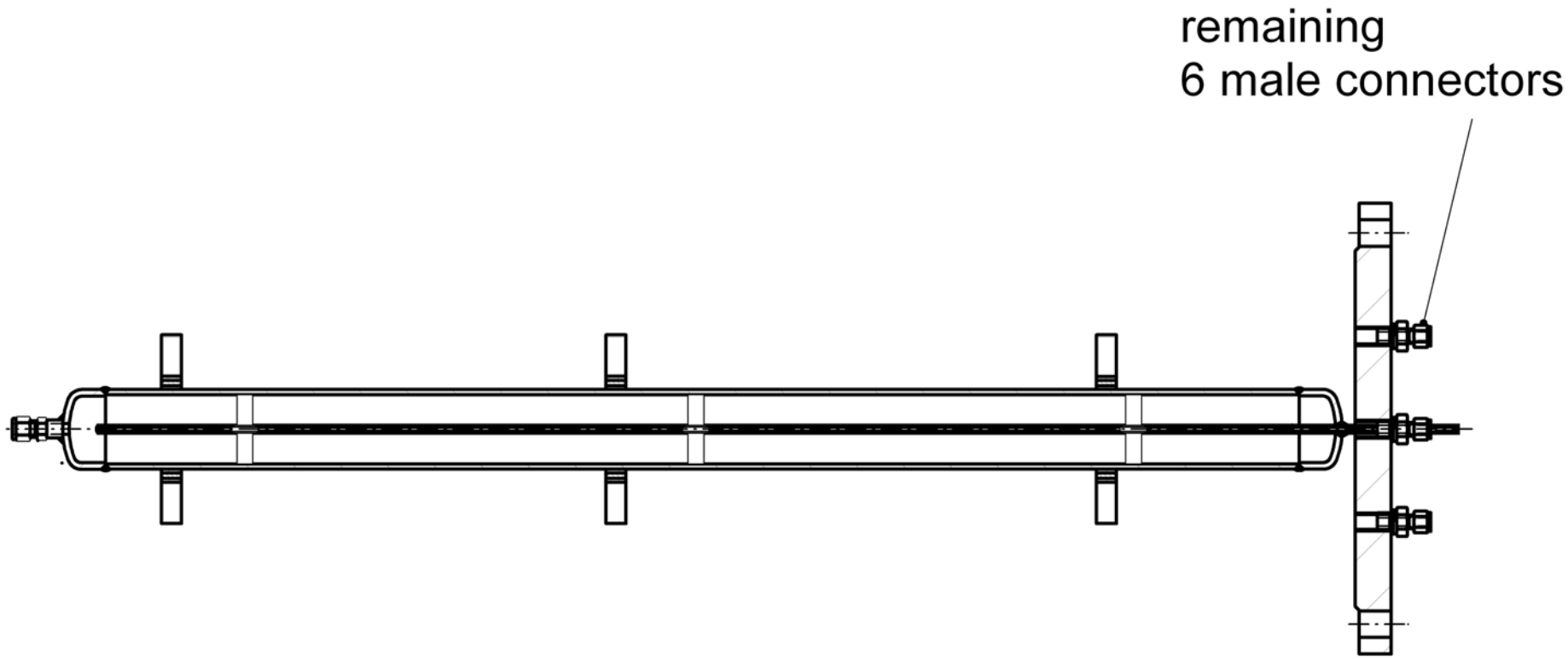
The tube bundle support consists of 6 cylindrical half-shells which are connected by nose-pieces to the central full-shell on the inner reactor element.
The free area for oil flow at the position of the baffle is blue.

Assembling – step 1

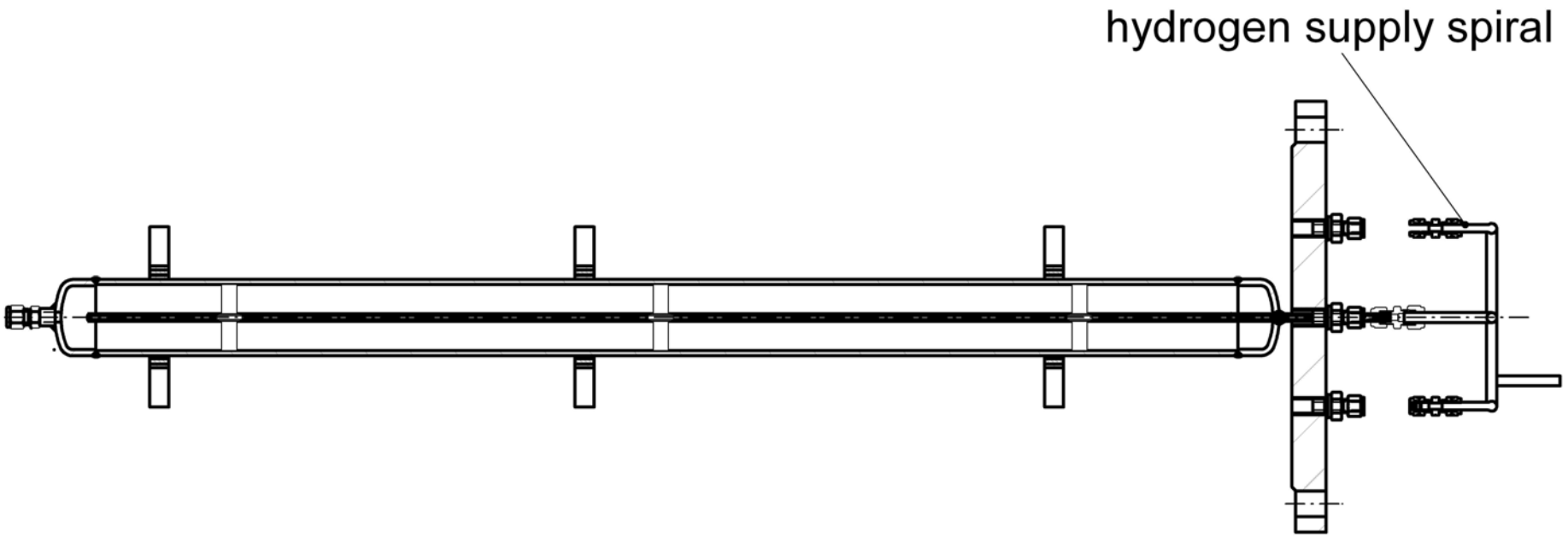


- Important aspects for assembly:
- There must be enough space to set on tools like wrenches.
- Due to the ferrules, tube fittings and related parts and elements are not always detachable.

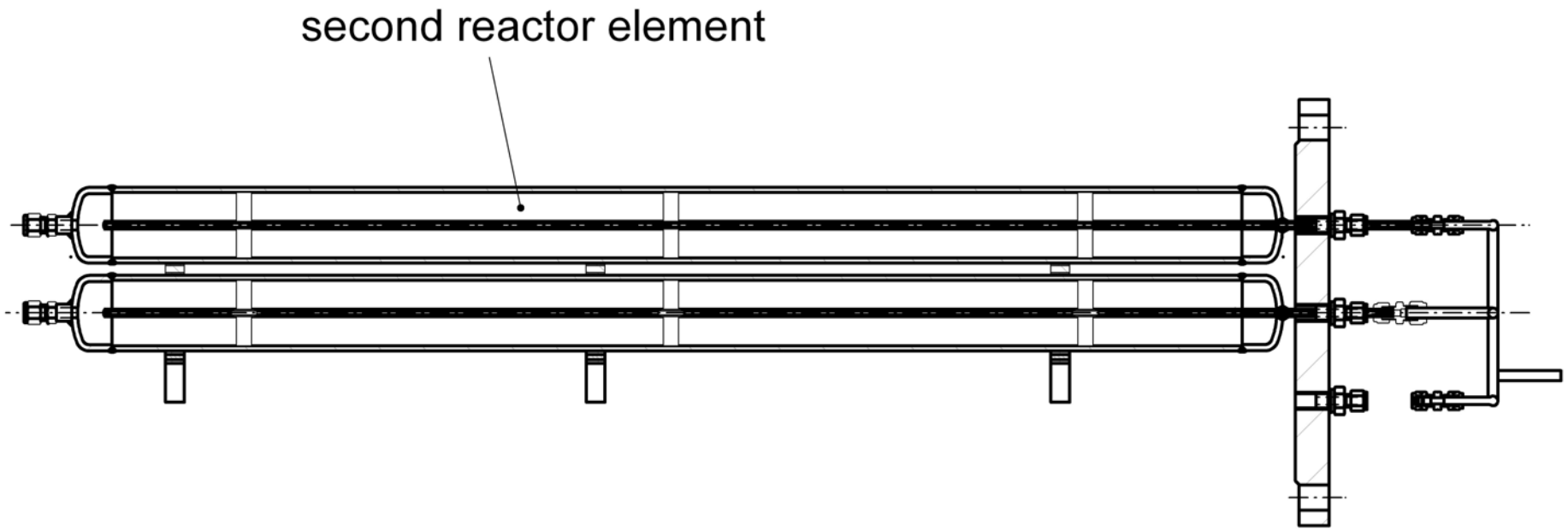
Assembling – step 2



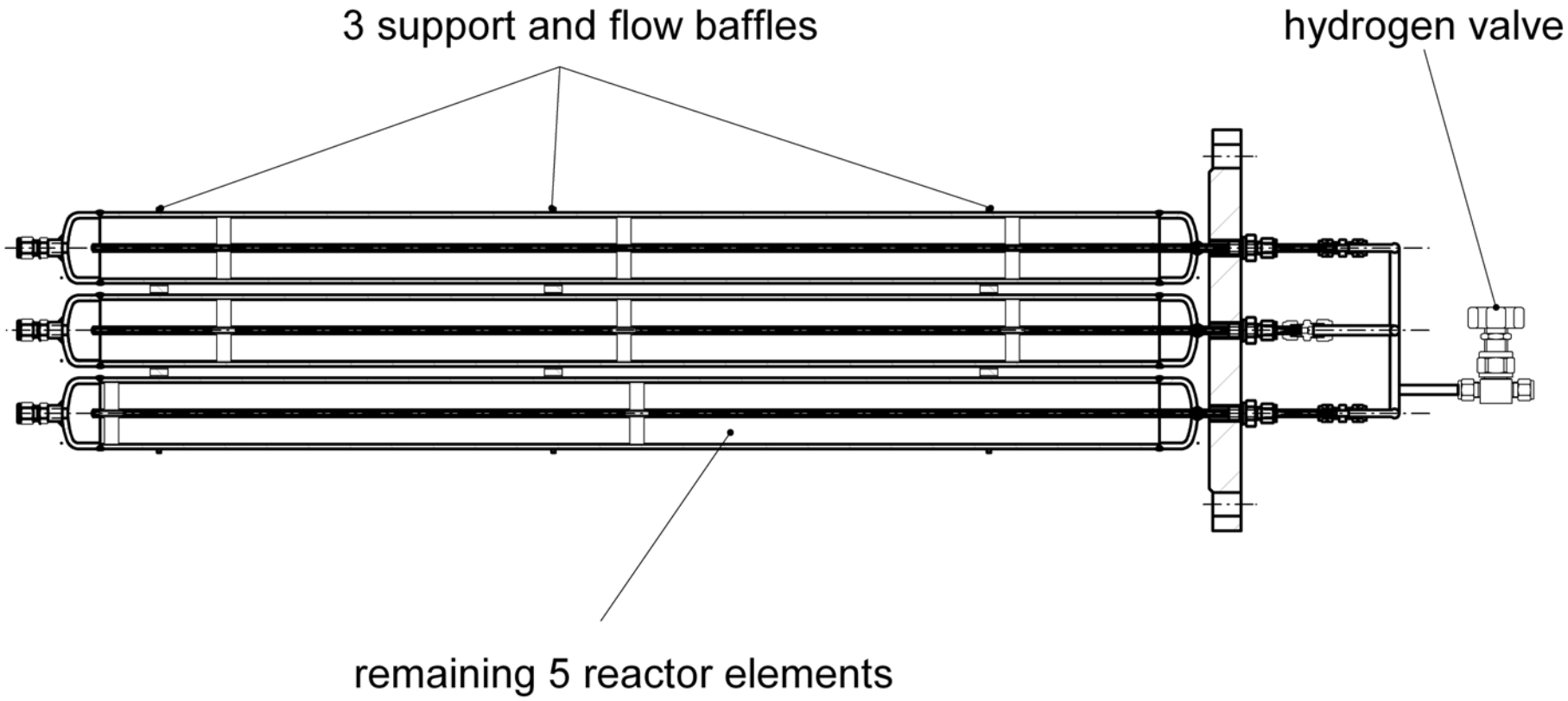
Assembling – step 3



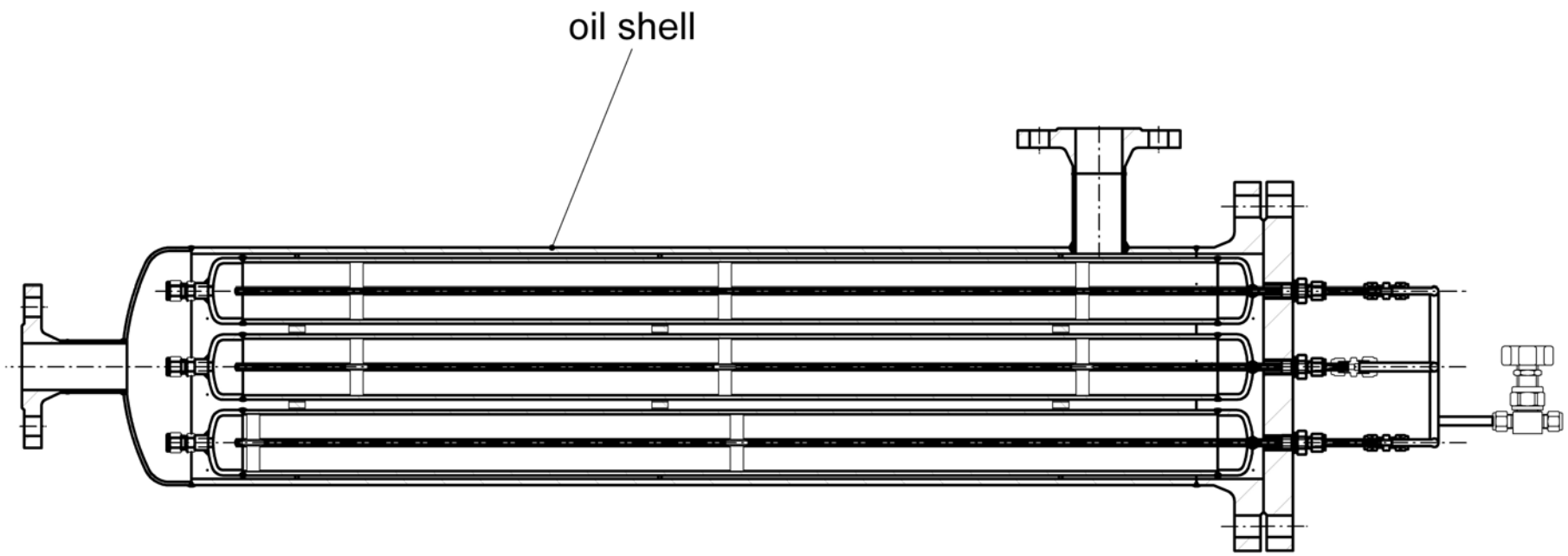
Assembling – step 4



Assembling – step 5



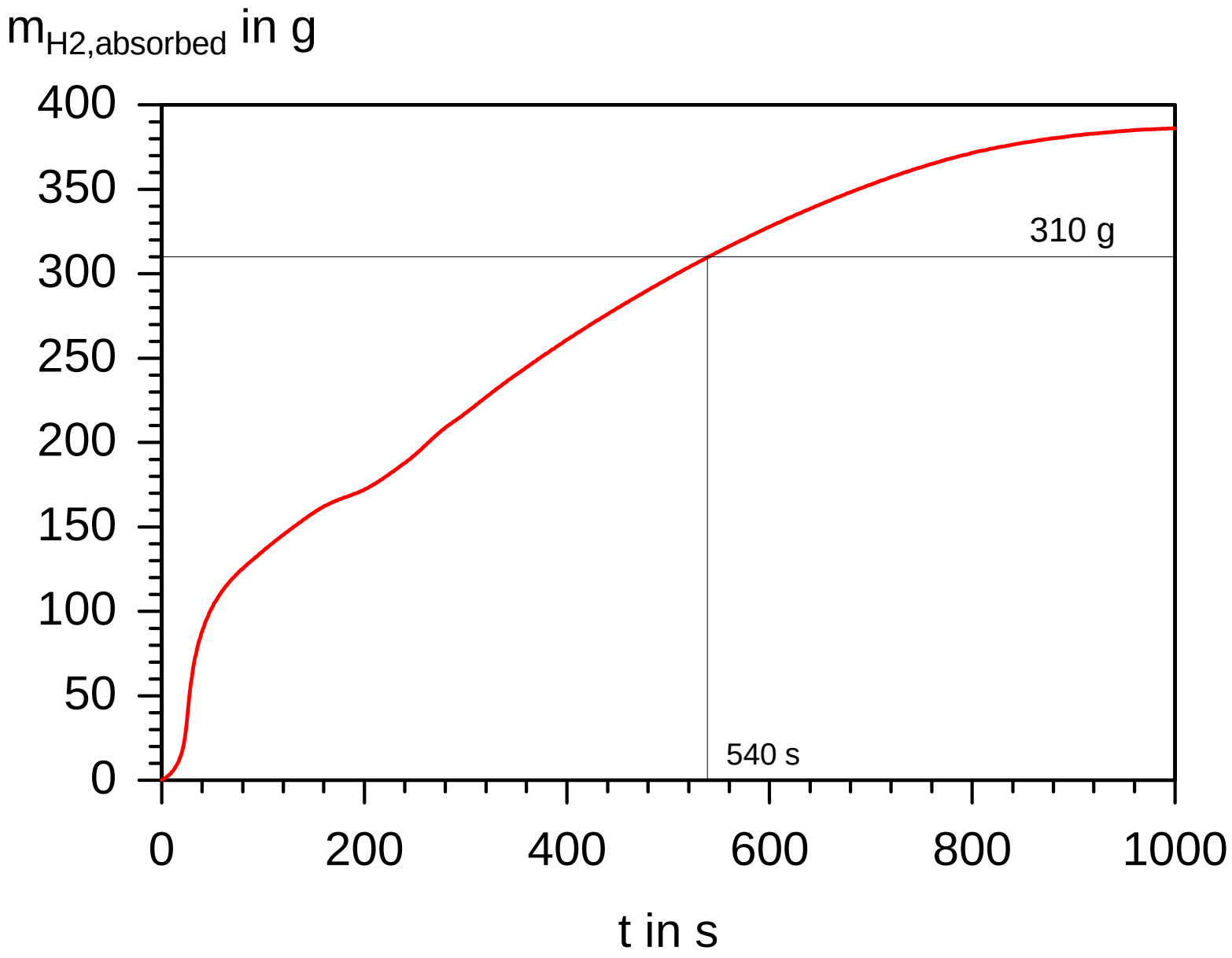
Assembling – step 6



Performance data

Oil flow area in cm^2	138
Oil flow area at flow baffle in cm^2	50
Wetted perimeter in m	1.98
Hydraulic diameter in mm	28
Mean oil velocity in m/s	0.24
Re	14046
Nu	91
Heat transfer coefficient in $W/(m^2\ K)$	361
Pressure loss in mbar (inlet, outlet, longitudinal flow and three sharp orifices at flow baffles)	190

Performance of 8 kg storage tank



Thank you for your attention.

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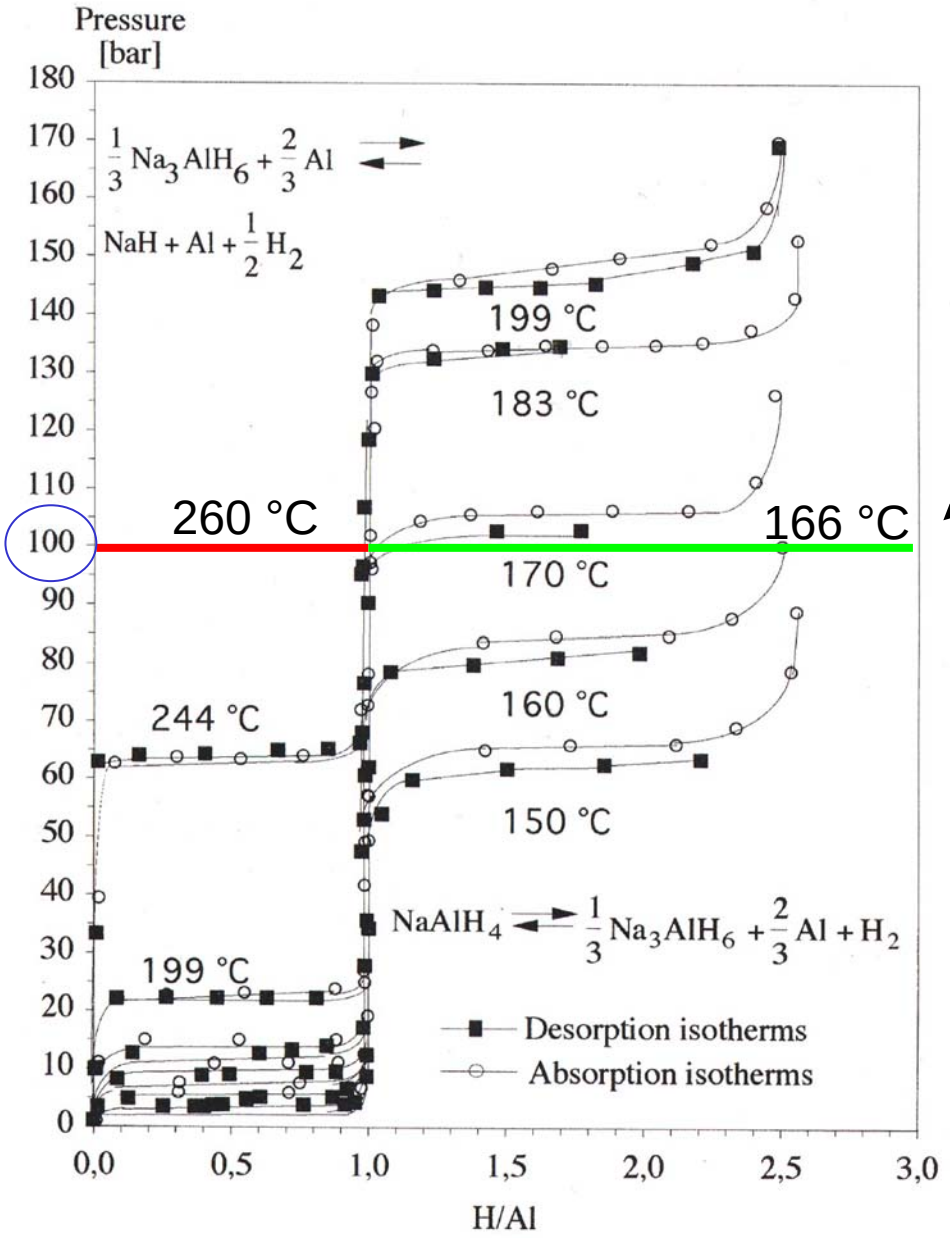
Important data for discussion

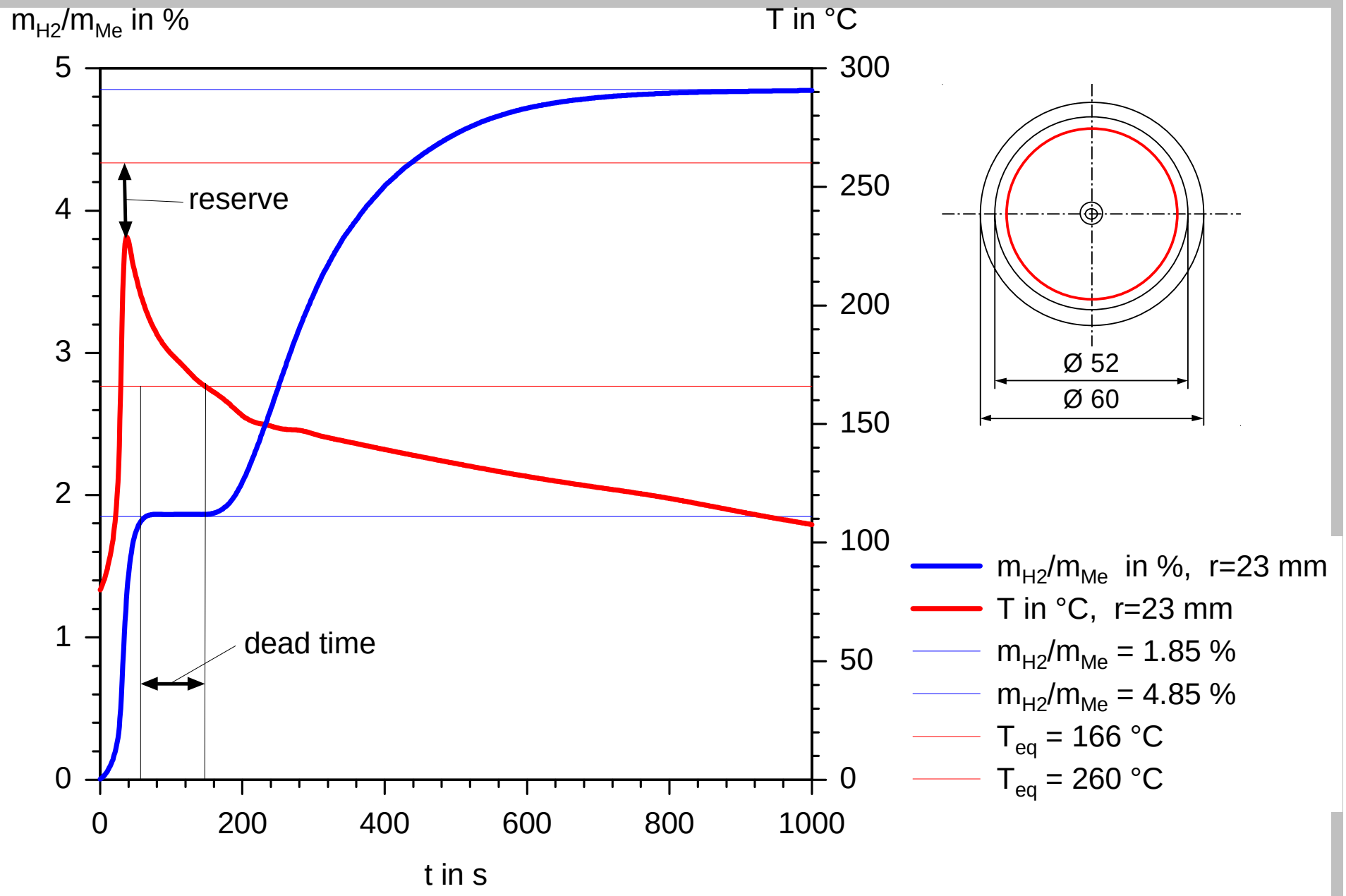
- Equilibrium temperature of the first reaction step is 260 °C at 100 bars.
- Equilibrium temperature of the second reaction step in 166 °C at 100 bars.
- During the first reaction step the hydrogen concentration can become 1.85 %.
- During the second reaction step the hydrogen concentration can increase by another 3 %, i.e. 4.85 % in total.

PCI curves by Bogdanovic

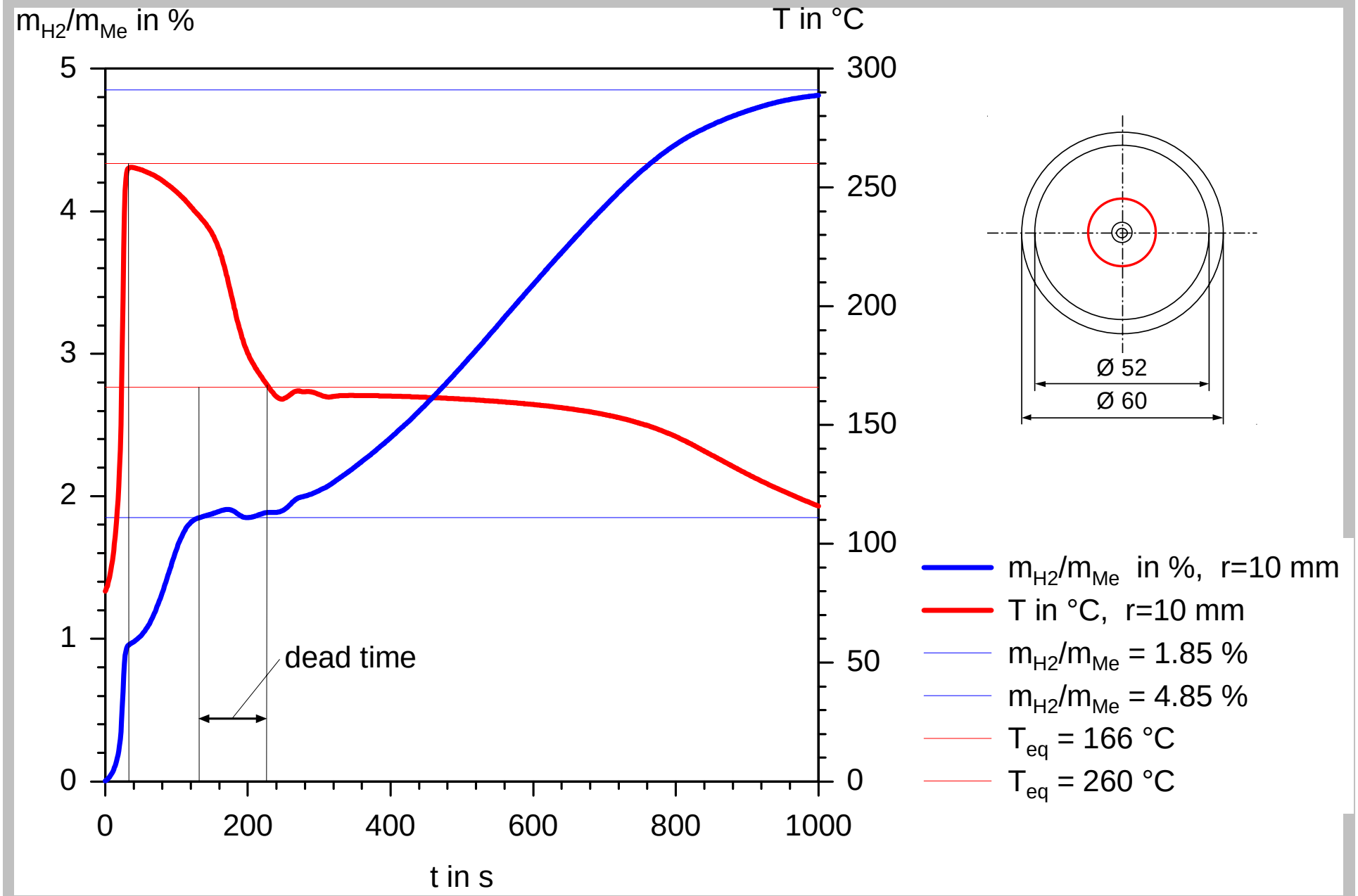


Own measurements

Performance of reactor element (r = 23 mm)



Performance of reactor element (r = 10mm)



Pressure equipment directive (97/23/EC)

- Classification of pressure equipment:
- Maximum allowable pressure: PS = 150 bar
- Volume: V = 15 l
- PS * V = 2250 bar l $\Rightarrow$ category IV
- The conformity assessment procedure of category IV consists of the following modules: B+D, B+F, G and H1

Module of conformity assessment

- B: EC type examination, EG-Baumusterprüfung
- D: Production quality assurance, Qualitätssicherung Produktion
- F: Product verification, Prüfung der Produkte
- G: EC unit verification, EG Einzelprüfung
- H1: Full quality assurance with design examination and special surveillance of the final assessment, Umfassende Qualitätssicherung mit Entwurfsprüfung und besonderer Überwachung der Abnahme

AD 2000 code

- Calculation pressure: p = 150 bar
- Calculation temperature: T = 300 °C
- The design strength value is the 1% proof strength of 1.4571 at 300 °C: K = 175 N/mm^2
- Design strength value: Festigkeitskennwert
- 1% proof strength: 1% Dehngrenze

Influence of calculation temperature

T in °C	100	200	300	
K in N/mm^2	218	196	175	
s in mm	2.96	3.27	3.64	4.00
m/L in kg/m	4.19	4.60	5.09	5.55

Influence of calculation temperature on reactor element tube: p = 150 bar, D_a = 60,3 mm. The outer tube diameter is constant. Wall thickness and mass per length are increasing with increasing temperature because the design strength value descreases.

Proof test (Druckprüfung)

- Proof test (Druckprüfung)
- Final assessment of pressure equipment must include a test for the pressure containment aspect, which will normally take the form of a hydrostatic pressure test at a pressure at least equal, where appropriate, to the value laid down in 7.4.

- 7.4. Hydrostatic test pressure
- For pressure vessels, the hydrostatic test pressure must be no less than:
  - that corresponding to the maximum loading to which the pressure equipment may be subject in service taking into account its maximum allowable pressure and its maximum allowable temperature, multiplied by the coefficient 1.25, or
  - the maximum allowable pressure multiplied by the coefficient 1.43.

Flange connections

	amount	screw	nut	washer	total
M 16 2 x DN 40	8	2.52 €	1.07 €	0.27 €	33.04 €
M 20 DN 200	12	5.38 €	1.60 €	0.52 €	96.24 €

Graphite gaskets with an insert from stainless steel:
DN 200: 20.30 € (Egraflex)
2 x DN 40: 2 x 0.95 € =1.90 € (Novaphit)

Performance data

Mass of metal hydride in kg	8
Effective density of metal hydride bed in kg/m^3	600
Volume of metal hydride in l	13.3
Mass of hydrogen in kg	0.4
Volume of oil in l	15
Mass of oil in kg	12
Free gas volume of empty tank in l	15

Design strengths of austenitic steels

Number	Composition	0.2 % proof strength at 200 °C in N/mm²
1.4311	X2CrNiN18 -0	187
1.4406	X2CrNiMoN17-11-2	198
1.4439	X2CrNiMoN17-13-5	210
1.4429	X2CrNiMoN17-13-3	198
1.4571	X6CrNiMoTi17-12-2	196

1.4571, also AISI316Ti or V4A
(1.4301: X5CrNi18-10, also AISI 304 or V2A,
1.4541: X6CrNiTi18-10)

Open design aspects

- Saddle supports for horizontal storage tank
- Lifting lugs (Hebeösen)
- Contact for potential equalisation
- Insulation
- Feedthrough of thermocouple

Volume expansion

- The metal hydride bed shrinks by 14 % during the first reaction step of loading.
- After the second reaction step the volume has increased by 16 % compared to the initial volume, i.e. 30 % from first to second step.
- These data are very uncertain.