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Permeation studies on polyethylene pipes at different temperatures

GUT 6789/22

Final Report

Imprint

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PermeaPE100+

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Duration

01.11.2021 bis 31.03.2022

Client

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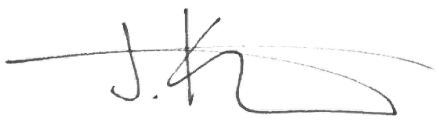

Janko König, project engineer

Final report

Various pipes made of polyethylene (PE) (DN110, SDR17) were examined on behalf of the PE100+ Association. For the PE pipes, the permeation coefficients for hydrogen should be determined at different temperatures:

- At target pressure 6.3 barg[1] for 3 different target temperatures (8°C, 14°C and 20°C)

Hydrogen (purity ≥ 99.999) was used as test gas.

To prepare the test specimens, they were closed with a cap on one side. The open pipe sides were provided with a stub flange and sealed with a blind and loose flange. The pipes were filled with the test gas via measuring connections in the blind flange. At the same time, this ensured permanent pressure control for constant examination conditions.

The test pipes were conditioned over a period of about four weeks. During conditioning, the plastic is saturated with the permeate until a stationary phase and thus a constant permeation rate has been established.

Conditioning parameters:

- Pressure: 6.3 barg
- Temperature: 20°C
- Medium: Hydrogen
- Duration: 4 weeks

After conditioning, the test pipes were adjusted to the appropriate test pressure and clamped in permeation measuring cells. The measuring cells were flushed with nitrogen and adjusted to a pressure of 100 mbarg. During the investigation, gas samples were taken from the measuring cells at regular intervals and analyzed in a gas chromatograph (GC). This analysis provides the gas composition, which is then used to derive information about how much permeate penetrated the pipe wall and was concentrated in the measuring cell. Table 1 shows the examination matrix for the series of measurements.

Table 1: investigation matrix

Label	Material	Manufacturer	Medium	Target Gauge Pressure	Target Test Temperature
PE80	PE80 MDPE YELLOW	BOREALIS	H_2	6.3 barg	8°C, 14°C, 20°C
PE100	PE100 (C4-based) BLACK	SABIC	H_2	6.3 barg	8°C, 14°C, 20°C
PE100 RC (C4)	PE100 RC (C4-based) BLACK	LyondellBasell	H_2	6.3 barg	8°C, 14°C, 20°C
PE100 RC (C6)	PE100 RC (C6-based) BLACK	INEOS	H_2	6.3 barg	8°C, 14°C, 20°C

[1] gauge pressure = barg
absolute pressure = bara

After the conditioning phase and under constant test conditions, the permeation rate runs in a linear function. Taking into account the pipe and test parameters, the permeation coefficient can be calculated from the permeation rate according to the following formula.

$P_l = \frac{V_n \cdot s_R}{\pi \cdot d_i \cdot L_p \cdot p_R}$	P_l	- specific permeation coefficient	$\left[\frac{cm^3\ i.N. \cdot mm}{m^2 \cdot bar \cdot day}\right]$
	V_n	- permeated volume in Standard state per unit of time	[cm³ i.N./day]
	s_R	- pipe wall thickness	[mm] = $\left[\frac{d_n [mm]}{SDR\ ratio}\right]$
	π	- circular ratio Pi	3,1415…
	d_i	-inner diameter of pipe specimen	[m]
	d_n	-nominal diameter	[mm]
	L_p	- test length within the measuring cell	[m]
	p_R	- partial pressure (absolut)	[bara]

1 Investigation of the permeation coefficients

To determine the permeation coefficients, the pipes are examined in each case at three different temperatures. For the examination at different temperatures the same test pipes are used for each material. This approach excludes material differences as a cause for the change in permeation rates, and makes sure, that the change in the permeation coefficients can only be attributed to the temperature.

1.1 Permeation coefficient on PE80-pipes for hydrogen

The permeation coefficients for PE80 were determined on a DN110, SDR 17 pipe (s_R = 6,47 mm, d_i = 97,06 mm). The same pipe was used in each case for the investigations. The real test temperatures can deviate slightly from the planned temperatures. The real pressures and temperatures are included in the calculation of the permeation coefficient. Table 2 lists the permeation coefficients for PE80 and hydrogen, graded according to the test temperature.

Table 2: permeation coefficient of hydrogen through PE80

material	manufacturer	avg. temperature	avg. pressure	permeation coefficient
PE80 MDPE	BOREALIS	8.6 °C	6.0 barg	70 $^{cm^3 i.N. \cdot mm}/_{m^2 \cdot bar \cdot day}$
PE80 MDPE	BOREALIS	15.2 °C	6.4 barg	90 $^{cm^3 i.N. \cdot mm}/_{m^2 \cdot bar \cdot day}$
PE80 MDPE	BOREALIS	20.5 °C	6.5 barg	115 $^{cm^3 i.N. \cdot mm}/_{m^2 \cdot bar \cdot day}$

1.1.1 permeation coefficient PE80, target temperature 8°C

Table 3 shows the measured values of the measurement series for PE80 at a target temperature of 8°C. Figure 1 shows the recording of the constant permeation rates of hydrogen on the PE80 pipe at an internal pipe pressure of approx. 6.3 barg and an ambient temperature of approx. 8°C.

Table 3: measurement results hydrogen PE80, target temp. 8°C

date	runtime [min]	avg. temperature [°C]	avg. pipe pressure [barg]	pressure measuring cell [bara]	measured value hydrogen [Vol.-%]	permeated volume i.N. H_2, [cm³]
09.02.22	0	8.6	6.0	1.110	0.000	0.000
14.02.22	7,560			1.110	0.499	40.680
17.02.22	11,835			1.150	0.754	63.684
21.02.22	17,560			1.150	1.164	98.313
24.02.22	21,930			1.130	1.447	120.090

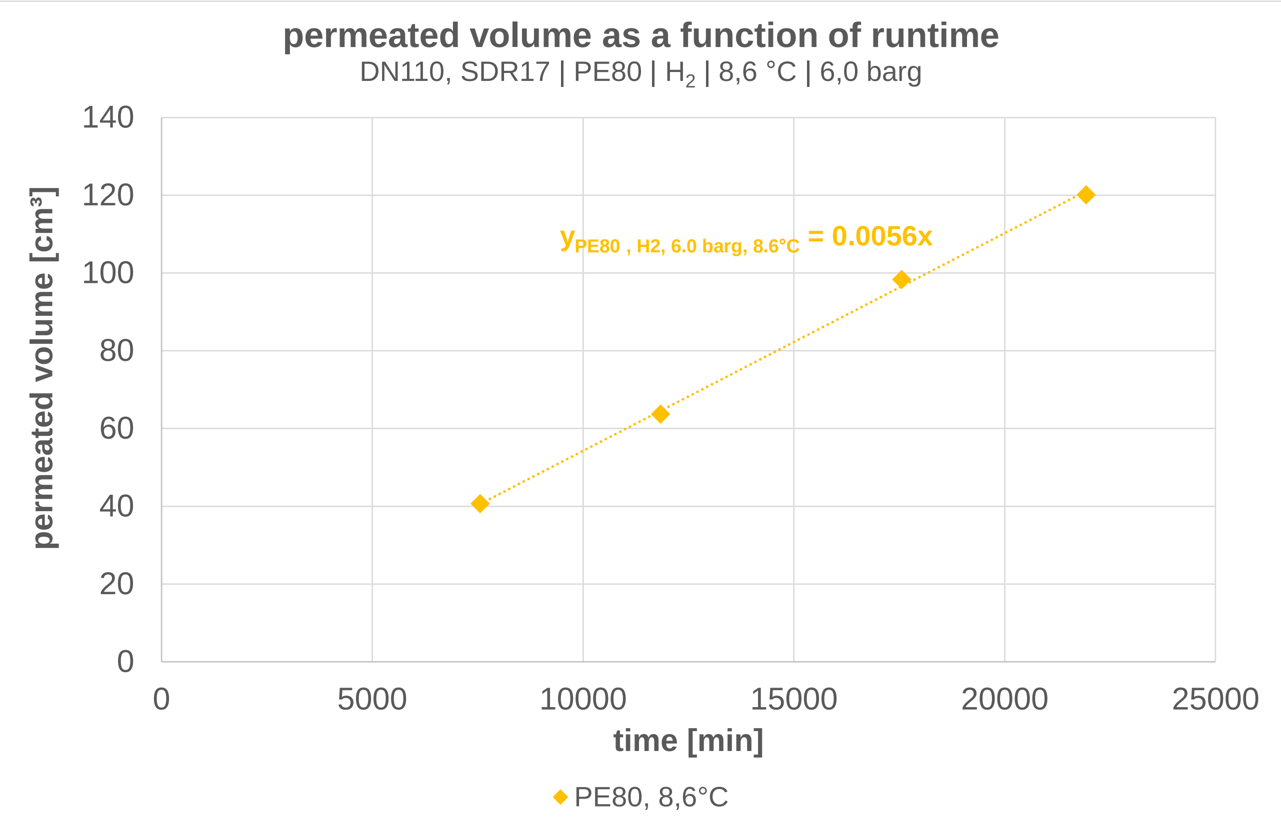

Figure 1: Permeated volume of hydrogen through PE80 at 8.6°C and 6.0 barg internal pipe pressure

The following permeation coefficients were calculated for the PE80 test pipe using four GC measuring points.

- Hydrogen: $P_{PE80,\ 6.0\ barg,\ 8.6°C,\ H_2} = 70\ \frac{cm^3 i.N.\cdot mm}{m^2\cdot bar\cdot day}$

1.1.2 permeation coefficient PE80, target temperature 14°C

Table 4 shows the measured values of the measurement series for PE80 at a target temperature of 14°C. Figure 2 shows the recording of the constant permeation rates of hydrogen on the PE80 pipe at an internal pipe pressure of approx. 6.3 barg and an ambient temperature of approx. 14°C.

Table 4: measurement results hydrogen PE80, target temp. 14°C

date	runtime [min]	avg. temperature [°C]	avg. pipe pressure [barg]	pressure measuring cell [bara]	measured value hydrogen [Vol.-%]	permeated volume i.N. H_2, [cm³]
26.11.21	0			1.110	0.000	0.000
02.12.21	8,695			1.072	0.796	61.178
06.12.21	14,700	15.2	6.4	1.079	1.400	108.332
09.12.21	18,975			1.088	1.761	137.302
13.12.21	24,750			1.089	2.368	184.917

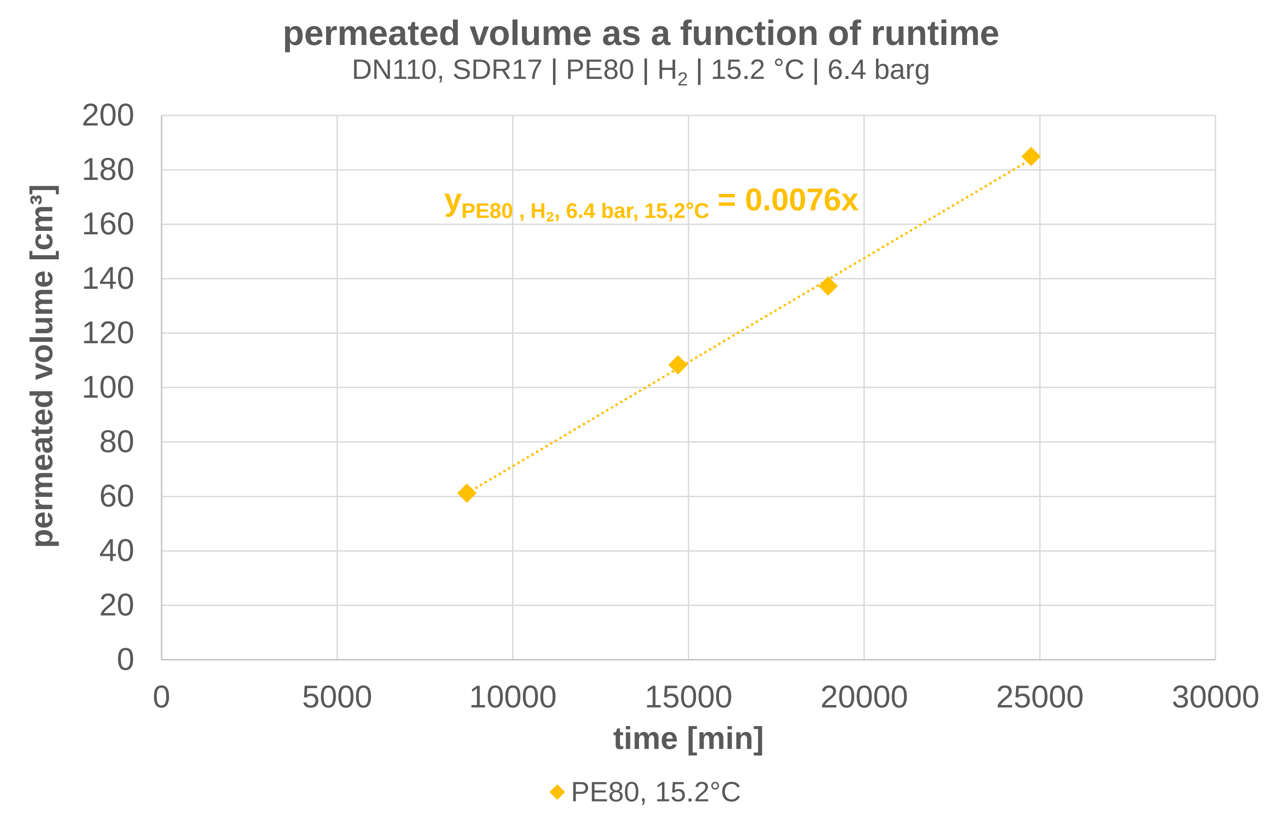

Figure 2: Permeated volume of hydrogen through PE80 at 15,2°C and 6.4 barg internal pipe pressure

The following permeation coefficients were calculated for the PE80 test pipe using four GC measuring points.

- Hydrogen: $P_{PE80,\ 6.4\ barg,\ 15.2°C,\ H_2} = 90\ \frac{cm^3 i.N. \cdot mm}{m^2 \cdot bar \cdot day}$

1.1.3 permeation coefficient PE80, target temperature 20°C

Table 5 shows the measured values of the measurement series for PE80 at a target temperature of 20°C. Figure 3 shows the recording of the constant permeation rates of hydrogen on the PE80 pipe at an internal pipe pressure of approx. 6.3 barg and an ambient temperature of approx. 20°C.

Table 5: measurement results hydrogen PE80, target temp. 20°C

date	runtime [min]	avg. temperature [°C]	avg. pipe pressure [barg]	pressure measuring cell [bara]	measured value hydrogen [Vol.-%]	permeated volume i.N. H_2, [cm³]
14.12.21	0	20.5	6.5	1.100	0.000	0.000
15.12.21	1,350			1.000	0.150	10.519
22.12.21	11,400			1.100	1.533	118.258
05.01.22	31,830			1.150	3.894	314.043

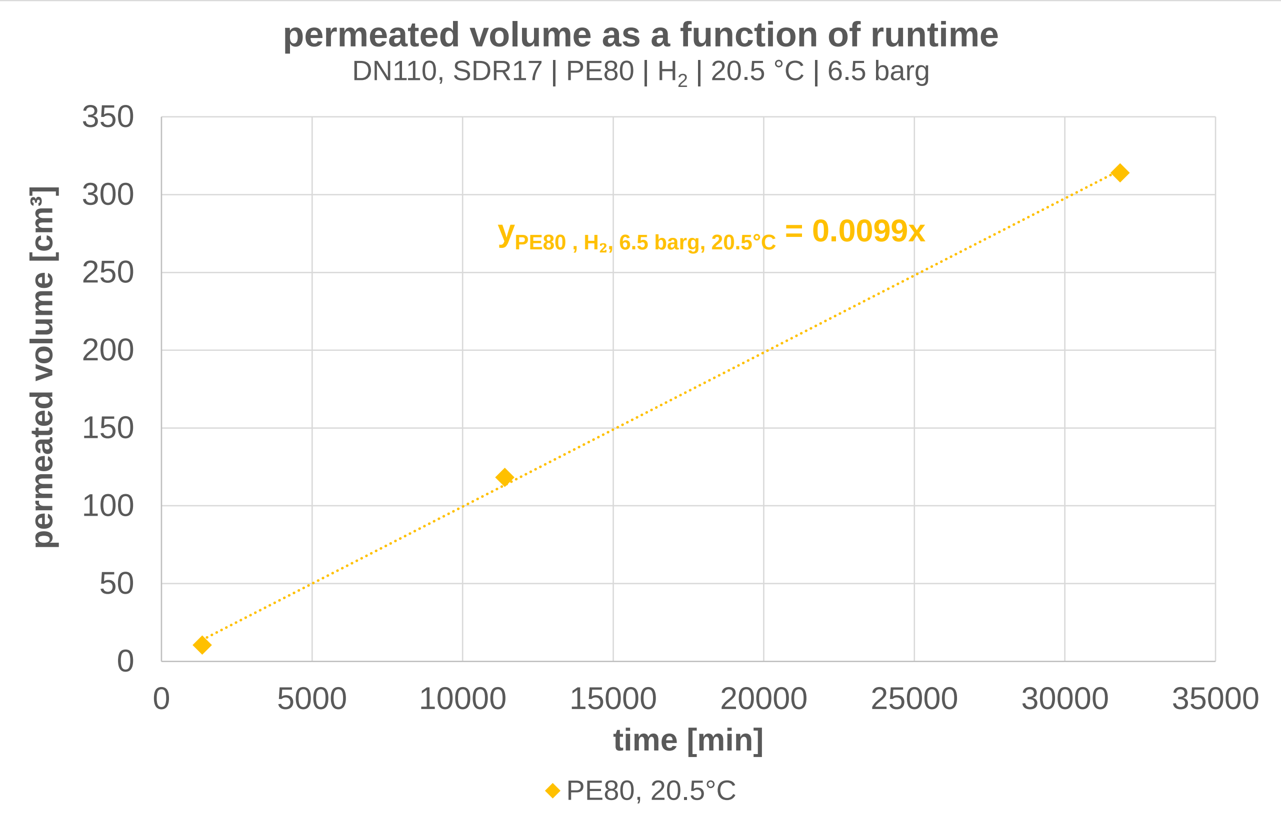

Figure 3: Permeated volume of hydrogen through PE80 at 20.5°C and 6.5 barg internal pipe pressure

The following permeation coefficients were calculated for the PE80 test pipe using three GC measuring points.

- Hydrogen: $P_{PE80,\ 6.5\ barg,\ 20.5°C,\ H_2} = 115\ \frac{cm^3 i.N.\cdot mm}{m^2\cdot bar\cdot day}$

1.1.4 Summary PE80

The measurement results show the temperature dependency of the permeation coefficients. The dependency is assumed to be an exponential function. Figure 4 shows the course of the permeation coefficient as a function of temperature using measured values. The assumed course of the permeation coefficient can be described with the equation $P_{PE80,\,x,\,H_2} = 20.5\ e^{0{,}105x-1}+51$.

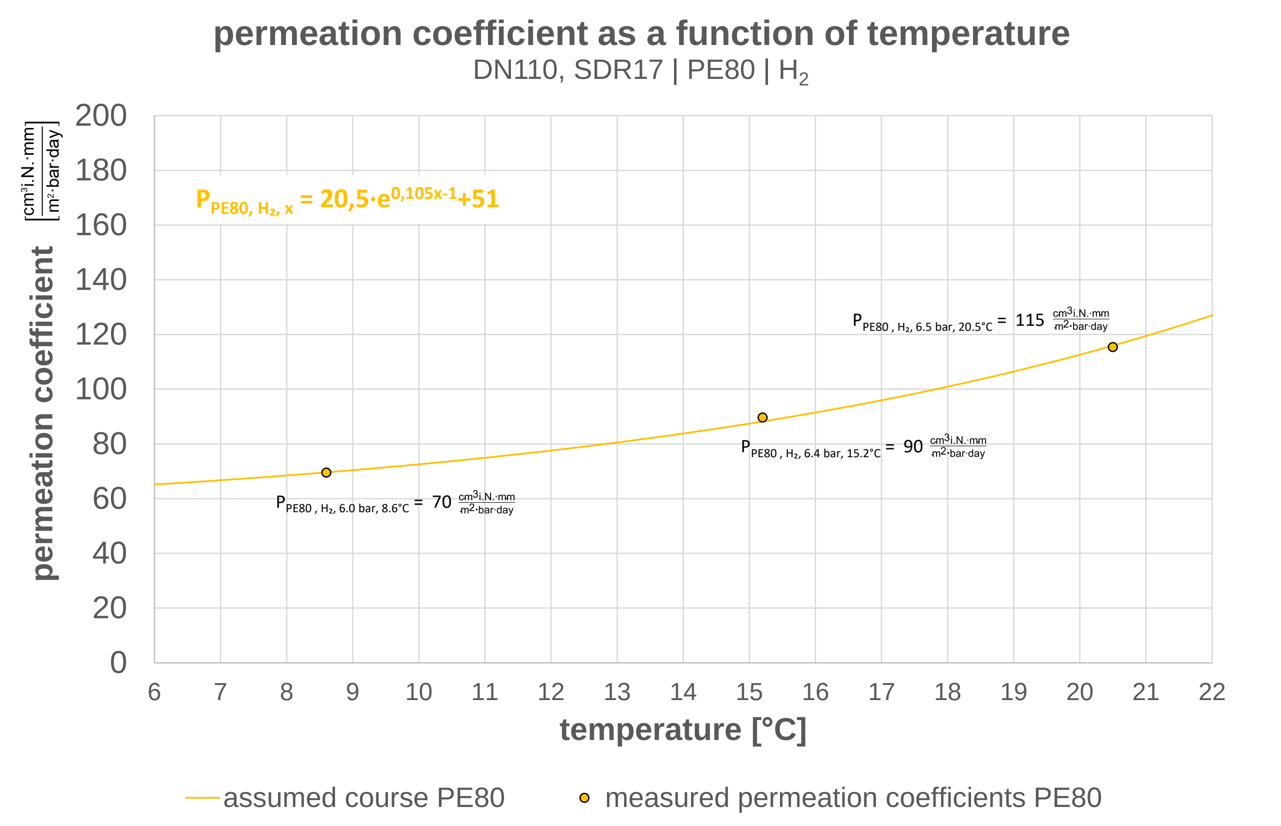

Figure 4: permeation of hydrogen through PE80 as a function of temperature

1.2 permeation coefficient on PE100-pipes with hydrogen

The permeation coefficients for PE100 were determined on a DN110, SDR 17 pipe (s_R = 6,47 mm, d_i = 97,06 mm). The same pipe was used in each case for the investigations. The real test temperatures can deviate slightly from the planned temperatures. The real pressures and temperatures are included in the calculation of the permeation coefficient. Table 6 lists the permeation coefficients for PE100 and hydrogen, graded according to the test temperature.

Table 6: permeation coefficient of hydrogen through PE100

material	manufacturer	avg. temperature	avg. pressure	permeation coefficient
PE100	SABIC	6.8 °C	6.0 barg	52 $^{cm^3 i.N.\cdot mm}/_{m^2\cdot bar\cdot day}$
PE100	SABIC	12.6 °C	6.4 barg	71 $^{cm^3 i.N.\cdot mm}/_{m^2\cdot bar\cdot day}$
PE100	SABIC	20.5 °C	6.7 barg	113 $^{cm^3 i.N.\cdot mm}/_{m^2\cdot bar\cdot day}$

1.2.1 permeation coefficient PE100, target temperature 8°C

Table 7 shows the measured values of the measurement series for PE100 at a target temperature of 8°C. Figure 5 shows the recording of the constant permeation rates of hydrogen on the PE100 pipe at an internal pipe pressure of approx. 6.3 barg and an ambient temperature of approx. 8°C.

Table 7: measurement results hydrogen PE100, target temp. 8°C

date	runtime [min]	avg. temperature [°C]	avg. pipe pressure [barg]	pressure measuring cell [bara]	measured value hydrogen [Vol.-%]	permeated volume i.N. H_2, [cm³]
09.02.22	0	6.8	6.0	1.104	0.000	0.000
14.02.22	7,560			1.071	0.413	32.498
17.02.22	11,835			1.049	0.626	48.215
21.02.22	17,560			1.054	0.975	75.497
24.02.22	21,930			1.055	1.192	92.334

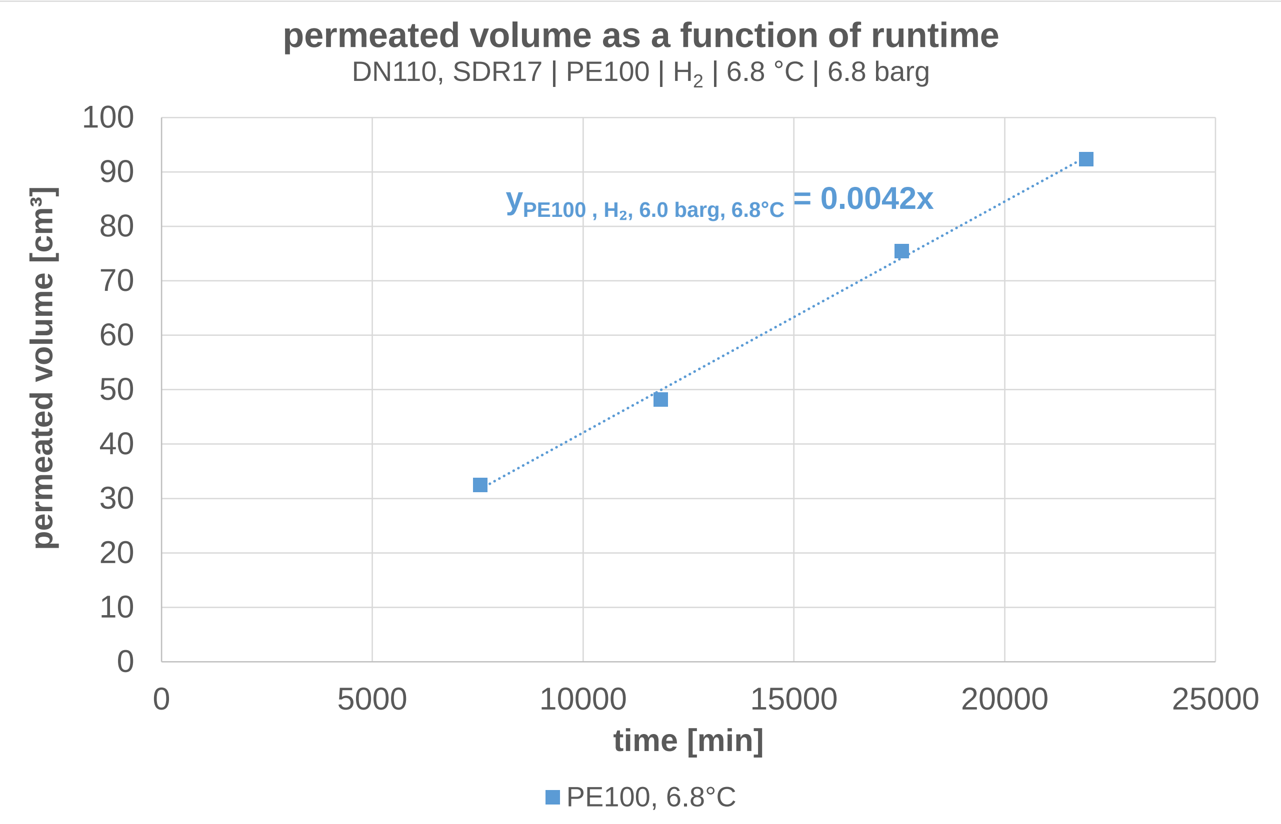

Figure 5: Permeated volume of hydrogen through PE80 at 6.8°C and 6.0 barg internal pipe pressure

The following permeation coefficients were calculated for the PE100 test pipe using four GC measuring points.

- Hydrogen: $P_{PE100,\ 6.0\ barg,\ 6.8°C,\ H_2} = 52\ \frac{cm^3 i.N.\cdot mm}{m^2 \cdot bar \cdot day}$

1.2.2 permeation coefficient PE100, target temperature 14°C

Table 8 shows the measured values of the measurement series for PE100 at a target temperature of 14°C. Figure 6 shows the recording of the constant permeation rates of hydrogen on the PE100 pipe at an internal pipe pressure of approx. 6.3 barg and an ambient temperature of approx. 14°C.

Table 8: measurement results hydrogen PE100, target temp. 14°C

date	runtime [min]	avg. temperature [°C]	avg. pipe pressure [barg]	pressure measuring cell [bara]	measured value hydrogen [Vol.-%]	permeated volume i.N. H_2, [cm³]
26.11.21	0	12.6	6.4	1.099	0.000	0.000
02.12.21	8,695			1.097	0.623	49.016
06.12.21	14,700			1.102	1.014	80.143
09.12.21	18,975			1.108	1.414	112.366
13.12.21	24,750			1.109	1.800	143.169

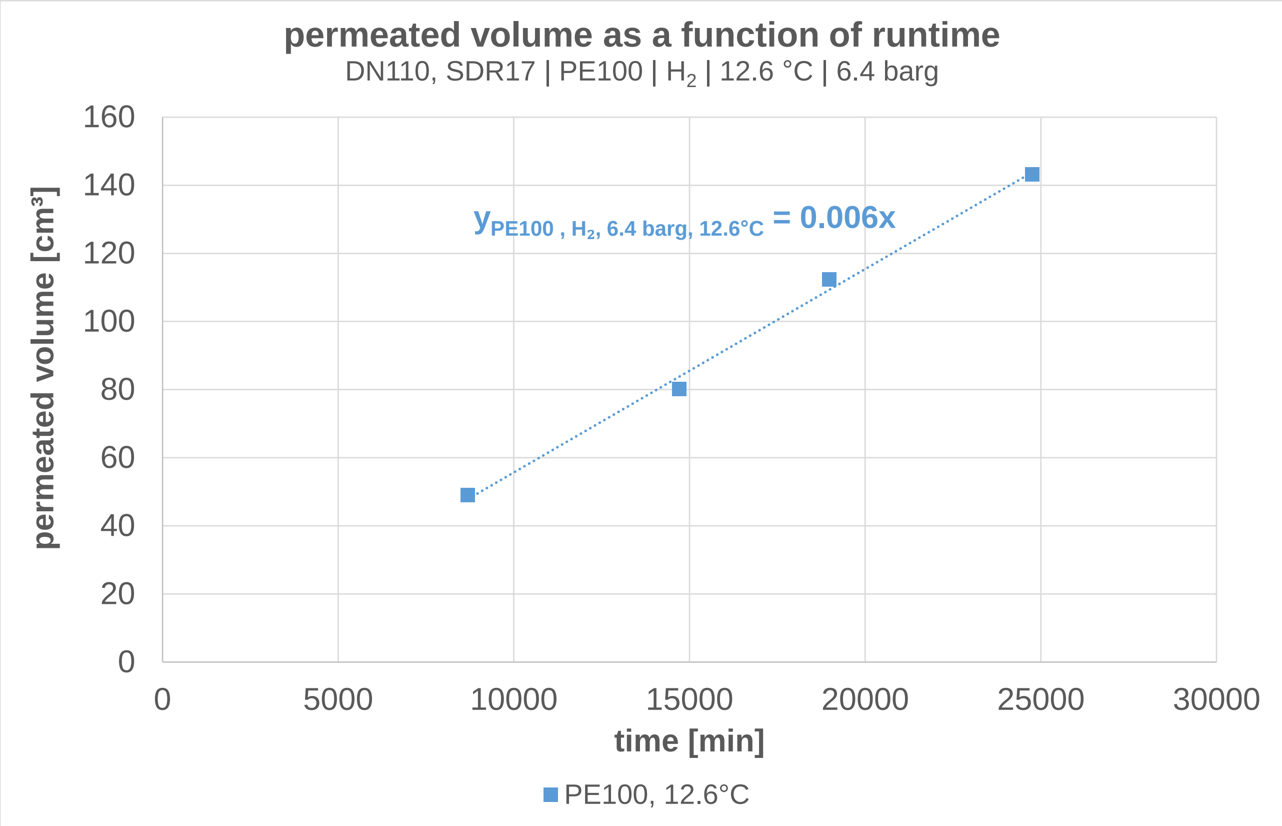

Figure 6: Permeated volume of hydrogen through PE1000 at 12.6°C and 6.4 barg internal pipe pressure

The following permeation coefficients were calculated for the PE100 test pipe using four GC measuring points.

- Hydrogen: $P_{PE100,\ 6.4\ barg,\ 12.6°C,\ H_2} = 71\ \frac{cm^3 i.N. \cdot mm}{m^2 \cdot bar \cdot day}$

1.2.3 permeation coefficient PE100, target temperature 20°C

Table 9 shows the measured values of the measurement series for PE100 at a target temperature of 20°C. Figure 7 shows the recording of the constant permeation rates of hydrogen on the PE100 pipe at an internal pipe pressure of approx. 6.3 barg and an ambient temperature of approx. 20°C.

Table 9: measurement results hydrogen PE100, target temp. 20°C

date	runtime [min]	avg. temperature [°C]	avg. pipe pressure [barg]	pressure measuring cell [bara]	measured value hydrogen [Vol.-%]	permeated volume i.N. H_2, [cm³]
14.12.21	0	20.5	6.7	1.107	0.000	0.000
15.12.21	1,350			1.103	0.142	10.979
22.12.21	11,400			1.119	1.308	102.616
05.01.22	31,830			1.147	3.853	309.791

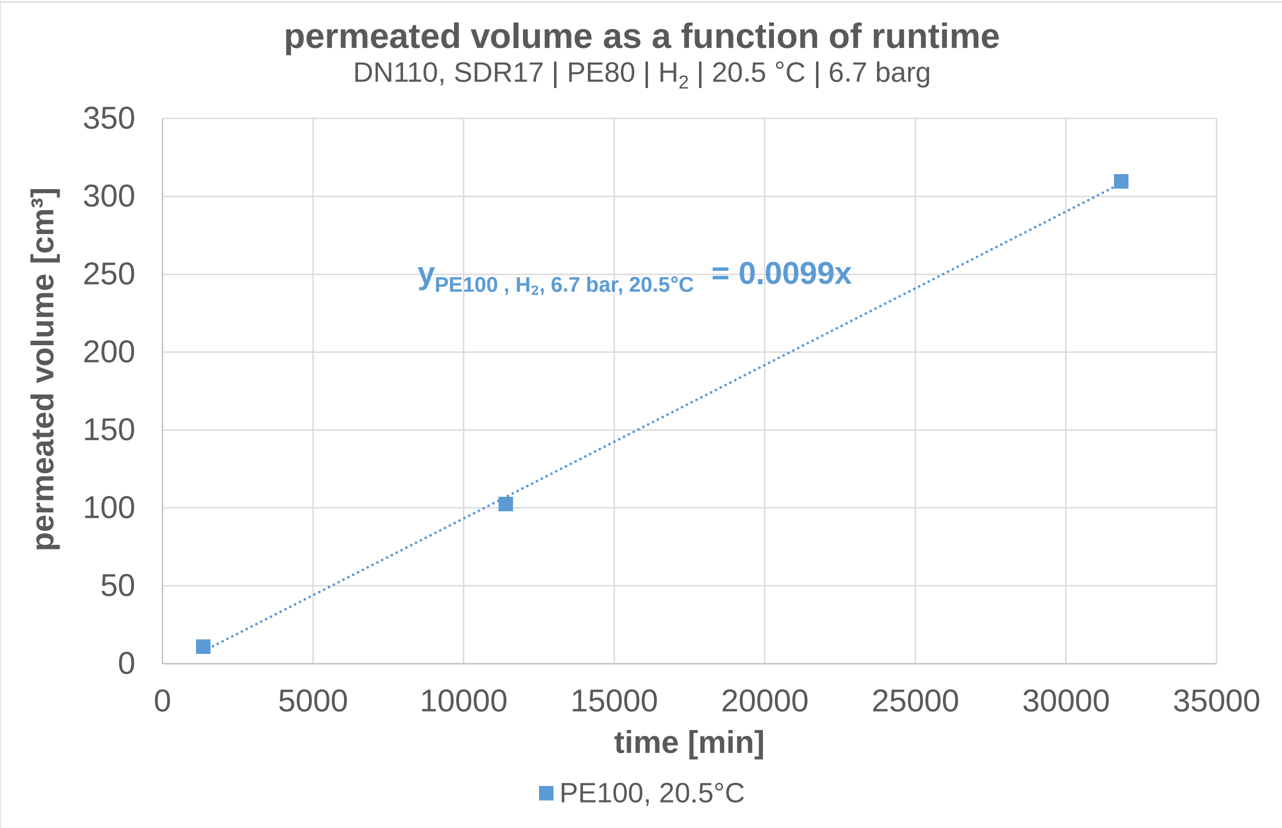

Figure 7: Permeated volume of hydrogen through PE100 at 20.5°C and 6.7 barg internal pipe pressure

The following permeation coefficients were calculated for the PE100 test pipe using three GC measuring points.

- Hydrogen: $P_{PE100,\ 6.7\ barg,\ 20.5°C,\ H_2} = 113\ \frac{cm^3 i.N.\cdot mm}{m^2\cdot bar\cdot day}$

1.2.4 Summary PE100

The measurement results show the temperature dependency of the permeation coefficients. The dependency is assumed to be an exponential function. Figure 8 shows the course of the permeation coefficient as a function of temperature based on measured values. The assumed course of the permeation coefficient can be described with the equation $P_{PE100,\ 6.3\ barg,\ x,\ H_2} = 28.5\ e^{0,1x-1}+33$.

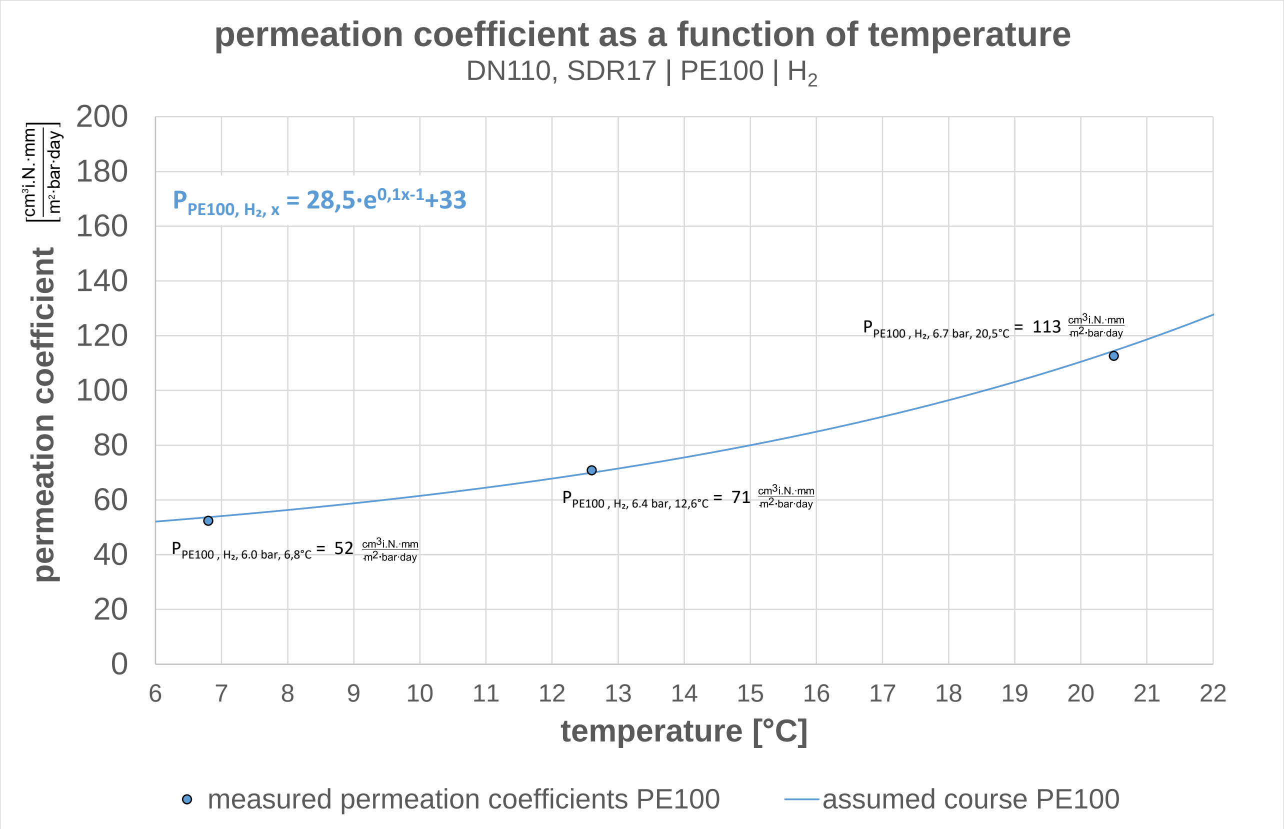

Figure 8: permeation of hydrogen through PE100 as a function of temperature

1.3 permeation coefficient on PE100 RC-pipes (C4 based) with hydrogen

The permeation coefficients for PE100 RC (C4-based) were determined on a DN110, SDR 17 pipe (s_R = 6,47 mm, d_i = 97,06 mm). The same pipe was used in each case for the investigations. The real test temperatures can deviate slightly from the planned temperatures. The real pressures and temperatures are included in the calculation of the permeation coefficient. Table 10 lists the permeation coefficients for PE100 RC (C4-based) and hydrogen, graded according to the test temperature.

Table 10: permeation coefficient of hydrogen through PE100 RC (C4-based)

material	manufacturer	avg. temperature	avg. pressure	permeation coefficient
PE100 RC (C4)	LyondellBasell	7.3 °C	6.2 barg	59 $^{cm^3 i.N.\cdot mm}/_{m^2\cdot bar\cdot day}$
PE100 RC (C4)	LyondellBasell	15.2 °C	6.3 barg	91 $^{cm^3 i.N.\cdot mm}/_{m^2\cdot bar\cdot day}$
PE100 RC (C4)	LyondellBasell	20.9 °C	6.5 barg	125 $^{cm^3 i.N.\cdot mm}/_{m^2\cdot bar\cdot day}$

1.3.1 permeation coefficient PE100 RC (C4 based), target temperature 8°C

Table 11 shows the measured values of the measurement series for PE100 RC (C4-based) at a target temperature of 8°C. Figure 9 shows the recording of the constant permeation rates of hydrogen on the PE100 RC (C4-based) pipe at an internal pipe pressure of approx. 6.3 barg and an ambient temperature of approx. 8°C.

Table 11: measurement results hydrogen PE100 RC (C4-based), target temp. 8°C

date	runtime [min]	avg. temperature [°C]	avg. pipe pressure [barg]	pressure measuring cell [bara]	measured value hydrogen [Vol.-%]	permeated volume i.N. H_2, [cm³]
09.02.22	0	7.3	6.2	1.073	0.000	0.000
14.02.22	7,560			1.031	0.569	43.069
17.02.22	11,835			1.033	0.867	65.784
21.02.22	17,560			1.039	1.247	95.120
24.02.22	21,930			1.041	1.455	111.222

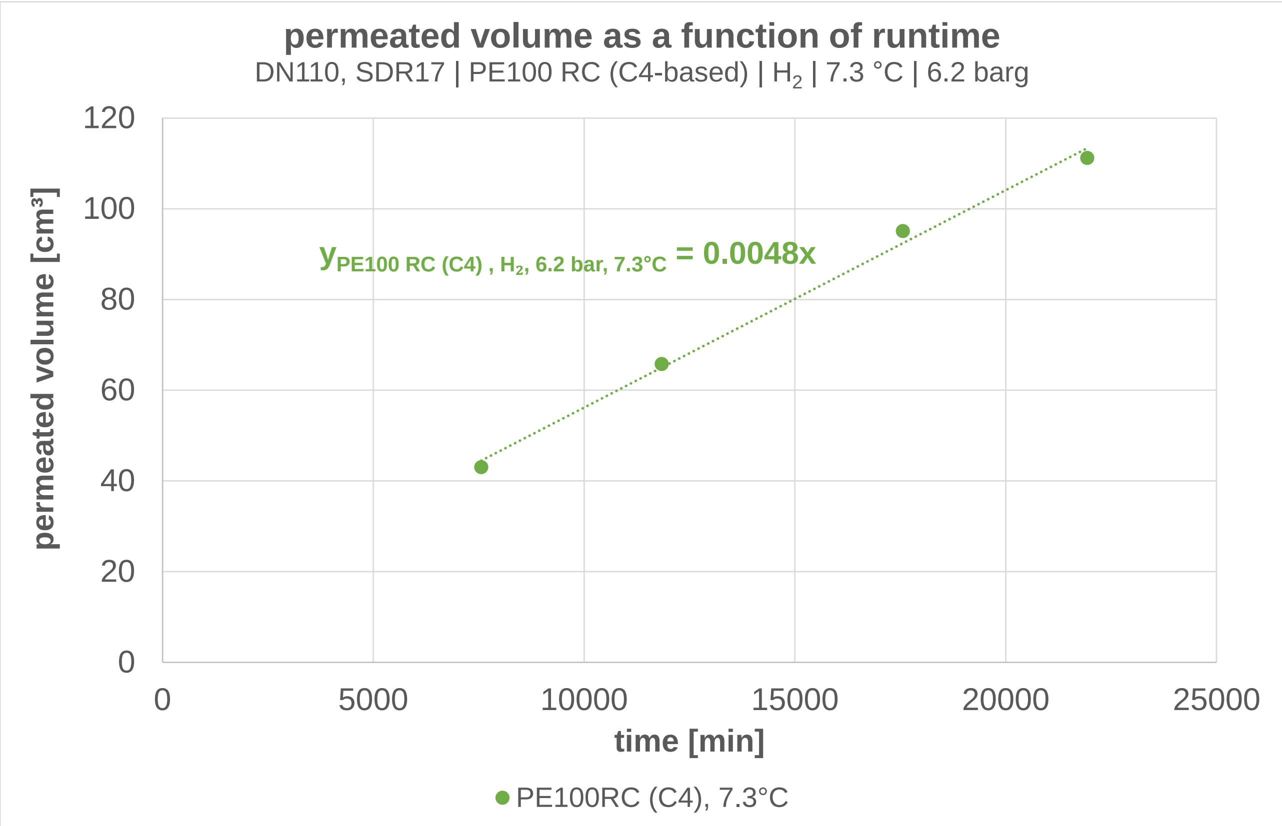

Figure 9: Permeated volume of hydrogen through PE100 RC (C4) at 7.3°C and 6.2 barg internal pipe pressure

For the PE100 RC (C4) test pipe, the following permeation coefficients were calculated for hydrogen using four GC measuring points.

- Hydrogen: $P_{\text{PE100 RC (C4), 6.2 barg, 7.3°C, } H_2} = 59 \, \frac{cm^3 i.N. \cdot mm}{m^2 \cdot bar \cdot day}$

1.3.2 permeation coefficient PE100 RC (C4 based), target temperature 14°C

Table 12 shows the measured values of the measurement series for PE100 RC (C4-based) at a target temperature of 14°C. Figure 10 shows the recording of the constant permeation rates of hydrogen on the PE100 RC (C4-based) pipe at an internal pipe pressure of approx. 6.3 barg and an ambient temperature of approx. 14°C.

Table 12: measurement results hydrogen PE100 RC (C4-based), target temp. 14°C

date	runtime [min]	avg. temperature [°C]	avg. pipe pressure [barg]	pressure measuring cell [bara]	measured value hydrogen [Vol.-%]	permeated volume i.N. H_2, [cm³]
14.12.21	0	15.2	6.3	1.083	0.000	0.000
15.12.21	1,320			1.075	0.146	11.250
17.12.21	4,260			1.082	0.443	34.368
22.12.21	11,250			1.092	1.202	94.138
05.01.22	31,740			1.115	3.057	244.262

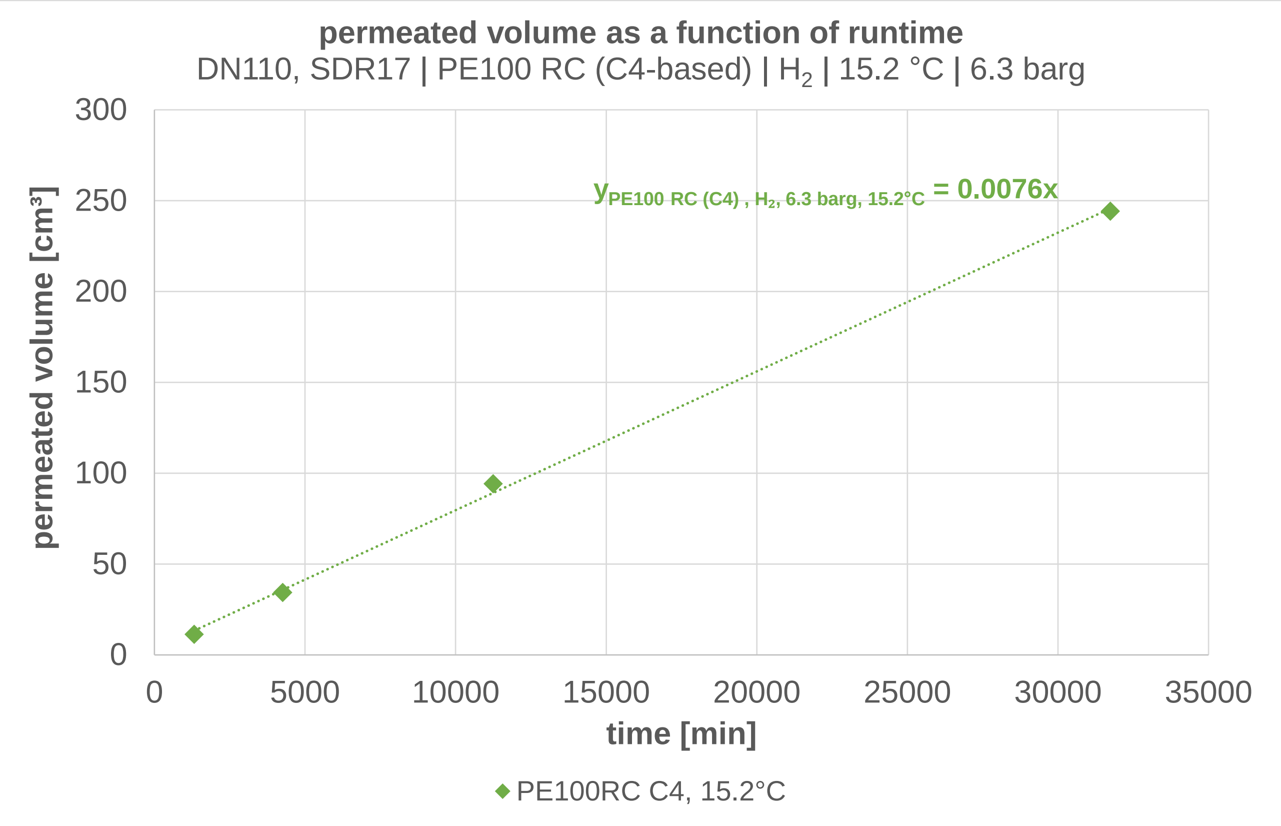

Figure 10: Permeated volume of hydrogen through PE100 RC (C4) at 15.2°C and 6.3 barg internal pipe pressure

For the PE100 RC (C4) test pipe, the following permeation coefficients were calculated for hydrogen using four GC measuring points.

- Hydrogen: $P_{\text{PE100 RC (C4), 6.3 barg, 15.2°C, } H_2} = 91\ \frac{cm^3 i.N.\cdot mm}{m^2\cdot bar\cdot day}$

1.3.3 permeation coefficient PE100 RC (C4 based), target temperature 20°C

Table 13 shows the measured values of the measurement series for PE100 RC (C4-based) at a target temperature of 20°C. Figure 11 shows the recording of the constant permeation rates of hydrogen on the PE100 RC (C4-based) pipe at an internal pipe pressure of approx. 6.3 barg and an ambient temperature of approx. 20°C.

Table 13: measurement results hydrogen PE100 RC (C4-based), target temp. 20°C

date	runtime [min]	avg. temperature [°C]	avg. pipe pressure [barg]	pressure measuring cell [bara]	measured value hydrogen [Vol.-%]	permeated volume i.N. H_2, [cm³]
10.01.22	0	20.9	6.5	1.119	0.000	0.000
12.01.22	3,090			1.135	0.468	37.190
14.01.22	5,984			1.139	0.901	71.869
17.01.22	10,335			1.147	1.534	123.242
20.01.22	14,220			1.154	1.940	156.757

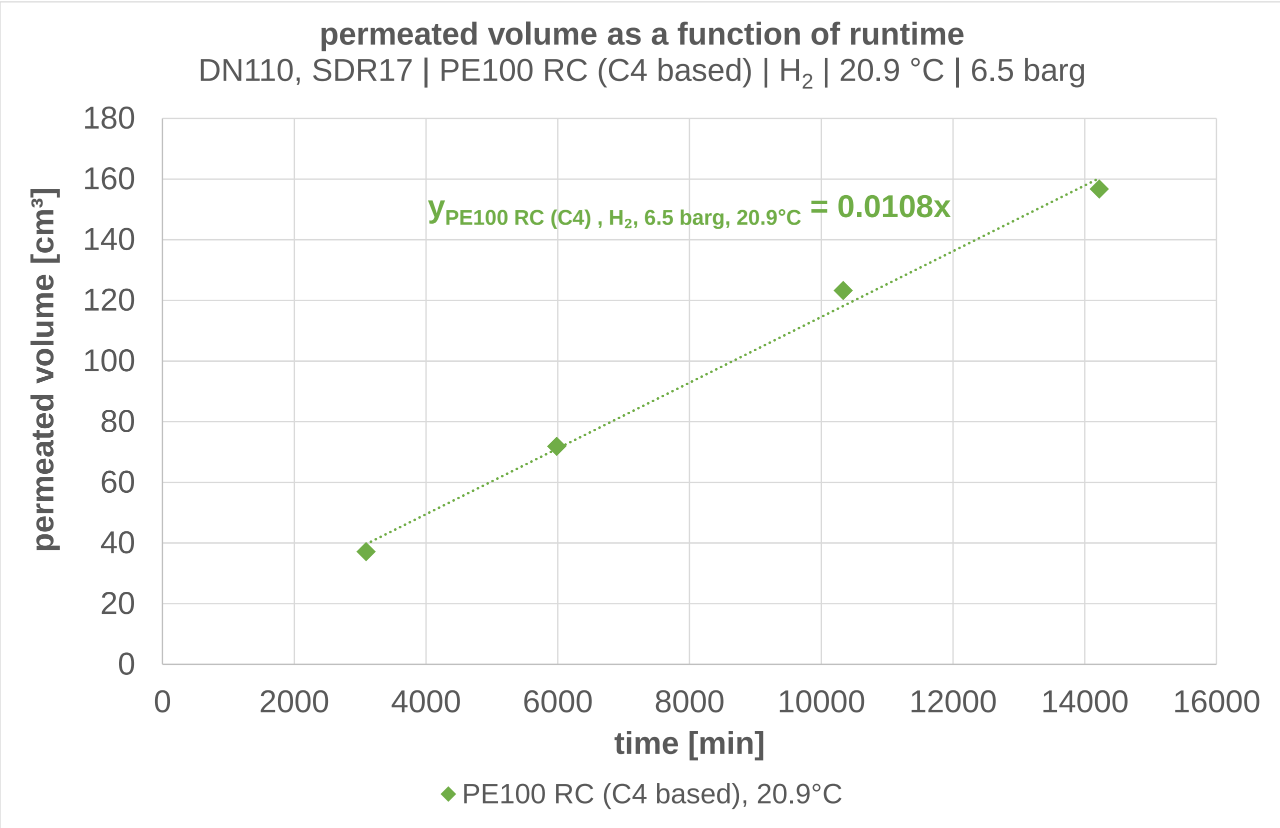

Figure 11: Permeated volume of hydrogen through PE100 RC (C4) at 20.9°C and 6.5 barg internal pipe pressure

For the PE100 RC (C4 based) test pipe, the following permeation coefficients were calculated for hydrogen using four GC measuring points.

- Hydrogen: $P_{PE100\ RC\ (C4),\ 6.5\ barg,\ 20.9°C,\ H_2} = 125\ \frac{cm^3 i.N.\cdot mm}{m^2\cdot bar\cdot day}$

1.3.4 Summary PE100 RC (C4 based)

The measurement results show the temperature dependency of the permeation coefficients. The dependency is assumed to be an exponential function. Figure 12 shows the course of the permeation coefficient as a function of temperature using measured values. The assumed course of the permeation coefficient can be described with the equation $P_{PE100\ RC\ (C4),\ 6.3\ barg,\ x,\ H_2} = 68\ e^{0,07x-1}+18$.

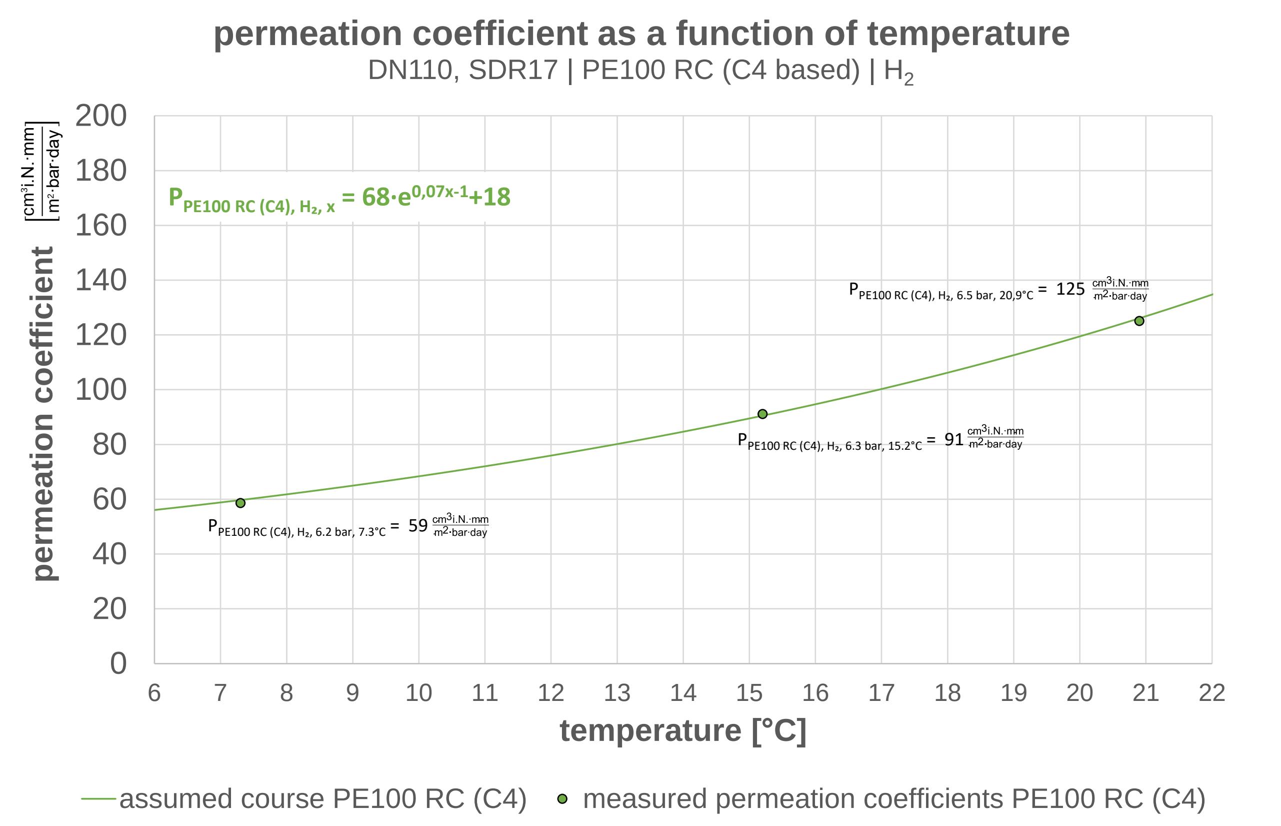

Figure 12: permeation of hydrogen through PE100 RC (C4 based) as a function of temperature

1.4 Permeation coefficient on PE100 RC (C6 based) with hydrogen

The permeation coefficients for PE100 RC (C6-based) were determined on a DN110, SDR 17 pipe (s_R = 6,47 mm, d_i = 97,06 mm). The same pipe was used in each case for the investigations. The real test temperatures can deviate slightly from the planned temperatures. The real pressures and temperatures are included in the calculation of the permeation coefficient. Table 14 lists the permeation coefficients for PE100 RC (C6-based) and hydrogen, graded according to the test temperature.

Table 14: permeation coefficient of hydrogen through PE100 RC (C6-based)

material	manufacturer	avg. temperature	avg. pressure	permeation coefficient
PE100 RC (C6)	INEOS	8.4 °C	6.2 barg	66 $^{cm^3 i.N. \cdot mm}/_{m^2 \cdot bar \cdot day}$
PE100 RC (C6)	INEOS	12.6 °C	6.1 barg	73 $^{cm^3 i.N. \cdot mm}/_{m^2 \cdot bar \cdot day}$
PE100 RC (C6)	INEOS	20.9 °C	6.7 barg	123 $^{cm^3 i.N. \cdot mm}/_{m^2 \cdot bar \cdot day}$

1.4.1 Permeation coefficient PE100 RC (C6 based), target temperature 8°C

Table 15 shows the measured values of the measurement series for PE100 RC (C6-based) at a target temperature of 8°C. Figure 13 shows the recording of the constant permeation rates of hydrogen on the PE100 RC (C6-based) pipe at an internal pipe pressure of approx. 6.3 barg and an ambient temperature of approx. 8°C.

Table 15: measurement results hydrogen PE100 RC (C6-based), target temp. 8°C

date	runtime [min]	avg. temperature [°C]	avg. pipe pressure [barg]	pressure measuring cell [bara]	measured value hydrogen [Vol.-%]	permeated volume i.N. H_2, [cm³]
25.02.22	0	8.4	6.2	1.150	0.000	0.000
02.03.22	7,350			1.103	0.491	39.614
07.03.22	14,385			1.108	0.969	78.547
10.03.22	18,905			1.125	1.243	102.304
14.03.22	24,710			1.120	1.627	133.254

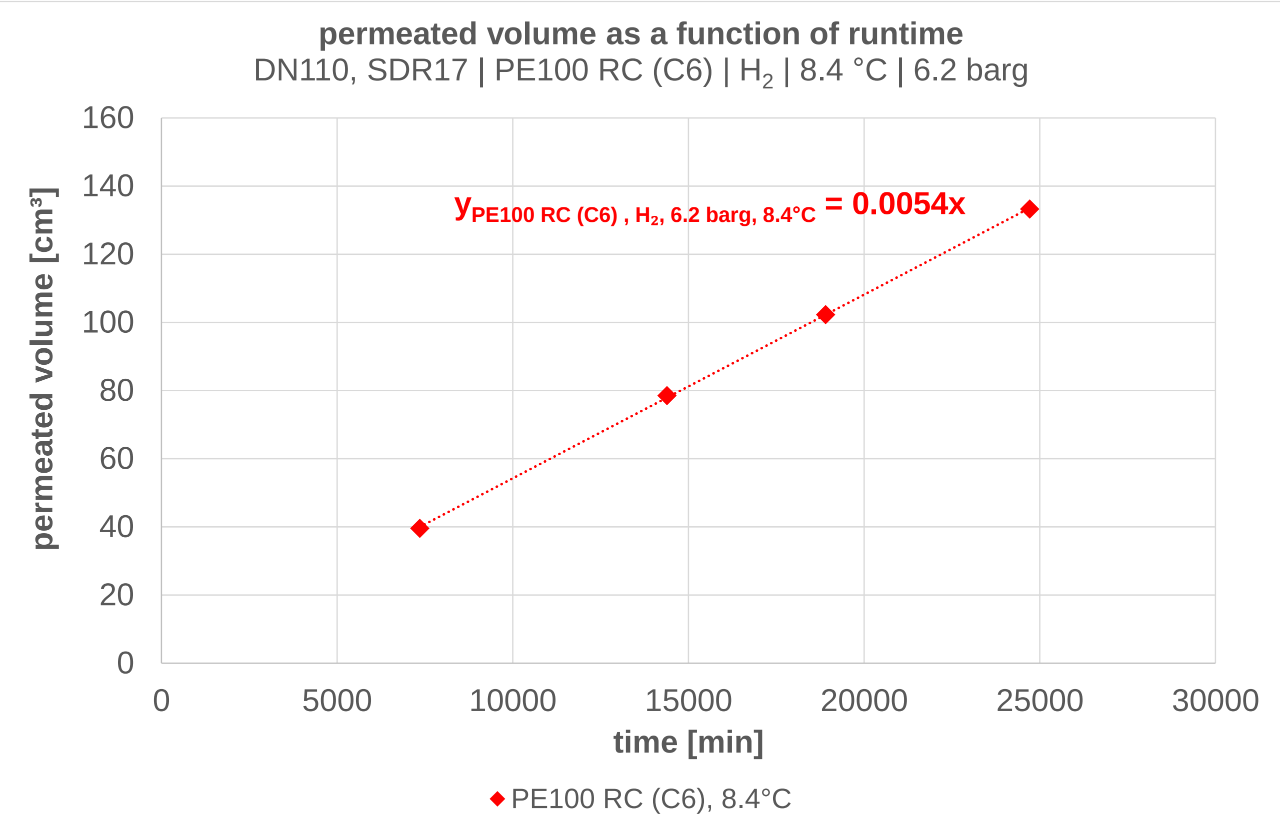

Figure 13: permeated volume of hydrogen through PE100 RC (C6) at 8.4°C and 6.2 barg internal pipe pressure

For the PE100 RC (C6) test pipe, the following permeation coefficients were calculated for hydrogen using four GC measuring points.

- Hydrogen: $P_{PE100\ RC\ (C6),\ 6.2\ barg,\ 8.4°C,\ H_2} = 66\ \frac{cm^3 i.N.\cdot mm}{m^2 \cdot bar \cdot day}$

1.4.2 Permeation coefficient PE100 RC (C6 based), target temperature 14°C

Table 16 shows the measured values of the measurement series for PE100 RC (C6-based) at a target temperature of 14°C. Figure 14 shows the recording of the constant permeation rates of hydrogen on the PE100 RC (C6-based) pipe at an internal pipe pressure of approx. 6.3 barg and an ambient temperature of approx. 14°C.

Table 16: measurement results hydrogen PE100 RC (C6-based), target temp. 14°C

date	runtime [min]	avg. temperature [°C]	avg. pipe pressure [barg]	pressure measuring cell [bara]	measured value hydrogen [Vol.-%]	permeated volume i.N. H_2, [cm³]
14.12.21	0	12.6	6.1	1.078	0.000	0.000
15.12.21	1,320			1.070	0.098	7.516
17.12.21	4,260			1.078	0.324	25.041
22.12.21	11,250			1.089	0.895	69.851
05.01.22	31,740			1.103	2.359	186.478

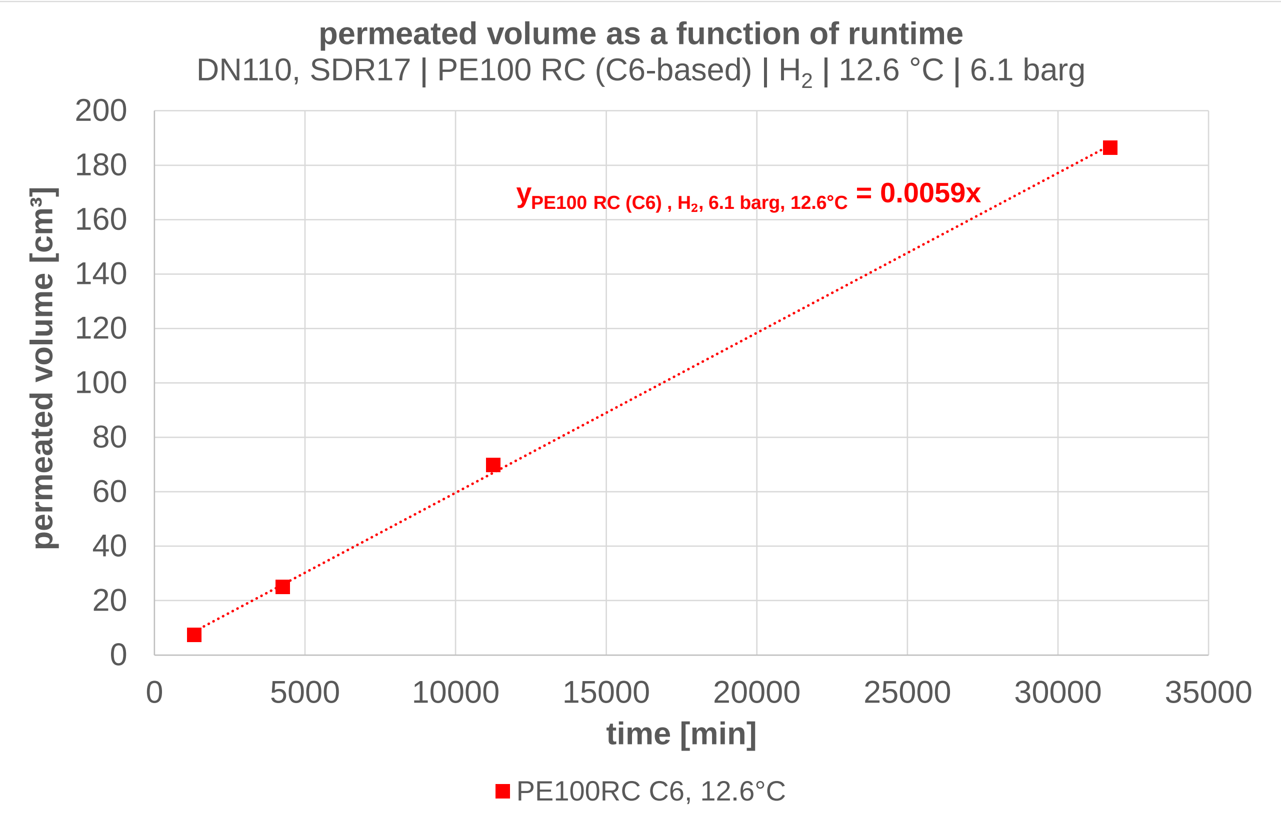

Figure 14: Permeated volume of hydrogen through PE100 RC (C6 based) at 12.6°C and 6.1 barg internal pipe pressure

For the PE100 RC (C6 based) test pipe, the following permeation coefficients were calculated for hydrogen using four GC measuring points.

- Hydrogen: $P_{\text{PE100 RC (C6), 6.1 barg, 12.6°C, } H_2} = 73\ \frac{cm^3 i.N.\cdot mm}{m^2\cdot bar\cdot day}$

1.4.3 Permeation coefficient PE100 RC (C6 based), target temperature 20°C

Table 17 shows the measured values of the measurement series for PE100 RC (C6-based) at a target temperature of 20°C. Figure 15 shows the recording of the constant permeation rates of hydrogen on the PE100 RC (C6-based) pipe at an internal pipe pressure of approx. 6.3 barg and an ambient temperature of approx. 20°C.

Table 17: measurement results hydrogen PE100 RC (C6 based), target temp. 20°C

date	runtime [min]	avg. temperature [°C]	avg. pipe pressure [barg]	pressure measuring cell [bara]	measured value hydrogen [Vol.-%]	permeated volume i.N. H_2, [cm³]
10.01.22	0	20.9	6.7	1.128	0.000	0.000
12.01.22	3,090			1.144	0.410	32.839
14.01.22	5,984			1.147	0.793	63.704
17.01.22	10,335			1.154	1.345	108.755
20.01.22	14,220			1.161	1.900	154.483

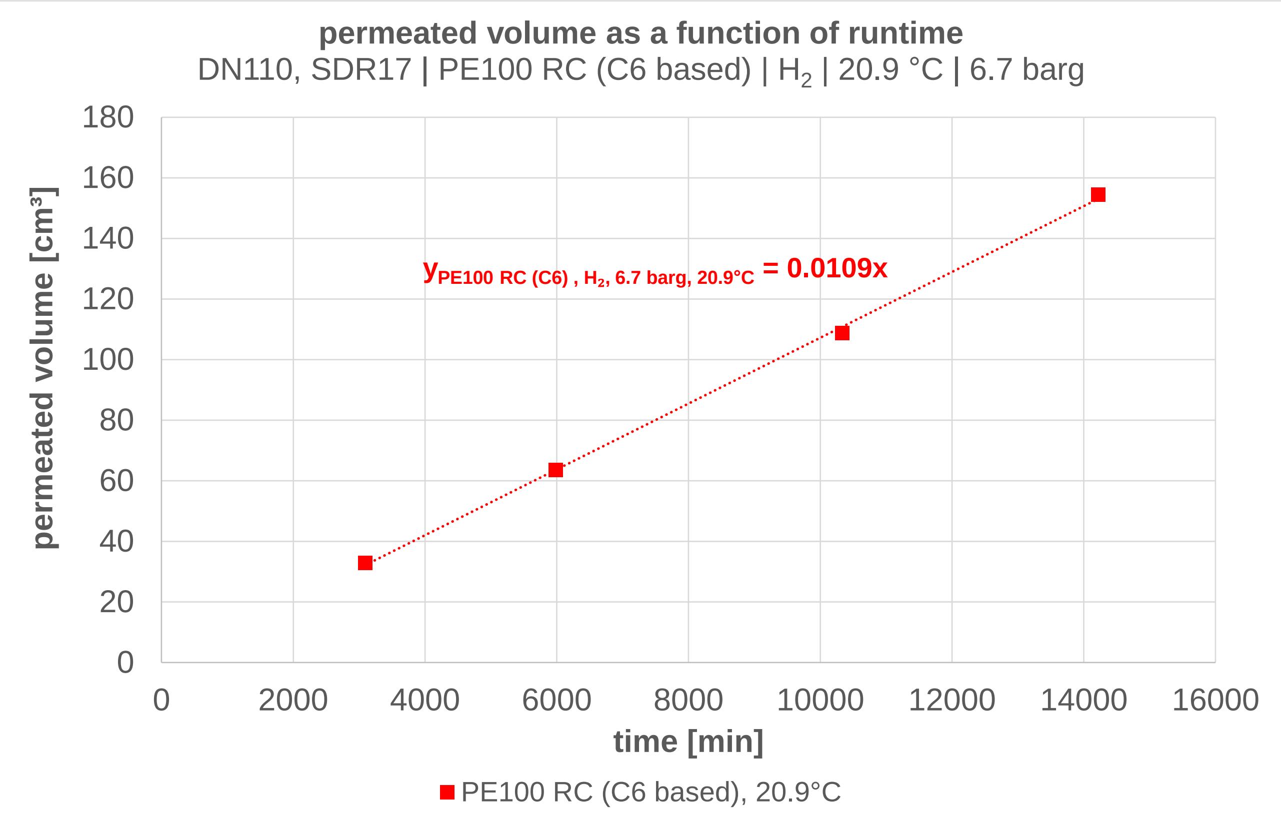

Figure 15: Permeated volume of hydrogen through PE100 RC (C6) at 20.9°C and 6.7 barg internal pipe pressure

For the PE100 RC (C6 based) test pipe, the following permeation coefficients were calculated for hydrogen using four GC measuring points.

- Hydrogen: $P_{\text{PE100 RC (C6 based), 6.7 barg, 20.9°C, }H_2} = 123\ \frac{\text{cm}^3 \text{i.N.}\cdot\text{mm}}{\text{m}^2\cdot\text{bar}\cdot\text{day}}$

1.4.4 Summary PE100 RC (C6 based)

The measurement results show the temperature dependency of the permeation coefficients. The dependency is assumed to be an exponential function. Figure 16 shows the course of the permeation coefficient as a function of temperature using measured values. The assumed course of the permeation coefficient can be described with the equation $P_{PE100\ RC\ (C6),\ 6.3\ barg,\ x,\ H_2} = 4\ e^{0,18x-1}+60$.

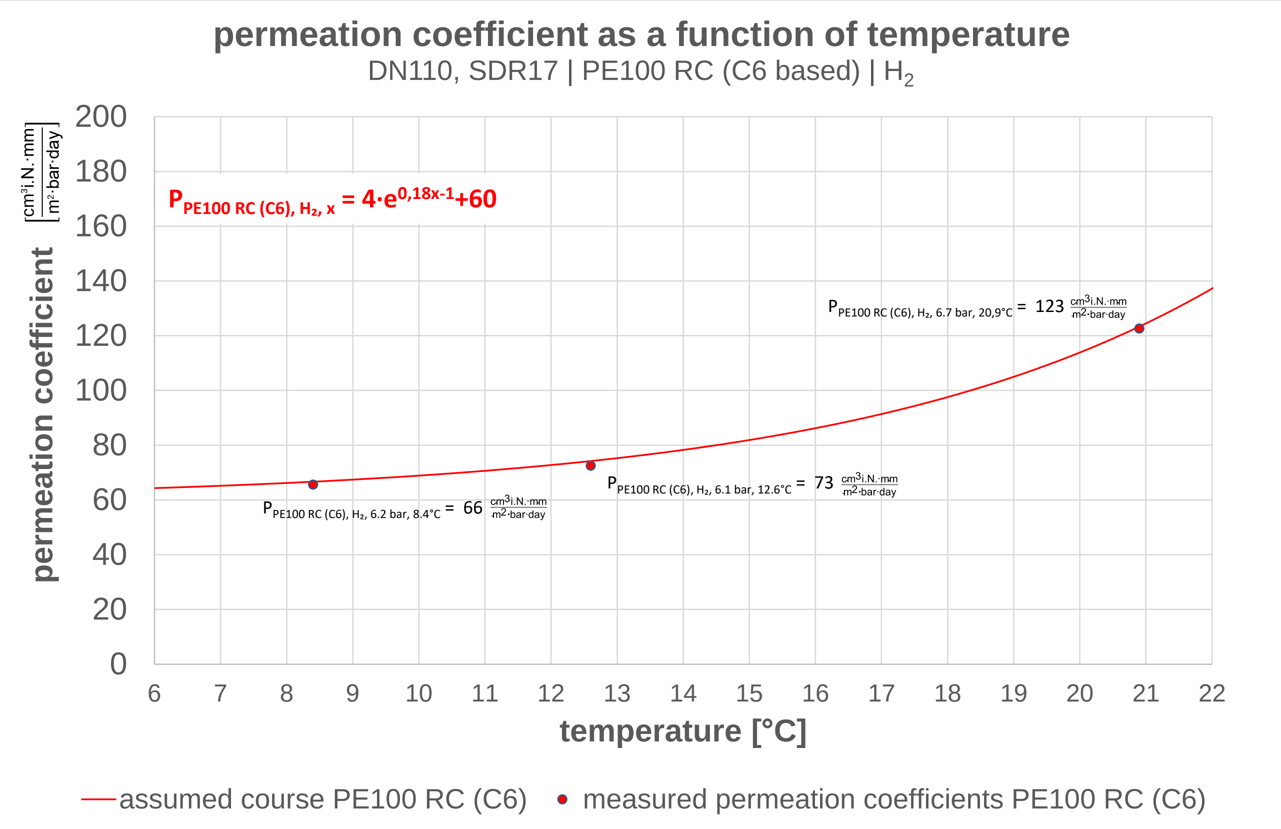

Figure 16: permeation of hydrogen through PE100 RC (C6 based) as a function of temperature

2 Evaluation

The comparison of the permeation coefficients of hydrogen on polyethylene pipes shows that the permeability of the investigated materials is in a similar range. The temperature dependence of the permeation coefficients for hydrogen is also comparable. Table 18 shows the calculated permeation coefficients of hydrogen for the target temperatures through the different PE materials.

Table 18: calculated permeation coefficients of hydrogen for the target temperatures through the investigated PE materials

material	calculated values for the target temperatures		
	8°C	14°C	20°C
PE80	68 cm^3i.N.·mm/m^2·bar·day	84 cm^3i.N.·mm/m^2·bar·day	113 cm^3i.N.·mm/m^2·bar·day
PE100	56 cm^3i.N.·mm/m^2·bar·day	76 cm^3i.N.·mm/m^2·bar·day	110 cm^3i.N.·mm/m^2·bar·day
PE100-RC C4	62 cm^3i.N.·mm/m^2·bar·day	85 cm^3i.N.·mm/m^2·bar·day	119 cm^3i.N.·mm/m^2·bar·day
PE100-RC C6	66 cm^3i.N.·mm/m^2·bar·day	78 cm^3i.N.·mm/m^2·bar·day	114 cm^3i.N.·mm/m^2·bar·day

The description of the temperature dependence of the permeability is an assumption based on the measured permeation coefficients at different temperatures and a compensation function based on an exponential function.

Taking into account a certain scattering of the measured values and slight deviations (pressure, temperature) of the individual series of measurements/materials, the permeation coefficients for hydrogen for PE materials can be recorded according to table 19.

Table 19: permeation coefficient of hydrogen through the investigated PE-materials

temperature = 8°C	temperature = 14°C	temperature = 20°C
55-65 cm^3i.N.·mm/m^2·bar·day	75-85 cm^3i.N.·mm/m^2·bar·day	110-120 cm^3i.N.·mm/m^2·bar·day

In Figure 17, the permeation coefficients determined for hydrogen are plotted at three different temperatures. The compensation functions describing the temperature-dependent permeation coefficients are also plotted.

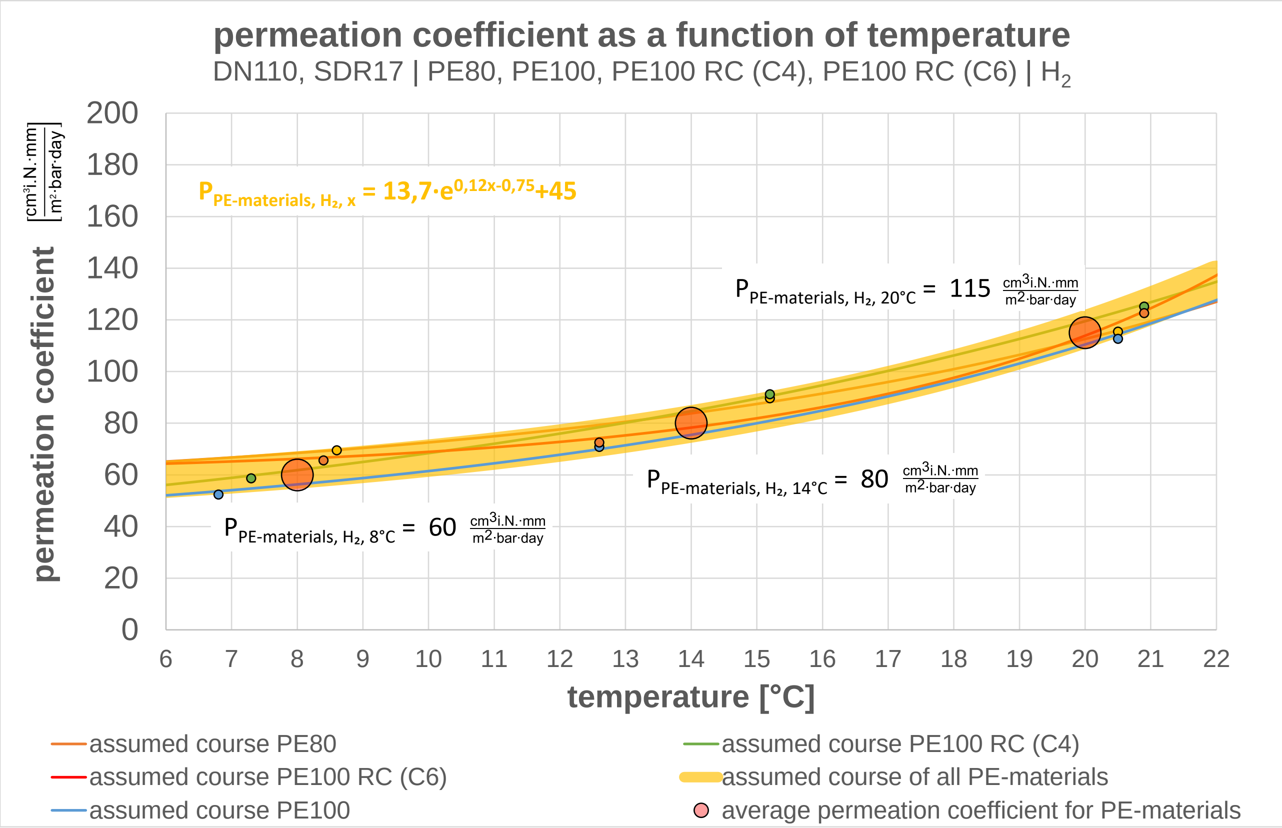

Figure 17: permeation coefficient as a function of temperature – PE80, PE100, PE100 RC (C4), PE100 RC (C6)

The permeation coefficients of the investigated materials are in line with expectations and comparable to similar products made of polyethylene.