COMPARISON OF DIFFERENT POLYMERIC SEALINGS FOR HOT WATER STORAGES

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1. Introduction

Solar heating systems with collector areas over 20 m² for hot water preparation and space heating mostly require heat storages with a volume of ≥ 2 m³. Due to limited space and narrow door passages, the installation of the necessary storage volume can be difficult or impossible, especially in residential buildings. Within a research project financed by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety*, a new concept for the design of a hot water storage was developed that helps to solve that problem. Fig. 1 shows a simplified design of the concept. A frame made of steel profiles defines the geometry and takes up mechanical loads. Sandwich insulation panels made of metal sheets and polyurethane foam provide thermal insulation and dispose the surface load of the hydrostatic water pressure to the steel frame elements.

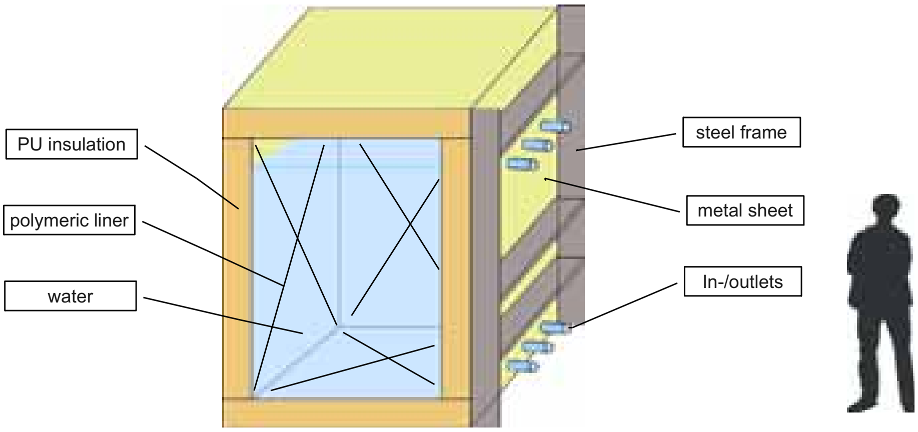

Fig. 1: Multi-component hot water storage with an inner liner/membrane made of polymeric materials.

Regarding water sealing, several polymeric materials were reviewed and tested within the research project. Three materials were selected for further investigation:

1. EPDM (ethylene-propylene-dien-monomer rubber), a synthetic elastomer with a wide operation temperature range from -40 to 130°C. EPDM is widely used in different sealing applications such as sealings, roof covers or flexible tubes.
2. IIR (butyl rubber), a synthetic elastomer with very good air impermeability properties. Typical applications are tire innertubes and membranes in expansion vessels.
3. PP-H (homopolymer propylene) is a polyolefine polymer with low permeation properties and a temperature range from 0 to 100°C. Big underground pipes and tanks e.g. for chemicals are made of PP-H.

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To evaluate the capability of the selected materials, not only physical properties of the polymers are relevant. For a successful design of a storage sealing, different aspects like processing, costs, tank construction, joining techniques have to be taken into account, as described in Wilhelms (2011).

This paper discusses the water vapour transport and ageing properties of the three preselected polymers. To get most lifelike results, own measurements has been carried out where the materials has been exposed under same conditions like in the focused application.

2. Determination of Water Vapour Transport Properties

Regarding the function of polymers in the storage as a sealing liner, the knowledge of the amount of water loss of a hot water storage as a result of water vapour transport is important. EPDM, IIR, and PP-H were exposed in hot water baths for up to 15.000 h at 78°, 88° and 98°C. The experimental device was especially constructed for the investigation of liner material under realistic conditions and was strongly inspired by a design of a test rig discussed in Ochs (2008). With standardised measurement procedures[*] it is nearly not possible to evaluate the suitability of the materials since the water vapour permeation is measured only up to a temperature of 38°C. However, the water vapour permeation increases exponentially with rising temperatures. Fig. 2 shows the device and a schematic of the flanges.

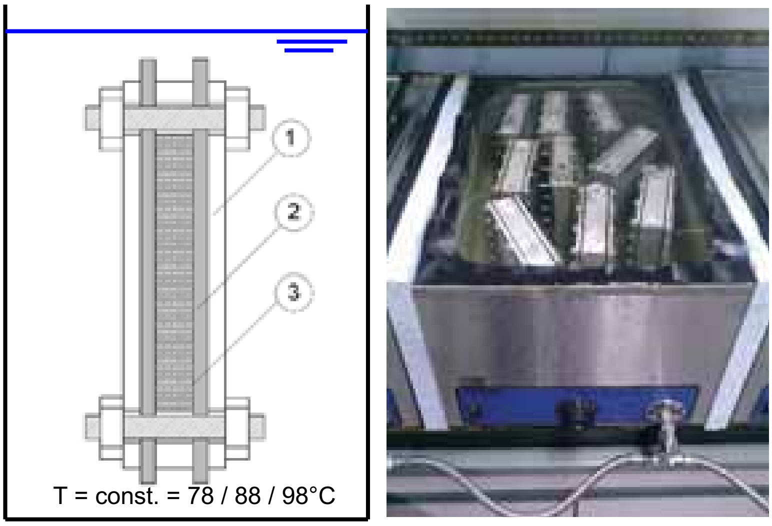

Fig. 2: Testing device for determination of the water vapour permeation resistance factor for different polymers at different temperatures. Sketch of the set-up (left) and picture of the tempering bath (right).
1: aluminium flange, 2: test specimen, 3: desiccant (Zeolith 4A)

The samples are mounted in a flange with a sorption material inside. Thus, the sample liner is in contact with hot water on one side and dry air on the other. This corresponds to the position of an installed liner in the hot water storage. Furthermore, this setup allows the measurement of the water vapour transport in a simple way within a range of water vapour diffusion resistance factor up to $\mu < 1.000.000$. As a well-known reference material, PE-HD with its low permeation properties was also tested.

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[*] e.g. EN 12086, EN 12572, ISO 15106, ASTM E398, JIS K7129

Two indicators were determined: The water vapour diffusion resistance factor μ and the water vapour transmission rate WVTR, where μ is defined as

$$\mu = \frac{\delta_a}{\delta} \quad [-] \quad \text{(eq. 1)}$$

and WVTR as

$$WVTR = \frac{\delta_a}{\mu} \cdot \Delta p_v \quad [\frac{g \cdot mm}{m^2 d}] \quad \text{(eq. 2)},$$

δ_a is the permeability rate in air, δ the permeability rate of the investigated material and Δp_v the total pressure drop across the material. During the exposure, the mass gain in a specific time slot of the sorption-filled flanges was measured. WVTR was determined by the test directly by applying

$$WVTR = \frac{\Delta m_{Flange}}{A_F \Delta t} \cdot d \quad \text{(eq. 3)}$$

with the surface of the liner A_F, time interval $\Delta t = 24$h and thickness of the liner d. Fig. 3 shows the results of PE-HD in comparison to reference data from Gibbesch (1996), Ochs (2010) and Geipel (1986). A good agreement could be demonstrated, although the exact compositions of the materials are not known.

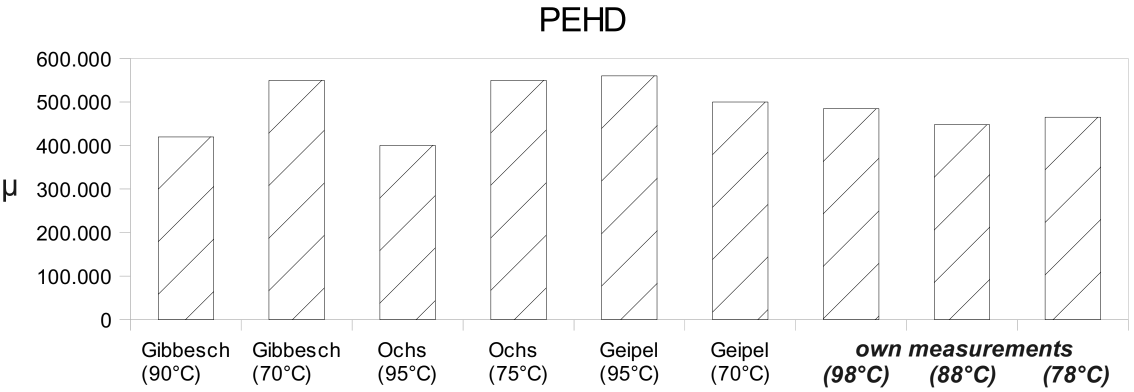

Fig. 3: Determined water vapour diffusion resistance factor of PEHD in comparison to literature values.

Fig. 4 to 5 show the results of the investigated materials. A strong dependency of WVTR regarding the exposal temperature can be seen. While IIR and PP-H allow a fairly low water vapour transport, the water loss through EPDM can be a maximum of WTVR=85 g mm/m²d.

If using EPDM as an inner liner for hot water storages, it is strongly recommended to take care of that, e.g. by using an EPDM liner with vapour barrier material like aluminum sheets or PE-HD layers. In cooperation with Contitech Elastomer Coatings GmbH, a compound liner with a thin aluminum inner layer was developed and tested. Fig. 7 shows the results of the water vapour diffusion measurements. “Trapped” water between the EPDM and aluminum layers transported by vapour diffusion through EPDM leads to a strong deviation and overall decrease of the single measurements. Nevertheless, comparing with standard EPDM material, the water vapour diffusion could be reduced by a factor of ten. The material has been patented 2010 by Contitech (pat. no. EP 2246181).

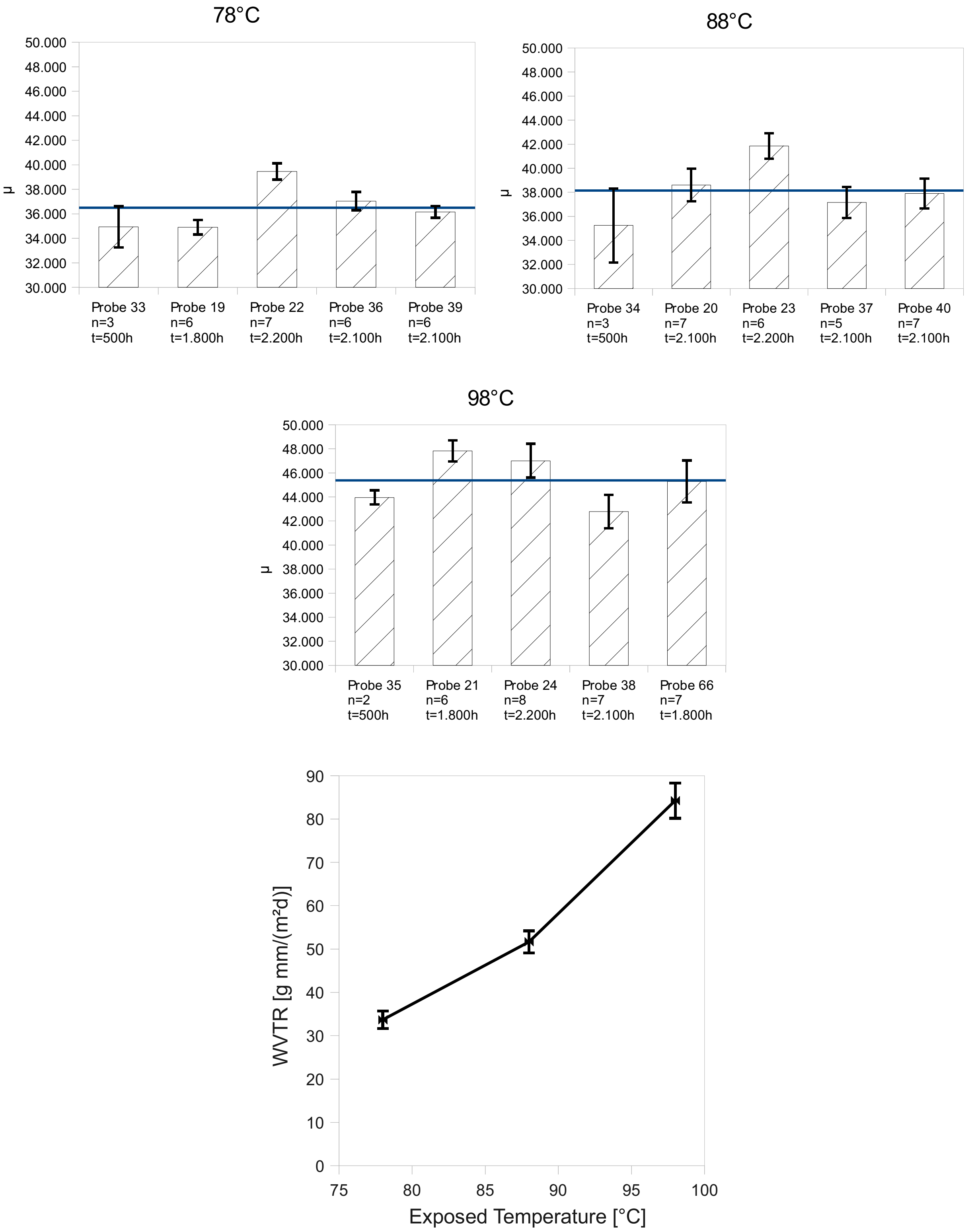

Fig. 4: Determined water vapour resistance factor μ and water vapour transmission rate WVTR of EPDM at the exposal temperatures 78, 88 and 98°C. The average of μ is 40.000.

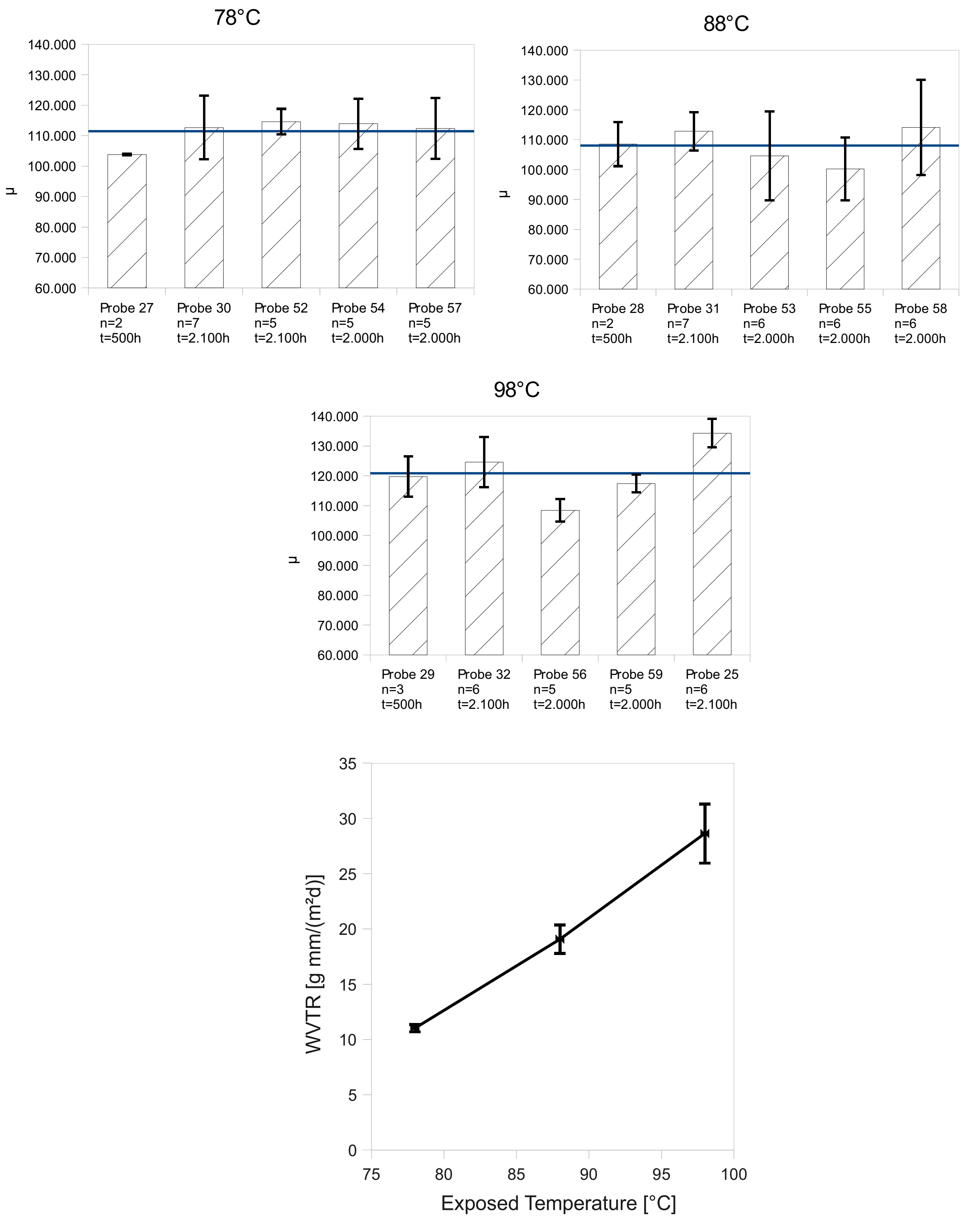

Fig. 5: Determined water vapour resistance factor μ and water vapour transmission rate WVTR of IIR at the exposal temperatures 78, 88 and 98°C. The average of μ is 113.500.

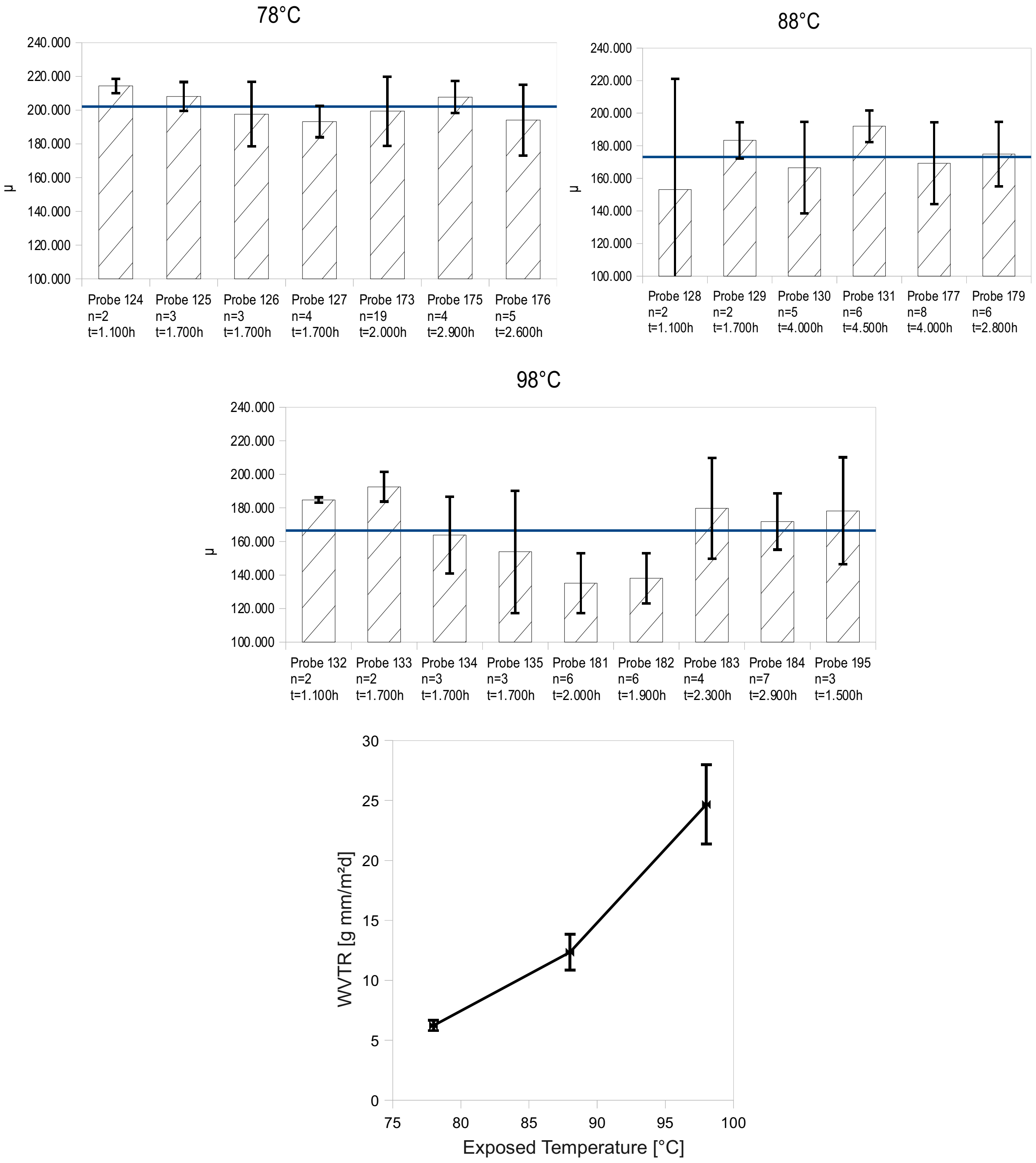

Fig. 6: Determined water vapour resistance factor μ and water vapour transmission rate WVTR of PP-H at the exposed temperatures 78, 88 and 98°C. The average of μ is 181.000.

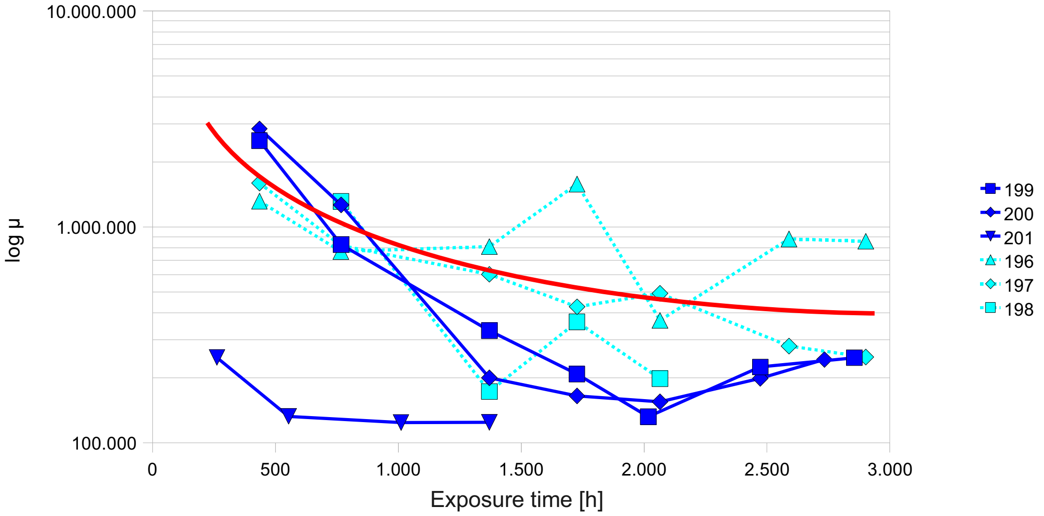

Fig. 7: Determined water vapour resistance factor µ for the multi-layer Al/EPDM layer of different samples. The average of µ is approximately 400.000 (red curve).

3. Ageing of the material

A long lifetime of the inner liner of a minimum of 20 years is required. The material is exposed to fluctuating temperatures in the tank from 15 to 95°C. The same samples used for the water vapour transport measurements were used for the ageing investigations.

Stretch tests were carried out for PP-H, EPDM and IIR after different exposure intervals to find out whether a change of the strength and ultimate strain can be observed as a function of time and hot water temperature.

Fig. 8 to 10 show the measured data. Regarding EPDM and PP-H, no significant reduction in elasticity or strength could be detected at all three temperatures. The strong deviation of the measured elasticity values comes from problems with the fixing of the thin liner material at the stretch testing machine.

The stress and strain values of IIR decrease considerably, especially the material that was exposed at 88 and 98°C. After 8.000 h, the strength is reduced from 12 to 6 MPa. Looking at the samples with 98°C bath temperature, half of the original elasticity is reached after 12.000 h. In literature, a material is often defined as “broken” if the original value is reduced by 100%, see Kahlen (2009) and Brown (2000).

To get further indications of ageing, also the hardness of the three materials was analysed. For the elastomeric materials the shore hardness was measured; polypropylene was the ball hardness. Fig. 11 to 13 show results.

As expected, the hardness of EPDM increases slightly over time to 110% after 16.000 h. If the hardness gets too high, cracks or porosities can occur in operation. In contrast to that the hardness of the reviewed IIR decreases over time. This can be explained by cracking of sulfur cross-linkings and depolymerisation of the elastomeric structure due to the influence of the (too) high exposal temperatures. PP-H shows nearly no change of the hardness over time, as to be expected by a polyolefine. The hardness tests confirm that IIR shows clearly first ageing effects after the test time.

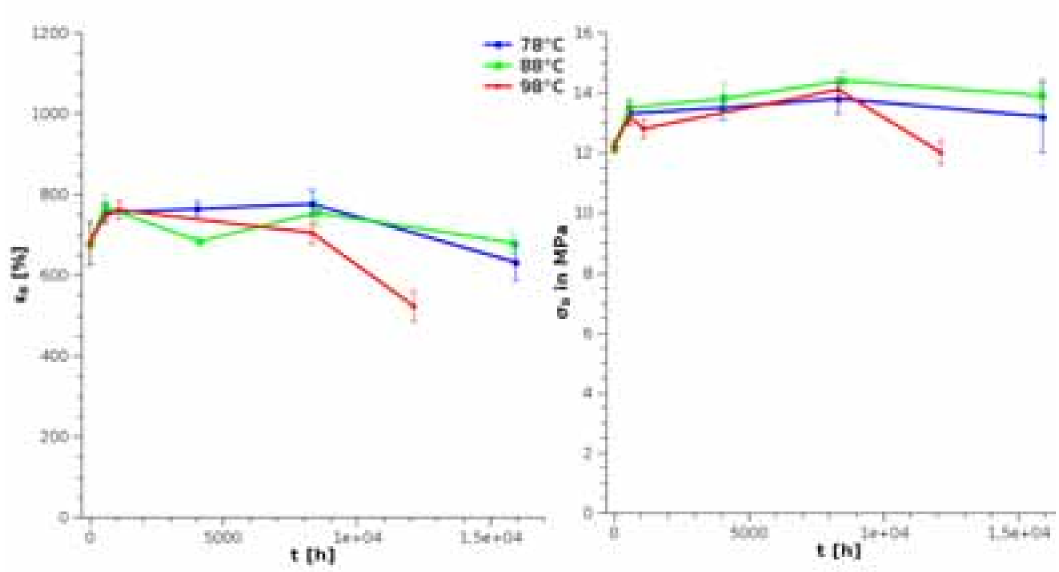

Fig. 8: Maximum strain (left) and stress (right) of EPDM measured after different exposal times and temperatures.

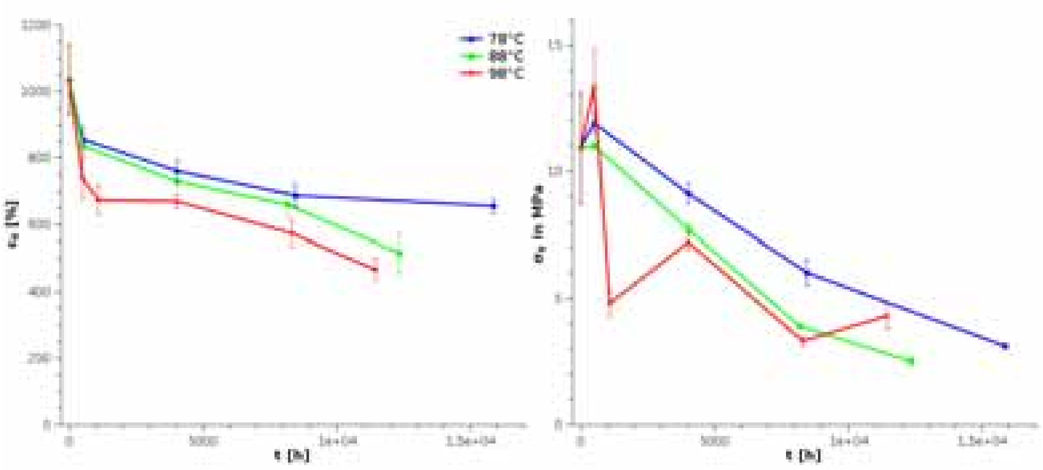

Fig. 9: Maximum strain (left) and stress (right) of IIR measured after different exposal times and temperatures.

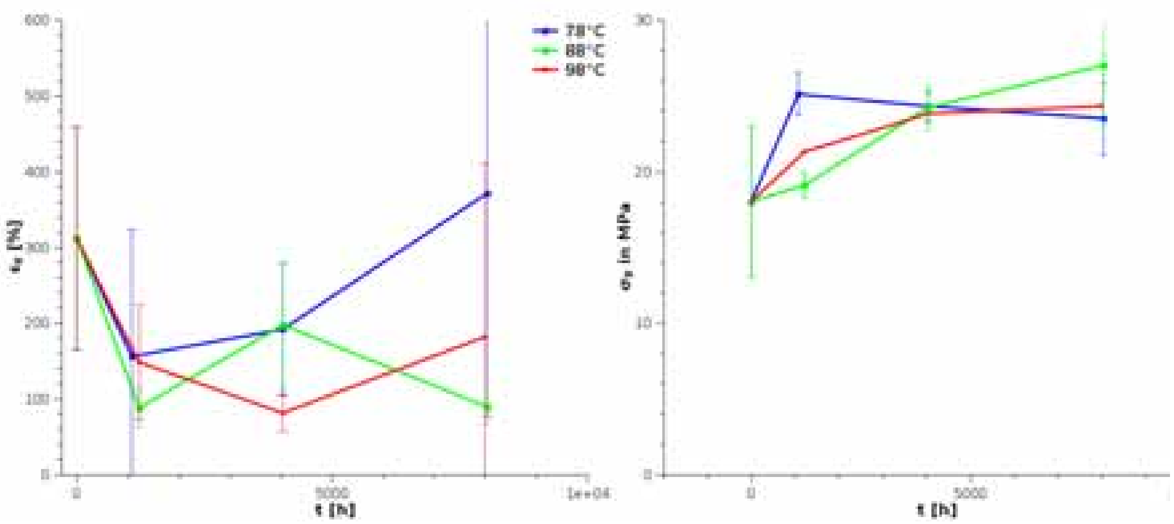

Fig. 10: Maximum strain (left) and stress (right) of PP-H measured after different exposal times and temperatures.

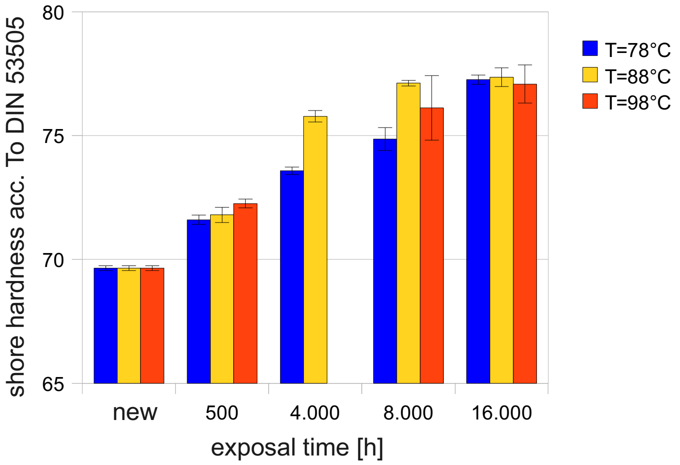

Fig. 11: Shore hardness of EPDM

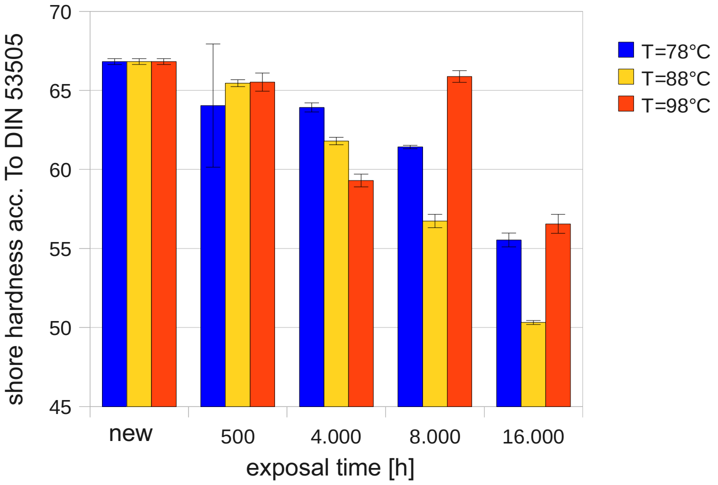

Fig. 12: Shore hardness of IIR

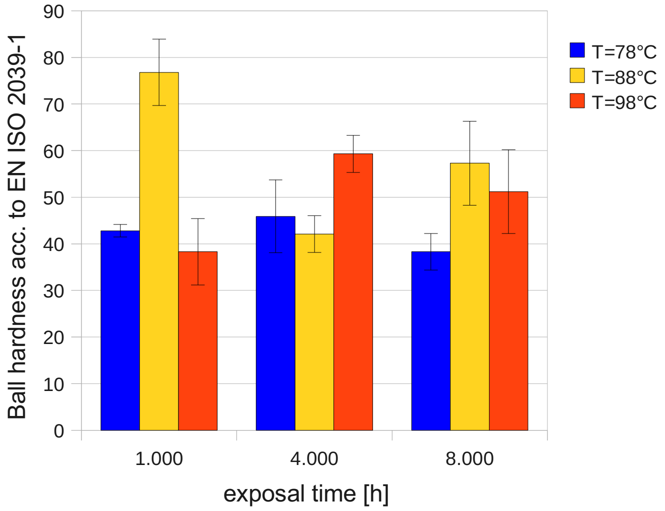

Fig. 13: ball hardness of PP-H

4. Conclusion

The application of polymers for sealing hot water tanks offer new possibilities of tank design for solar thermal applications. Water vapour transport and ageing properties at high operating temperatures of three commonly used materials EPDM, IIR and PP-H were investigated in the frame of IEA-SHC Task 39 (SHC-Task 39 „Polymeric Materials for Solar Thermal Applications).

EPDM shows a very good ageing behaviour. No ageing effects could be detected after exposing the material for at least 15.000 h. However, the high water vapour transport through the liner, up to WVTR=85 gmm/(m²d), must be reduced by applying a vapour barrier. A thin aluminum foil was implemented between two EPDM layers and the water vapour transport could be reduced by a factor of 10.

IIR shows a tolerable transport of up to WVTR=30 g mm/(m²d) but this material showed first ageing effects after 5.000 h of exposure.

PP-H shows similar water vapour transport porperties. Inside the testing period of 8.000 h, no ageing effects could be detected.

5. References

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