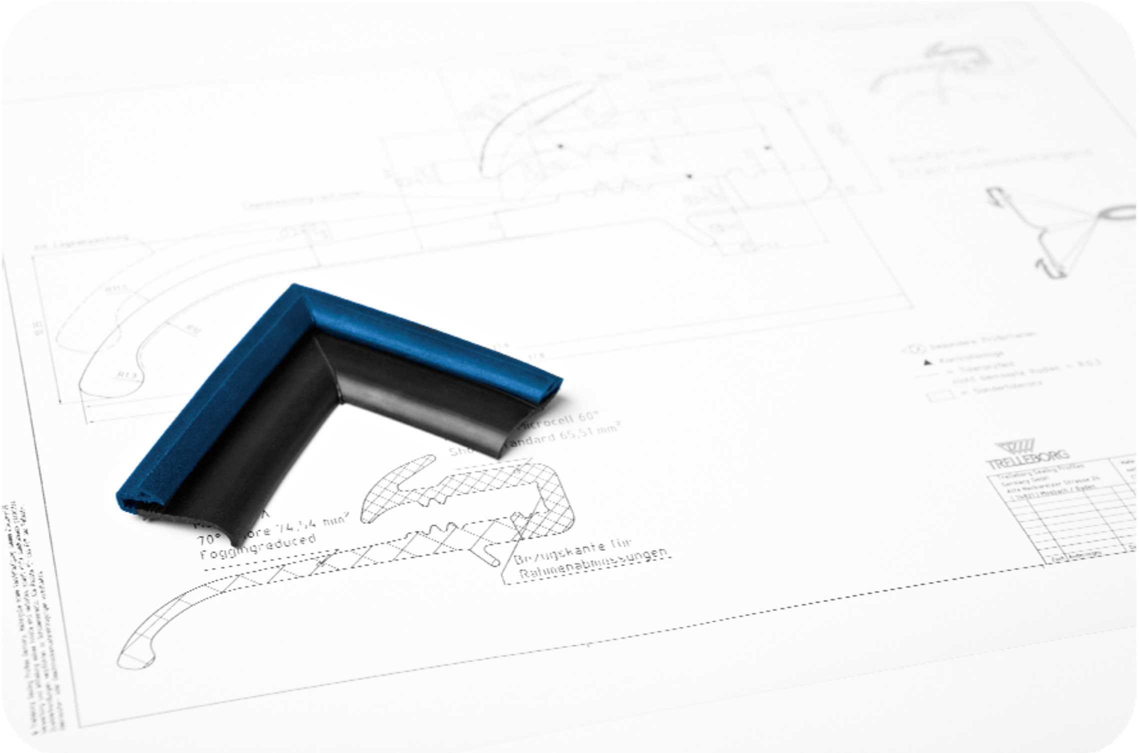
Guideline for sealings in solar thermal collectors

SP Sveriges Tekniska Forskningsinstitut



Energitekniky Technology

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Executive Summary

This document gives guidance on how to define requirements on materials for seals and gaskets in solar collectors, mainly of flat plate type, potentially resulting in higher product quality and optionally also lower costs. The guideline focuses on glazed (or covered) flat plate collectors, since it is of the highest relevance to the European market and collector industry today. Two main types of sealings are treated in this guide: Preformed seals that are solid and flexible and sealing compound that is applied in putty-like form and cure to become flexible solids.

European collector manufacturers have participated, sharing their knowledge and experience in this field by answering a questionnaire and discussing different aspects on sealings. Combined with a review of relevant standards and literature, a number of highly relevant issues related to these components have thus been discussed and are described in this guide.

Different applications for sealings in collectors are described as well as the different stresses they are exposed to. Functional properties of the sealings are explained, the methods used to characterize them, and the different materials that can be used to produced them are briefly summarized. Some practical aspects on collector design related to sealings are highlighted and the most relevant standards are described. Finally, the results of the questionnaire survey are reported in two annexes.

1 Introduction and background

The idea of writing this guide came up in a meeting between SP Technical Research Institute of Sweden and the Swedish sealing manufacturer Trelleborg AB. Trelleborg had been trying to map the level of knowledge with regard to polymer sealings in the solar thermal industry for some time and concluded that there was room for improvement. A project proposal was submitted to the Solar Keymark Certification Fund SCF and later approved. The work was mainly carried out by SP with a strong support from Trelleborg AB and Sunstrip AB, a Swedish absorber and collector manufacturer. Furthermore, five more European collector manufacturers have participated, sharing their knowledge and experience in this field by answering a questionnaire.

A number of issues related to these components are of high relevance to manufacturers of solar thermal collectors:

- In order to have a good dialogue with the sealing suppliers and to be able to define and to follow up on a strong requirement specification, a certain level of in house expertise is most valuable
- The durability of the sealings will in many cases also have an effect on the lifetime of the entire collector
- Low quality components are hard to distinguish from good ones without access to specialist knowledge and test equipment
- Cost savings can be achieved by defining appropriate requirements on sealings

Looking into the future, the building integration of energy producing elements such as solar collectors and PV panels is expected to grow fast and it holds a great potential. This will further increase the requirements on life expectancy as the products will be seen as “building products” just as any other, instead of add-ons to buildings. On the other hand, the better protected environment for the collectors may reduce some of the stresses they are exposed to as e.g. connection pipes will be hidden in façade or roof and not exposed to outdoor weather conditions.

This guideline will focus on the glazed (or covered) flat plate collector, since it is of the highest relevance to the European market and collector industry today. It is used for a wide range of applications but most commonly for tap water and room heating in working temperature ranges from 50 to 75°C. More advanced designs can have working temperatures up to and above 200 °C.
Two main types of sealings are treated in this guide:

- Preformed seals that are solid and flexible. They are held in place by the pressure exerted by other components.
- Sealing compound that is applied in putty-like form and cure to become flexible solids. They are normally held in place by adhesion as well as external pressure.

The durability of sealings can also mean that special requirements for the operation of the collector must be met. One of the ISO test standards reviewed, ISO 188, suggests performing an accelerated ageing equivalent to a total stagnation time of three months over the lifetime of the collector. This means that the collector risks being damaged if e.g. being left in stagnation for a long time during installation.

2 Objective and scope

This document gives guidance on how to define requirements on materials for seals and gaskets in solar collectors, mainly of flat plate type, potentially resulting in higher product quality and optionally also lower costs. By doing this, collector manufacturers will be able to find more optimal technical/ economical solutions. It will also increase the sealing suppliers' ability to design sealings for the correct lifetime by facilitating the dialogue between sealings- and collector manufacturers.

As a part of the work on this guide we have been trying to collect present knowledge from the solar business and also to identify knowledge gaps in the solar business when it comes to polymer sealings. Experiences from similar applications were mainly picked up from the automotive industry where e.g. fogging or outgassing is a well-known problem.

2.1 Solar collectors and PV panels

<u>This work focuses on applications in solar collectors</u>. Solar collectors are used to produce heat, normally to be used as domestic hot water or for room heating in buildings, but there is in fact a large variety of applications ranging from swimming pool heating to steam generation for power production. In a PV panel, solar light is converted directly to electricity. In general the thermal stress on sealings is higher in solar collectors than in PV panels due to higher temperatures and temperature changes. Nevertheless, there are of course many similarities in the way the two products are being mounted and exposed to environment conditions and therefore some of the information in this guide will have relevance also for PV panels.

2.2 Solar thermal collector types and applications

Three main types of collectors can be distinguished in the market today. ***For the purpose of this guide, focus will be on type 2 as it is of the highest relevance to the European market and manufacturers today***:

1. **Unglazed collectors**. Normally used for low temperature applications (below 50°C) such as pool heating or in combination with heat pumps. Sealings are normally not used in these collectors, except for in pipe connectors, since they are un-insulated and made of polymers.
2. **Glazed (or covered) flat plate collectors.** Used for a wide range of applications but most commonly for domestic hot water and room heating in working temperature ranges from 50 to 75°C. Advanced designs can have working temperatures up to 200°C.
3. **Vacuum tube or "Evacuated tubular collectors" (ETC).** Used in the same applications as 2) but additionally for medium temperature applications i.e. 100-200°C, mainly in process heat or solar cooling applications.

In terms of building integration, type 2) is the type best suited for this and the one expected to find more new ways for integration in the built environment.

In addition to these a number of new or reviewed designs exist, but so far none have reached commercial scale/ full maturity in a European context. For some tracking concentrating designs it could be argued that there are plenty of products around. However, as our knowledge on these products is limited and these collector types normally operate in a significantly higher temperature range than the main types mentioned the results presented here, they are not the main scope of this study. Nevertheless, results can be partly applicable also to these collector types.

Figure 1. Glazed flat plate collector. Source: www.wagner-solar.com

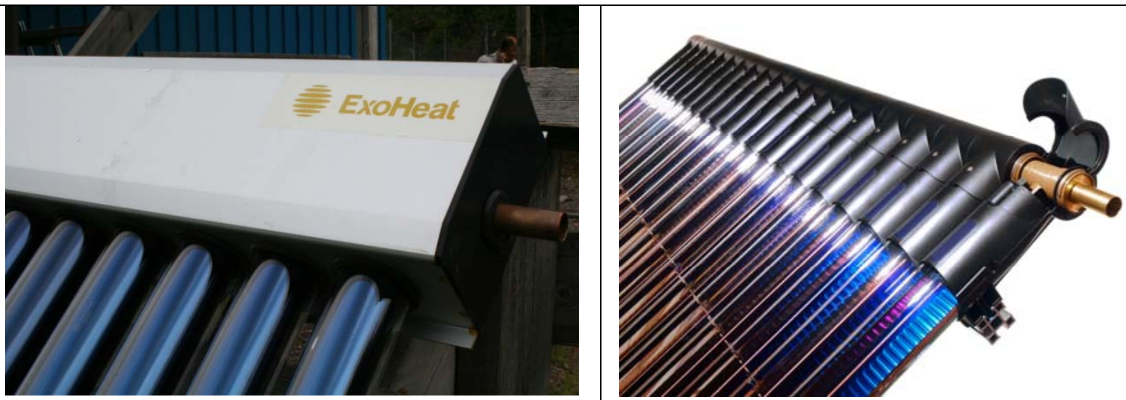

Figure 2. Vacuum tube collectors. Source: Exoheat (left) and ESTIF (right)

2.3 Operation modes and temperatures

A solar collector in general is exposed to significantly lower temperatures in standard operation mode compared to what is defined as “stagnation under high irradiance levels”. Table 1 shows nominal operating temperatures and maximum stagnation temperatures for the three main collector types mentioned.

Table 1. Characteristic temperatures for three main collector types

Collector type	Standard operating temperature range [°C]	Stagnation temperature at 1000 W/m^2 irradiance and 30°C ambient temperature [°C]
1	20-50	60-90
2	25-100	150-250
3	50-150	200-300

Stagnation is to be considered as an exceptional operation mode which is in general to be avoided. However it is a fact that most collectors do spend time also in high irradiance stagnation. How long this time is differs within a very wide range depending on load conditions, system design, probability for power failures etc. The time between commissioning of the collector field and the start of normal operation can be a significant part of the total time in high irradiance stagnation and can thus have a relatively large impact on the condition of the sealings used in the collector. It should therefore be kept as short as possible.

The way the EN 12975 standard for collector testing is written today, a collector must be able to cope with stagnation under high irradiance conditions for some time (minimum 30 hours at > 850 W/m^2 and a few hours >1000 W/m^2), meaning that all components of the collector must be able to withstand the high temperatures reached in this condition. The actual time a given collector will spend in stagnation during its lifetime is impossible to accurately predict. One must rather try to estimate it by assuming some worst case conditions that will prevail, e.g:

- At the time of installation, some systems will be left in stagnation for days, weeks or in the worst case months before being taken into operation. This might actually be the biggest challenge ever for the collector and as this situation cannot be completely avoided, at least not in large systems, installation manuals for efficient collectors (i.e. collectors having high stagnation temperatures) should therefore pay attention to this fact.
- The risk of long lasting power failures in summer is very small in Europe, but might be significant in other markets such as in Africa or India.

In the ongoing revision of the EN 12975 [1] and ISO 9806 [2] standards the requirement that the collector shall be able to withstand stagnation is about to be abandoned. The reason is that the concept of “active protection” is introduced. This means that the collector manufacturer will be able to utilize different measures to protect the collector from these extreme temperatures. Quoting the text of the current (December 2012) draft: “If the collector includes active systems to protect itself, these protections shall be active and operational during the exposure test…. Collectors shall be mounted outdoors but shall not be filled with heat transfer fluid, unless controls are used to manage both a no-flow and high temperature condition according to the manufacturer’s instructions. In that case, collectors shall be filled with the heat transfer fluid and such controls shall be verified. “

What temperatures are the sealings actually exposed to? It shall be noted that the temperatures given in table 1 refers to stagnation temperatures as measured according to the EN 12975 standard which are in principal the overall maximum temperature of the collector. These temperatures are <u>not</u> relevant to all sealings in a collector, but can be relevant to some of them depending on the application.

2.4 Sealing applications in solar thermal collectors

Some basically different applications for sealings in the collectors can be distinguished.

For flat plate collectors:

I. **The sealing between glass and collector box.** Can be designed to provide a tight seal and/ or to fix the glass onto the box. It can be in the form of a sealing strip but it can also be a string of silicone or an adhesive tape applied on the edge under the glass.

   There is limited experience regarding what temperatures these sealings are exposed to. If exposed to direct sunlight one could expect temperatures at maximum 80°C. If covered by a glass sheet the temperature can probably reach up to 150°C and if additionally it is exposed to radiative heat transfer from the absorber (in view of the absorber) even higher

II. **The sealing which is applied to the pipe that connects the collector to the external fluid loop** (normally copper pipes Ø 10-22mm). The purpose of this sealing is mainly to prevent rain water from entering the collector box but also to prevent air circulation out of the box and to break a thermal bridge, both which would lower the collector performance.

   <u>*It is reasonable to assume that the temperatures these sealings are exposed to are in the same range as the maximum temperatures of the collector. Experience also tells us that these are the sealings having the toughest conditions in a flat plate collector.*</u>

It shall be noted that the second type of sealings are not as critical for a roof or facade integrated collector as for a free standing collector and that different types of integration like this is coming more and more in focus when solar collectors are applied to new buildings. I.e. depending on the collector application the relative importance of I) VS II) can differ.

For vacuum tube collectors:

I. The sealing of the top of the glass tube is in general a combination of a polymer “plug” and a metal “lid”. These two components shall provide a tight seal, preventing water, and as far as possible moist, from entering the glass tube.

   As the interior of the glass tube holds thin aluminum metal sheets for heat transfer from the inner glass wall to the heat pipe or U-pipe it is essential that this environment is kept dry.

II. The sealing which is applied to the pipe that connects the collector to the external fluid loop (normally copper pipes Ø 15-22mm). The purpose of this sealing is mainly to prevent rain water from entering the collector manifold box but also to prevent air circulation out of the box and to break a thermal bridge, both which would lower the collector performance.

   Again, i*t is reasonable to assume that the temperatures these sealings are exposed to are in the same range as the maximum temperatures of the collector.*

2.5 Pollutants and other exposure

For materials exposed to direct sunlight, the UV exposure and exposure to rain water must always be taken into account. Additionally, depending on the environment, salt, sulphur, ozone and other types of pollutants may occur. As very few collectors are airtight, these pollutants must also be expected to get in contact with sealings inside the collector box.

2.6 Rain and weather tightness

The most important purpose of the sealings is to keep humidity and water out of the collector box as far as possible. In general terms this is to protect the absorber surface and the insulation material from direct contact with water. All kinds of weather conditions must then be foreseen including rain (combined with positive or negative pressure differences between exterior and interior due to wind), snow, repeated melting and freezing etc.

3 Functional properties

Preformed gaskets and sealants have several functions in solar collectors. They bind components together, support the glazing, prevent ingress of water, isolate the absorber from external atmosphere and accommodate differences in thermal expansion of the collector components. There are several material properties that affect the function and sealing performance and they are described below.

3.1 Elasticity and hardness

When gaskets and sealants are used between substrates having different thermal coefficients of expansion or differing elongation under stress, they need to have adequate flexibility and elongation to maintain the sealing performance. The extent of the compression and tension (without breakage or crack formation) is considerable when materials with highly different thermal expansion coefficients are sealed. The ability to be stretched is indicated by the elongation-at-break, the maximum extension of an elastomer at the time of rupture. This is expressed as percentage of the original length. The ability to be compressed is indicated by the hardness of the material.

Figure 3. Tensile tester used for determination of maximum elongation and tensile strength

3.2 Compression set

A property called compression set is very important in flat plate collectors. A resilient gasket will maintain high enough pressure to ensure tightness. If the seal will set the binding between solar glazing and casing will disappear resulting in ingress of water and pollutant. Compression set test is intended to measure the ability of rubbers to retain their elastic properties i.e. sealing capability, at specified temperatures after prolonged compression at constant strain. 24 hour tests indicates cross link density and the 168 hour tests shows more how the seal will manage high temperature service for longer time. It is done in both elevated and low temperatures in order to induce expansion as well as contraction. A low test value on the compression set parameter is desirable.

3.3 Adhesion

A sealant is a viscous material that changes state to become solid once applied. Therefore an important functional property for sealants is adhesion, the ability to stick to surfaces. The surfaces consist of e.g. metal, plastic or glass materials and the ability to bond fully is important for the life span of the sealants. Tests for rubber bonded to a rigid substrate are typically performed using the same type of tester as the one used for tensile strength. In an adhesion test, the rubber portion of a rubber-bonded-to-substrate sample is pulled at a constant rate until either the rubber peels away from the metal (the bond fails) or the rubber itself ruptures (though the bond stays intact). Since different polymers bond differently with other materials, the material in the solar collector shall be used as substrate when testing the adhesion.

4 Environmental property influence

When designing a seal for a solar collector several characteristics have to be carefully considered since it is exposed to quite a harsh environment. Depending on the collector design, the sealants can experience prolonged exposure to relatively high temperatures. In addition the sealants are also exposed to environmental stresses such as high humidity, ozone, ultraviolet radiation etc. It should always be kept in mind that a long service life is a prerequisite in order to make an advanced solar collector a profitable investment. Life expectancy of 20 years and more is often expected by the clients and this of course also applies to the sealings.

4.1 Temperature Resistance

Preformed seals and sealing compound used to support the glazing and/ or to isolate the collector interior from external influences must withstand air temperatures as high as 150 °C. If stagnation occurs (i.e. when fluid circulation stops for instance due to a fault in the system) they may have to withstand temperatures between 150 and 250°C. It shall be noted that the temperatures refers to stagnation temperatures as measured according to the EN 12975 standard, which are in principal the overall maximum temperature of the collector. For glazed flat plate collectors this means measuring at the back of the absorber plate, inside the collector.

An important feature related to temperature that must be taken into account is the wide range within which the temperatures in a collector will vary during daily operation cycles. At daytime, temperatures will normally vary within the ranges 30-100°C but additionally, at night time the collector will cool down to ambient air temperature and even below due to cooling from a clear sky. This means that cycles with high amplitude will be occurring on a daily basis. There will also be one cycle occurring on yearly basis were the temperature varies between winter and summer time.

Elevated temperature combined with oxygen in the air is the factor that gives the highest aging effects on seals and sealants. To uphold the functional properties the gaskets and sealants must maintain their elasticity also at low temperatures. The flexibility of rubber material will get affected by low temperatures and when the flexibility gets poor the sealing function is lost.

4.2 Fogging /Outgassing

Long time exposure to air at elevated temperature will cause seals and sealings to emit additives such as plasticizers and stabilizers e.g. anti-oxidants and anti-ozonants. This behavior is called fogging and fogging on the solar glazing reduces the solar energy transmission i.e. it prevents the sun light from reaching the absorber plate. It will also cause the material to degrade; taking a permanent compression set and thereby decreasing the functional properties. There are also non-condensable chemicals that generally do not affect the solar light transmission. They will remain in gaseous state and usually escape to the surroundings. The emitting of these chemicals will also decrease the physical and mechanical properties of the polymer.

Results from experiments have shown that sealing compounds cause more fogging than preformed seals. In general sealing compound emits more volatile substances than preformed seals [3].

4.3 Weathering

Relative humidity, sunlight, rainfall and air pollutants (in addition to temperature) can lead to loss of physical properties and affect the life time of seals and sealants. Water can affect the hydrolysable groups in the material. Exposure to sunlight can cause brittleness and loss of elasticity, resulting in lost sealing performance and leakage of fluid. UV radiation can start degradation processes in the material. Some elastomers are resistant to UV degradation whereas others containing UV stabilizers will lose their UV-resistance over time. Polymers containing carbon black (black sealing) will not be affected by the UV radiation since it cannot penetrate the material. Ozone is an air pollutant that can result in cracks in a stretched rubber material.

5 List of most relevant standards

The following standards were reviewed during the work on this report and even though two of them are 15-20 years old, they are still considered fully relevant to be used in classifying and testing these collector components.

ISO 9553:1997 Solar energy methods of testing rubber seals and sealing compounds used in collectors.

This international standard gives requirements for the classification and testing of rubbers used to seal solar collectors. This is meant to aid collector manufacturers in their selection of sealing components for specific applications.

ISO 9808:1990 Solar Water heaters – Elastomeric materials for absorbers, connecting pipes and fittings.

This international standard specifies the means of assessing elastomeric materials for use in the manufacture of absorbers, connecting piping and fittings for use in solar water heaters.

ASTM D3667: 2010. Standard specification for rubber seals used in flat-plate solar collectors.

This specification covers the general requirements for material used in rubber seals of flat-plate solar collectors.

6 Material for construction

Extensive testing has been done on different sealing materials, especially in the United States. The differences between materials are huge. The type of polymer is not the only thing that determines the suitability in solar heating applications. Properties of elastomers depend on specific formulations. Two materials with the same polymer may have different properties and the properties of different formulations need to be considered when elastomers are selected.

Knowledge about the formulation is hard to achieve since their recipe is the possession of the manufacturer. This is why testing of the material that should be used as sealing solar collectors often is the only possibility to evaluate the suitability. A table with requirement criteria can be found in chapter 7.

Seals shall be made from rubber compounds that are resistant to the effect of ultraviolet light. This could be determined by exposure to a xenon arc in laboratory. After exposure slight surface chalking and dulling is permitted. Brittleness, cracking, loss of elongation or tackiness is not permitted. According to several investigations EPDM, silicon rubber, Fluoroelastomers and chloroprene rubber have suitable properties for use as sealing materials between solar glazing and casing of the collector. For sealing inside the collector (in direct contact with absorber or connecting pipes) a higher temperature resistance is required and silicone or flour rubber should be used. According to questionaries' sent out to manufacturers the types most frequently used are EPDM and Silicone.

Adhesives (classified as sealing compound, see 8.1) are getting more popular for bonding glass covers and frames together in solar collectors. The elastic bond creates a joint between the glass and the frame where the mechanical fastening is generally unnecessary. It also prevents penetration by air and water. Silicone adhesives can resist both UV radiation and weathering. Their high elasticity enables them to bond different materials together and compensate for the different coefficients of expansion.

There are two different types of adhesives, single component and two-component. Single component adhesive needs moist from the air in order to cure and the curing rate is therefore dependent on the surrounding environment. Two component adhesives also include a curing agent which accelerates the process and the reaction begins as soon as the two components are mixed.
Adjusting the curing time requires a lot of knowledge and the manufactures do provide advice to their clients. The mixture ratio of the two-component adhesive is important in order to optimize the adhesion ability. Except for adhesive test (8.3.10) collector manufacturers using the two-component adhesive are advised to check the mixture ratio every day before starting the production.

6.1 EPDM

EPDM cured with peroxide is a good choice of material in solar collectors where the temperature will not reach to high (< 125 °C). The peroxide produces compound with compression set properties that are superior to those of sulfur-cured EPDM compounds. After cure in 150 °C in uncompressed state will result in a better/lower compression set for peroxide cured EPDM.

EPDM contains propylene and ethylene (40 to 80 wt %) monomers and some general property trends can be stated about the polymer when the contents varies. As the ethylene content decreases and the propylene content increases the polymer is more flexible in low temperatures, lower in hardness and more elastic. On the other hand, the polymer has a lower compression set.

6.2 Silicone

Silicon rubber can be used in a wide temperature range. This is a suitable material choice for seals inside solar collectors designed for relatively high temperature levels. Silicone rubber has good low temperature flexibility as well as excellent heat resistance. Silicone elastomers can be divided into different classifications and bases are generally pre formulated for various properties as high strength or low compression set. The most common compound is made with VMQ, which means a silicone rubber containing both methyl ($-CH_3$) and vinyl (-Cl) groups on the silicone backbone according to the rubber terminology found in the standard ISO 1629 [4]. Silicon materials are more apt to emit volatile substances that will cause fogging and reduce the solar transmission.

6.3 Butyl

Butyl is a polymer that is resistant to oxygen, ozone, moisture and chemical attack and it has a high heat resistance. It is used as adhesive tapes for sealing between glazing and casing. If a collector is permanently filled with gas a silicone sealant is inadequate and butyl can be used. One should be aware that sometimes butyl tape is mixed with other polymers and bitumen but is still called butyl tape. The result of this mixing, which is done to make it cheaper, can be loss of adhesion ability. Good adhesion is easiest to obtain to aluminum and iron.

6.4 Polyurethane

Polyurethane (PUR) is a very versatile material and is found in a large number of applications. Polyurethane foam can be either soft or hard and is found in stuffed furniture and as insulation material. PUR gaskets have an extremely low permanent compression set. In addition, the mechanical properties remain stable in -50 to + 130 °C temperature range. The material can easily withstand various weather conditions. Adhesives, and coatings are other applications for polyurethanes.

6.5 Other

Solar collectors are getting more effective and the development requires materials that can withstand increasingly higher temperatures. In the end none of these polymers will be able to meet the requirements. Silicone and Flour rubber has the highest heat resistance and is able to cope with temperatures around 200°C. Solar collectors with higher temperatures (as type G and H in table 1) will probably need sealings based on other materials such as i.e. PTFE or PA.

6.6 Recycling

Knowledge and awareness about recycling of the sealing components was indicated by the questionnaires to be quite low, but someone made references to requirements in standards and certifications and expected legislation in a near future.

The process of fabricating rubber products involves vulcanization which is an irreversible reaction between elastomer and curing agent producing cross-links and formation of a three-dimensional chemical network. The presence of this network creates tremendous problems in rubber recycling. A number of methods have been applied in an attempt to solve these problems and to find more effective ways of rubber recycling. I.e. feedstock recycling, grinding- and pulverization methods, reclaiming processes and incineration. Different fields have standards handling recovery, disposal and related environmental issues.

7 Design and manufacturing

As we, the authors of this guide are not experts in design and manufacturing of solar collectors, this chapter is just a small collection of hints and advices related to these topics based on information we picked up during the study. Two specific problems were mentioned by the respondents to our questionnaires:

1. Purchasing preformed sealings that correspond to the initial specification could be a problem if requirements on dimensional and geometrical tolerances are not accurately specified. Worn out tools and inadequate production control can result in non-conformity. To support a positive outcome of this process the following two standards can be consulted and referred to when specifications are developed:
    a. ISO 3302-1:1996 Rubber - Tolerances for products - Part 1: Dimensional tolerances
    b. ISO 3302-2:2008 Rubber - Tolerances for products - Part 2: Geometrical tolerances
2. Applying adhesives in the construction of a collector can, depending on the function, require extremely rigorous preparation of the surfaces involved in the bond. This is equally valid for the surface textures and for the cleaning of the surfaces. Careful studies of the mounting instructions from the sealant supplier is a minimum requirement but in cases where load bearing capacity is involved, it is recommended to consult the supplier for additional advice, tailored to the specific application. Please note that the tensile strength of the bond should be evaluated using the same components as the ones that are used in the collector.

New challenges for polymer components in solar collectors can be foreseen in two fields:

- Façade and building integration per definition means that the collector in addition to energy conversion has at least one more task to fulfill. If this additional task is to form a part of the building envelope it could mean that requirements on durability and lifetime will increase. It could also mean that there is a need for more flexible systems where parts of a façade can easily be exchanged and additional requirements on e.g. noise reduction and fire resistance.

- Generation of process heat by means of solar collectors gets more and more attention and there is a demand for higher fluid temperatures. As has been shown in this guide, this will in many cases require new materials to be used in sealings.

7.1 Mountability/ Demountability

The number of questionnaires answered (see Annex 2) was too low to draw any general conclusions from. Extruded profiles seem to be difficult to handle in the manufacturing process for some, but not for others. The same goes for pipe bushings. Replacement does not seem to be an issue as long as adhesives are not used whereas in the latter case demounting is generally not possible without destroying the collector cover.

8 Testing polymer sealings

In the following, professional testing and standardized requirements on polymer sealings are described. However, there is always the possibility for “in house testing” that should be applied by all collector manufacturers: Outdoor exposure of the complete collector is cheap to perform and gives a complementary result to laboratory component testing. For further advice on in-house testing of solar collectors, see [5] and [6].

8.1 Classification

Sealing can be accomplished by one of the following methods:

a) Preformed rubber seal (PS)
b) Sealing compound (SC)

Type
There is also type classification and the type should be based on the maximum service temperature which normally occurs when the collector is under stagnation conditions. The long term performance of the seals is very important and sealing force may be lost due to stress relaxation and set when the polymer ages physically and chemically. Accelerated heat test is therefore to be in relation with the expected lifetime. Max service temperature is a lot higher than average temperature and is assumed to occur seldom. Test period suggested in ISO 188 for accelerated ageing is 14 days and is based on a total stagnation condition around 3 month. If this assumption should hold it is obviously of great importance that the collector, during the installation phase, is not left for too long in stagnation.

Table 2. “Type” classification based on the maximum service temperature

Type	Test temperature	Max service temperature
B	100	70
C	125	100
D	150	125
E	175	150
F	200	175
G	225	200
H	250	225

Grade
Grade designation for different degrees of hardness. The grade to be used in particular application depends on the design of the seal and shall be specified by the designer.

Table 3. “Grade” classification based on the hardness

Grade	Hardness
3	30 ±5
4	40 ±5
5	50 ±5
6	60 ±5
7	70 ±5
8	80 ±5

Class
Based on resistance to low temperatures the seals are also divided into different classes. The class selected should be based on the lowest temperature in which the collector is expected to operate.

Table 4. “Class” classification based on minimum service temperature

Class	Climate	Test temperature	Lowest service temperature
W	Warm	0	-10
M	Moderate	-25	-35
C	Cold	-40	-50
P	Polar	-60	-70

8.2 Dimensions

The design of the seal shall not permit the rubber to deflect more than 25 % in any direction during thermal expansion and contraction of the solar collector. For manufacturing tolerances see chapter 7.

8.3 Qualification tests

The test methods that are compiled in this study are described in detail in the referred standards. In the following a short description is given in order to convey a basic idea about how the different tests are performed. For more detailed descriptions please refer to the standards.

8.3.1 Hardness test in accordance with ISO 48 or ISO 7619

For rubber materials hardness is usually measured in the unit IRHD (International Rubber Hardness Degrees). The difference between the indentation of a ball into the rubber under a small contact force and a large indenting force is measured. A large value means that the rubber material is hard and a low value indicates a soft material. The measurements are preferably performed on flat test slabs. For further info on ISO 48 and ISO 7619, see [7] and [8].

8.3.2 Tensile strength according to ISO 37 using a type 2 dumbbell

Tensile testing is performed on dumb bell shaped test specimen. The specimen are clamped in a tensile testing machine and stretched until it breaks. The tensile force and elongation is measured continuously. After a performed test both elongation-at-break and stress-at-break are achieved. For rubber material stress at 100, 200 and 300% elongation is normally calculated. Each test series contains minimum three test slabs and a mean value is calculated and reported. For further info on ISO 37, see [9].

8.3.3 Compression set test shall be tested in accordance with ISO 815-1 and ISO 815-2

Compression set is performed on cylindrical test pieces cut from a sealing or a test slab. The test piece is compressed, usually 25% of initial thickness (depending on the hardness of the material) and thereafter exposed to room temperature, elevated temperature or sub-zero temperature for a given period of time. After exposure the test piece is released, allowed to relax and then the thickness is measured again. It is desirable that the thickness retain the initial thickness after 30 minutes of relaxation. If a rubber sets the sealing performance decreases. For further info on ISO 815, see [10].

8.3.4 Resistance to ozone according to ISO 1431 part 1 static strain

Some rubber materials are sensitive to ozone. Therefore test pieces are stretched and exposed to ozone for a suitable period of time. The elongation is typically 20%, ozone concentration in air 100 pphm (parts per hundred million) and test period 166 h and temperature 40 °C. For further info on ISO 1431-1, see [11].

8.3.5 Fogging test according to ISO 6452

A test piece is heated in a beaker and volatiles are allowed to condense either on a cooled glass plate or a piece of aluminum foil. Tests shall be done at high temperature for 16 h and the fogging is measured by weighing the aluminum foil or glass plate. The test is tailored for the automotive industry but could be useful for collectors as well. For further info on ISO 6452, see [12].

8.3.6 Determination of low temperature brittleness according to ISO 812

This is basically an impact test at very low temperature. For further info on ISO 812, see [13].

8.3.7 Accelerated ageing according to ISO 188

Accelerated ageing is performed in order to simulate longer periods of service for a polymeric material by exposing them to elevated temperatures. Test temperatures for ageing are chosen depending on the polymer classes. After ageing, conditioning the test pieces in standard laboratory temperature (23°C, 50% relative humidity) for at least 16 hours and maximum 96 hours before testing. For further info on ISO 188, see [14].

8.3.8 Volatiles loss

Determine the mass change from the difference in masses of test pieces before and after ageing at elevated temperature. This is a simplified variant of the fogging test, without any detailed analysis.

8.3.9 Adhesion loss

Substrates to be used are the material in the solar energy collector. ISO 9553, Annex A, is recommended to follow, see [15].

8.4 Preparation of test pieces

8.4.1 Preparation of test pieces from preformed seals

Preparation of test pieces from preformed seals should be done in accordance with ISO 4661-1, see [16].

8.4.2 Preparation of test pieces from sealing compound

Prepare five sheets 150x150x2 mm also prepare five adhesion assemblies. Condition both sheets and assemblies for 14 days at standard laboratory conditions.

8.5 Requirements

The rubber sealing materials recommended are divided into different classes in terms of hardness and therefore the maximum changes of material properties after ageing are different. The smaller the changes are in material properties after ageing the better. In order correlate material properties to sealing performance for a certain sealing it is advisable to perform leakage tests on either a real construction or a model of a solar thermal collector.

8.5.1 Requirements for Class PS material used to seal flat plate solar collectors

Table 5. Allowed changes for different material properties after ageing.

Property of material	Grade					Test method (Section ref.)
	4	5	6	7	8	
Hardness, IRHD +5/-4	40	50	60	70	80	8.3.1
Elongation at break, %	300	250	200	150	100	8.3.2
Compression set %						8.3.3
24^{-2} h at high temperature	30	30	30	30	30	
166^{+2}h at low temperature	60	60	60	60	60	
Resistance to heating (=Ageing. Properties below rel. to unaged samples)						8.3.7
Hardness change max IRHD	10	10	10	10	10	8.3.1
Elongation at break max %	30	30	30	30	30	8.3.2
Tensile strength max %	20	20	20	20	20	8.3.2
Volatiles lost max %	1	1	1	1	1	8.3.8
volatiles condensable max %	0,1	0,1	0,1	0,1	0,1	
***Fogging 100°C, 16 h**	1 mg					8.3.5
Resistance to ozone	No cracking					8.3.4
Resistance for low temperatures max °C	-40	-40	-40	-40	-40	8.3.6

Weight loss can give fogging problems but since it also can be a non-condensable subject it is safer to also perform a fogging test. Fogging testing is not included in the standards but is recommended to do. On the second line in table 5, desired elongation-at-break values for the different hardness classes are given. Compression set values are found on line 3 in the table and is always measured after different types of exposure. The next following values refer to changes of material properties after ageing, i.e. resistance to heating.

8.5.2 Requirements for Class SC material used to seal flat plate solar collectors

Table 6. Material properties for SC materials before heat exposure and allowed changes after heat exposure.

Property of material	Grade			Test method
	3	**4**	**5**	
Hardness, IRHD +5/-4	30	40	50	8.3.1
Elongation at break, %	150	100	100	8.3.2
Adhesion loss max cm^2	9	9	9	8.3.9
Resistance to heating (=Ageing. Properties below rel. to unaged samples)				8.3.7
Hardness change max IRHD	10	10	10	8.3.1
Elongation at break max %	30	30	30	8.3.2
Tensile strength max %	20	20	20	8.3.2
Volatiles lost max %	1	1	1	8.3.8
volatiles lost max %	0,1	0,1	0,1	
Fogging100°C, 16 h		1 mg		8.3.5
Resistance to ozone		No cracking		8.3.4
Resistance for low temperatures max °C	-40	-40	-40	8.3.6

8.6 Inspection

Manufacturers of preformed seals may use their quality control system for production inspection to ensure the seals conform to the specification. In case of dispute regarding the quality of a delivered product, a sample of five seals shall be taken from the lot and tested. If one of the five seals does not conform a second sample of five seals may be taken. If two or more of the ten seals does not conform the lot may be rejected.

9 References

This Guideline was prepared using following standards; the editions listed below were valid at the time of writing the report. All documents may be subject to revision, and interested parties are encouraged to investigate the possibility of applying the most recent editions of the documents indicated below.

1. EN 12975:2006. Thermal solar systems and components - Solar collectors - Part 2: Test methods
2. ISO 9806:1995. Test methods for solar collectors - Part 2: Qualification test procedures
3. Klimatfaktorernas inverkan på material i plana termiska solfångare. 1985. Hans Wennerholm
4. ISO 1629:1995. Rubber and latices - Nomenclature
5. www.estif.org/fileadmin/estif/content/projects/QAiST/quaist_brochure.pdf
6. www.estif.org/fileadmin/estif/content/projects/QAiST/QAiST_results/QAiST%20D2.3%20Guide%20to%20EN%2012975.pdf
7. ISO 48:2010. Rubber, vulcanized or thermoplastic - Determination of hardness (hardness between 10 IRHD and 100 IRHD)
8. ISO 7619:2010. Rubber, vulcanized or thermoplastic - Determination of indentation hardness - Part 1: Durometer method (Shore hardness) and Part 2: IRHD pocket meter method
9. ISO 37:2011. Rubber, vulcanized or thermoplastic -- Determination of tensile stress-strain properties
10. ISO 815:2008. Rubber, vulcanized or thermoplastic - Determination of compression set - Part 1: At ambient or elevated temperatures and Part 2: At low temperatures
11. ISO 1431-1: Rubber, vulcanized or thermoplastic -- Resistance to ozone cracking -- Part 1: Static and dynamic strain testing
12. ISO 6452:2007. Rubber- or plastics-coated fabrics - Determination of fogging characteristics of trim materials in the interior of automobiles
13. ISO 812:2011. Rubber, vulcanized or thermoplastic - Determination of low-temperature brittleness (ISO 812:2011, IDT)
14. ISO 188:2011. Rubber, vulcanized or thermoplastic -- Accelerated ageing and heat resistance tests
15. ISO 9553:1997 Solar energy methods of testing rubber seals and sealing compounds used in collectors
16. ISO 4661-2:1987. Rubber, vulcanized - Preparation of samples and test pieces - Part 2: Chemical tests
17. ISO 9808: 1990. Solar Water heaters – Elastomeric materials for absorbers, connecting pipes and fittings
18. Solar heating materials Handbook, Environmental and safety considerations for selection, Chapter 6 seals and sealants. 1981. Peter S Homann
19. Rubber technology compounding and testing for performance. 2009. Edited by John S. Dick
20. Forming bonds. Article on adhesives in solar collector manufacturing. Sun & wind energy 1/2012

10 Annexes

Annex 1. Questionnaire regarding polymer sealing in solar collectors

Annex 2. Results from questionnaire survey

Annex 1. Questionnaire regarding polymer sealings in solar collectors

1. Which type of collector are you producing? (E.g. Flat plate, ETC, CPC)
2. What sealing components are you using? (E.g. extruded profile, gaskets, bushings, silicone sealant, butyl tape etc. Please note type of environment in terms of UV and water exposure, average/max. operating temperature and finally the trade name/ type no of compound)
3. As 2) for a second collector type, if applicable
4. Are the rubber sealing easy to mount and to replace? Answer from a scale 1 (easy) to 5 (difficult)
5. Are you aware of any specific regulatory requirements with respect to recycling of these components?
6. Do you have any experiences related to recycling of these components?
7. What type of negative effects did you experience with polymer sealing?
8. How do you formulate you requirements when searching for an appropriate polymer sealing component?
9. How do you make sure that your requirements are fulfilled?
10. Do you consider that you have the knowledge required to be able to order the best choice of sealing products?
11. Is there any specific knowledge in this area that would be valuable to your company?
12. Anything else you would like to add?

Annex 2. Results from questionnaire survey

	Questions													
Solar collector	1	2			4		5	6	7	8	9	10	11	12
		Component type	Environ ment	Type	Mount	Replace								
1	Flat plate	Extruded profile	Wet 50/120	Silicone	1	2	No	No	Shrinking	Sending a detailed list of requirements	Data sheet and tests from supplier, laboratory and outdoor tests at our own factory	Yes. But always lots of discussion and comparison of different suppliers	News of new tested solarthermal suitable sealing products	Saving costs with sealings is risky i-e- silicone to EPDM. Has to be tight for 20 years in outdoor exposure which is hard to achieve with most polymers.
		Flashing	UV, wet 60/210	Silicone	3	4			-					
2	ETC	Fixing cup (bottom)	UV, wet ±30/80	EPDM	1	1	No	No	-	What we know we try to formulate in requirements. I.e. Temperature, radiation exposure plus intended function including durability and mounting ease	In house testing. Often designing own methods to be able to do it cheap, fast and reliable.	No (even though we believe ourselves to be good at this)	Ageing properties. How different mechanisms interact when polymers are damaged or their lifetime reduced	-
		vacuum tube plug	UV 100/350	Silicone	1	1			Dis-coloured					
		pipe bushings		Silicone	1	3			Melting					
		Fixing cup (top)	±30, 80/300	EPDM or silicone	1	1			-					
		Manifold box gable	UV, wet ±30, 50/100	Thermo set polymer?	-	-			-					
3	Flat plat e	Extruded profile	UV, wet, 60/210	EPDM	3	2	Part of ISO	EPDM recycling	Hard and brittle after	UV, ageing	Norms + experience	yes	Ageing of EPDM acc to	-

	Questions													
Solar collector	1	2			4		5	6	7	8	9	10	11	12
		Component type	Environ ment	Type	Mount	Replace								
							14000		many years		laboratory test acc to ETAG 002 and IEC 61215		DIN 7863-1	
		Extruded profile	UV, wet, 60/210	Silicone	-	-			-					
4	Flat plate	Extruded profile	UV, Wet 40/90	EPDM	2	1	Blue angel, Environ - mental friendly quality label	No but it will probably be mandato ry within ten years	-	Practical experience of suitable hardness. Silicone free of solvent. Requirements together with manufacturer.	Quality control, checking corners, rain penetration, fogging etc.	Would like to say yes but knowledge is based on experience. Would be good to have more professional knowledge.	For example to change from EDPM sealing to silicone glue. How this would be affected after 20-30 years. Alternative material for silicone gaskets.	EPDM, silicone, PA probably most common
		Gasket for pipe	UV, Wet 40/200	Silicone	4	2			-					
		Sealant back plate	UV, Wet 40/200	Silicone	1	3			-					
		O-ring	Wet 30/90	EPDM	-	-			-					
5	Flat plate	Extruded profile	UV, Wet, gases 50/120	?	4	-	No	No	-	Try to formulate after what we know. Hard to have a constructive dialogue with the supplier.	In house testing. Often designing own methods to be able to do it cheap, fast and reliable.	No (even though we believe ourselves to be good at this)	Ageing properties. How different mechanisms interact when polymers are damages or their lifetime reduced	-
		Pipe bushings	UV, Wet 80/200	Silicone	1	2			-					
		Box gap sealant	Wet 40/180	?	4	-			-					
		Dust protection insulation	80/200	Non-woven	-	-			-					

<table>
<tr><th></th><th colspan="14">Questions</th></tr>
<tr><th rowspan="2">Solar collector</th><th rowspan="2">1</th><th colspan="3">2</th><th colspan="2">4</th><th rowspan="2">5</th><th rowspan="2">6</th><th rowspan="2">7</th><th rowspan="2">8</th><th rowspan="2">9</th><th rowspan="2">10</th><th rowspan="2">11</th><th rowspan="2">12</th></tr>
<tr><th>Component type</th><th>Environ ment</th><th>Type</th><th>Mount</th><th>Replace</th></tr>
<tr><td rowspan="2">6</td><td rowspan="2">Flat plate</td><td>Pipe bushings</td><td>UV 80/200</td><td>Silicone</td><td>1</td><td>-</td><td rowspan="2">No</td><td rowspan="2">No</td><td>-</td><td rowspan="2">Try to formulate after what we know. Hard to have a constructive dialogue with the supplier.</td><td rowspan="2">In house testing. Often designing own methods to be able to do it cheap, fast and reliable.</td><td rowspan="2">No (even though we believe ourselves to be good at this)</td><td rowspan="2">Ageing properties. How different mechanisms interact when polymers are damages or their lifetime reduced</td><td rowspan="2">-</td></tr>
<tr><td>Glass glue</td><td>Wet 70/150</td><td>Silicone</td><td>1</td><td>-</td><td>-</td></tr>
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