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A Novel Production Technique for Flat Plate Solar Collectors with a Fully Adhesive Edge Bond

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Summary

The objective of the research is the utilisation of adhesive bonding technologies in the manufacturing process of solar flat plate collectors. To achieve a higher degree of automation as well as to open new paths for innovative collector designs, an approach based on the production of insulated glazing units (IGU) was considered. The adaption of this production technique for solar collectors with a fully adhesive edge bond is presented from the theoretical approach to its application. The technology was applied in several collector samples.

Keywords: Solar collector, Edge bond, Gas-filled, Production

1. Introduction

In 2010, the German Federal Ministry for the Environment, Nature conservation and Nuclear Safety (FME) presented a report on the future utilisation of solar thermal heat. Until 2030 more than 30 GWh per annum will be generated by solar thermal systems in Germany. In contrast, 2010 only 5 GWh•a^{-1} were produced by solar collectors. However, this view is also shared by others. The German Solar Industry Association (GSIA 2013) developed a road map including different scenarios (Fig. 1).

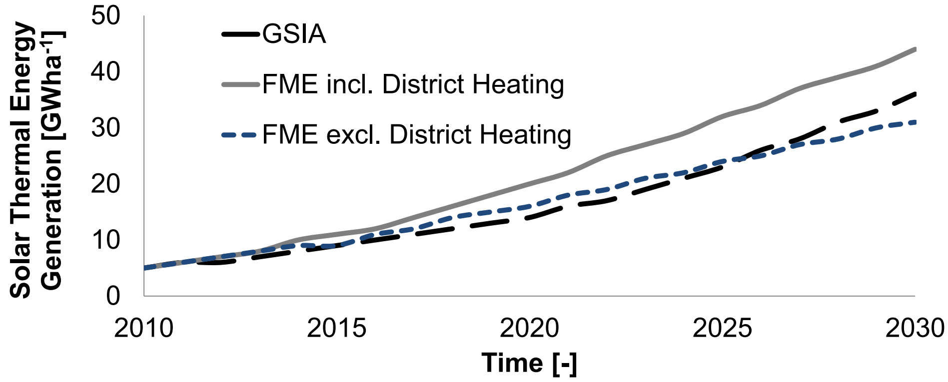

Fig. 1: Predicted expansion of solar thermal collectors till the year 2030 (FME 2010, GSIA 2013)

According to these studies, in the medium term, the European collector producers will be confronted with increasing sales and an increasing competition from Middle East, Asia and South America. To tackle this challenge, great potential is seen in a more standardised and automated production process.

However, comprehensive industry analyses with respect to mass production show a suboptimal current collector production. To overcome this and manage the changeover to industrialised collector production, novel production techniques and new collector designs that are suitable for high volume automated production need to be evaluated. Against this backdrop, a great potential is seen in modern adhesive technologies - providing a considerable degree of production flexibility and a high automation level. Consequently, the development of both a new solar collector and its production process should be carried out in parallel. New production techniques and materials should be analysed to allow the production of innovative collector designs.

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The conducted work is divided into two major aspects – the adaption of an insulated glazing unit (IGU) production technique for solar collectors and the research on a new collector design. The main focus of this paper, however, is on the adapted production technique.

2. Background and Motivation

In 2008, a market survey on the current state of the collector production was conducted for the German Solar Thermal Technology Platform (Müller and Zörner, 2008). By means of established appraisal criteria, the situation of the assembly of flat plate solar collectors was investigated. As a result of the analysis, it turned out that most collector producers are running a workshop operation instead of a mass production system. By judging the manufacturer sales figures, it was concluded that some collector producers are on the threshold to 'serial production' (Fig. 2).

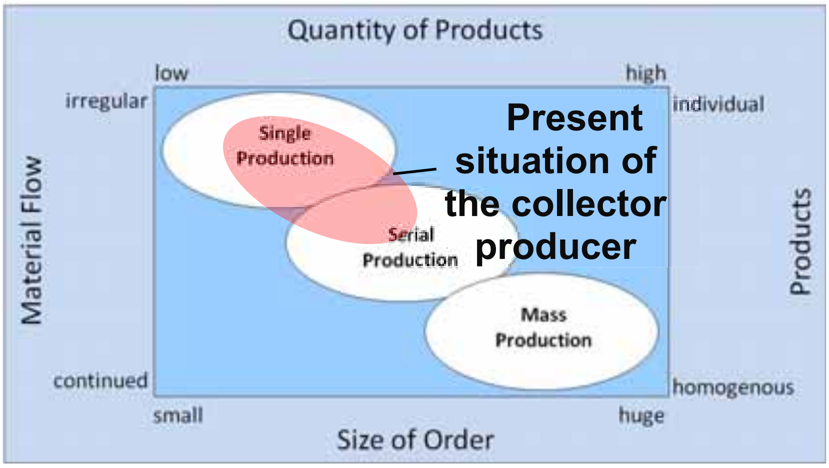


Fig. 2: Current situation in the collector production in Germany

It was emphasised that collector producers tend to simply duplicate a single collector assembly line to increase production capacity. However, Müller and Zörner query whether a collector production at an industrial scale is feasible with the current production technique.

In a further study Müller and Zörner (2010) enhanced the original study by including collector producers from Austria. The main focus of their analysis was the assessment of the automation level of 8 different collector manufacturers. To evaluate the collector assembly, the production process was divided in to the main work steps:

- Cleaning of the glass cover,
- Assembly of the frame,
- Assembly of the back plate,
- Assembly of the absorber and insulation,
- Application of the adhesive,
- Assembly of the glass cover,
- Curing of the adhesive.

Finally, the automation grade for each work step was analysed and compiled in a matrix. Even though, there are some automated sections, such as the adhesive application, the evaluation shows there is no fully automated produced collector. Furthermore, there is no common strategy among the manufacturers to standardise production of the same product type. For example, the assembly of the back plate may be done manually, semi-automatically, automatically or not at all (if a tray is used). In summary, there is no dominant strategy in the production of solar collectors. Although some of the producers in the survey are among the largest 3 collector producers in Europe, none of them is producing collectors on a fully automated assembly line (Fig. 3).

Fig. 3: Overview of the automation level of German and Austrian collector producers (Müller and Zörner 2010)

The reasons for this situation in the solar thermal industry are manifold and can be found among others in its history. In the 1980s, the first solar collectors were hand made in very low quantities. During the following decades, solar collector sales increased but the basic design of a flat plate solar collector did not change much. Müller and Zörner query therefore whether the current collector design is suitable for production at an industrial scale at all. Another reason for the patchy production situation is the unsteady European market. Since this work is focussed on technical aspects of collectors and their production, this circumstance is not further discussed in this paper.

In 2012, Berner published an overview of the situation in the German solar thermal industry. Absorber production was found to be a highly automated process whereas the assembly of the solar collector was found rather difficult to automate due to its design. According to Berner, the reason is the current collector design. Berner also claims that a higher degree of automation limits the producer flexibility.

For a better understanding of this situation a conventional flat plate solar collector production line is described more in detail. Fig. 4 shows the typical production process of a frame collector.

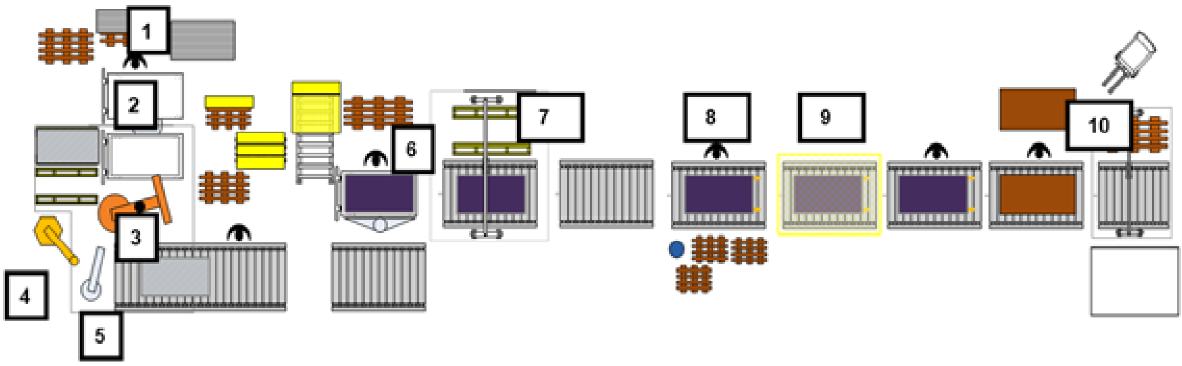


Fig. 4: The major steps of a flat plate collector production

As first step a worker positions the frame profiles (1) on a rotatable assembly bench (2). To join the frame parts and for extra stability, angle pieces are put into the corners of the frame. The frame is rotated into the automated production area. A robot picks up the back plate (3) and moves it to the gluing station (4) where an adhesive bead is applied. Subsequently, the robot assembles the back plate and the frame. The frame is clinched (5) and is put down on a roller conveyor. At the next station (6) a worker manually inserts the side wall and back insulation in the casing. Before the absorber is manually inserted, the insulation is suctioned to avoid pollution on the absorber surface. The next step is the mounting of the glazing (7) by a linear robot. At station (9) the collector is equipped with glazing ledges by a worker. Then the glazing ledges are fixed on the collector frame (10). Finally, the collector is packed and palletised (11).

The cycle time for a conventional framed collector on this production is about 10 minutes. Altogether, 6 people work at the production line.

There are some considerable advantages of this production method for the manufacturer. Given in the nature of the frame design, a wide range of collector dimensions can be produced on the same production line. Most manufacturers are producing at least 2 different collector types on the same production line. The low overhead costs allow a matched production according to the current market demand. This is because the biggest share of the production costs are held by personnel costs. Finally, a highly automated production line causes higher capital costs than a line as described in the example. However, taking the predicted growing collector market into account, the costs of a highly automated production line could be quickly amortised.

To meet the expectations of the manufacturers regarding a flexible and automated production, which is inevitable when designing a successful product, certain aspects need to be considered. A new production technology needs to be at least as flexible as the current technique. At the same time the automation degree needs to be higher, scalable and expandable.

A great potential is seen in the use of adhesives to improve both the automation level and the collector design (Epp and Berner 2010; Berner 2012). Adhesive technology is rapidly developing and is already well established in many sectors, such as the glazing industry. Most collector manufacturers use adhesives for the joints between the frame and back plate. Berner (2012) found adhesive technology to be the most frequently used method of joining the collector frame parts. In fact, more than half of all the collectors sold in Germany have glazing bonded onto to the frame by adhesives. In 2008 more than 62 % of the producers were still using mechanical bonding methods, such as clinching. Some collector producers are using fixing ledges in addition to adhesives to fix the glazing to the frame. This is actually not necessary but is a result of a product recall by a manufacturer in 2008 after the glazing came off the frame. The use of adhesives in collector production has several advantages. Beside the suitability for automation of adhesive techniques, components such as the upper sealant, cover strips and aluminium profiles can be saved and, thus, costs are reduced. However, compared to other industry sectors the adhesive technology for solar thermal applications is still in its infancy.

3. Proposed collector production method

In the glazing industry, especially for insulated glazing units, highly automated production processes paired with heavy-duty adhesive technology are a common standard. In order to achieve higher degree of automation in solar collector production as well as opening new paths for innovative collector designs, an approach based on the manufacture of IGU should be considered.

Since the introduction of insulated glazing, adhesive bonding techniques have been used to connect two or more glass panes. During the beginning of IGU production, metallic spacers have been used (Fig. . 5) to keep the panes at a fixed distance. Even though the production process of using metallic spacers is highly automated, there is a lack of flexibility in dimensions. More importantly, a considerable effort in the machinery set-up time is required as the spacers are assembled in an upstream operation. This makes matched production of different glass sizes problematic if idle periods are to be avoided. In the last decade a production technique replaced the metallic spacers by a fully adhesive edge bond. Using this technique, a mixed production of different IGU versions is feasible without idle periods or upstream operations. The structure of an IGU with a fully adhesive edge bond is shown in Fig. 5.

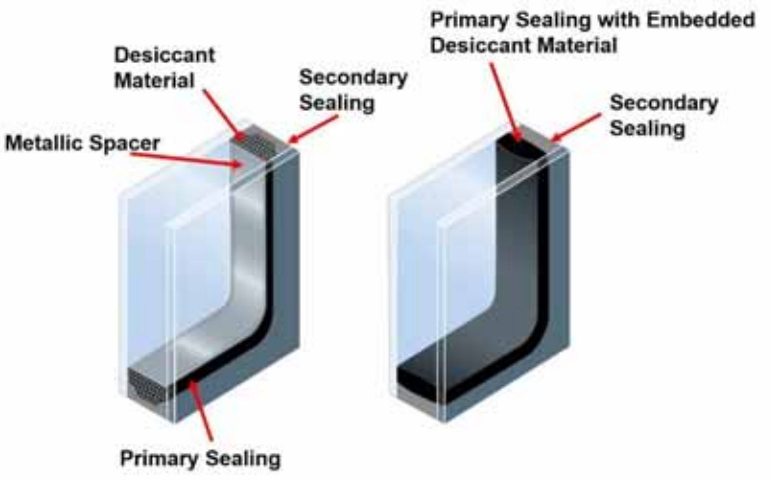


Fig. 5: Comparison of an IGU with a metallic spacer and an elastic fully adhesive edge bond

In contrast to solar collector production, an IGU assembly line is continuously automated. This results in cycle times for an IGU of less than 60 s. The high process speed is a result of the degree of automation, the high speed of the adhesive applicator and the removal of upstream operations. Fig. 6 shows an example of a line for insulated glazing units with a fully adhesive edge bond.

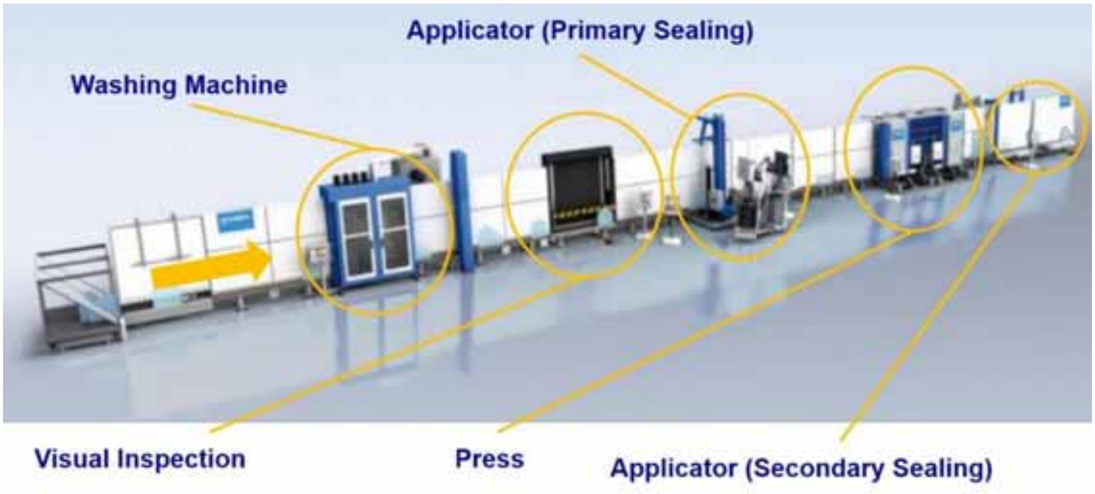


Fig. 6: Layout of the adapted production line

During the work, several physical models were built on a pilot plant to point out the feasibility of the approach. The layout of the collector is shown in Fig. 7.

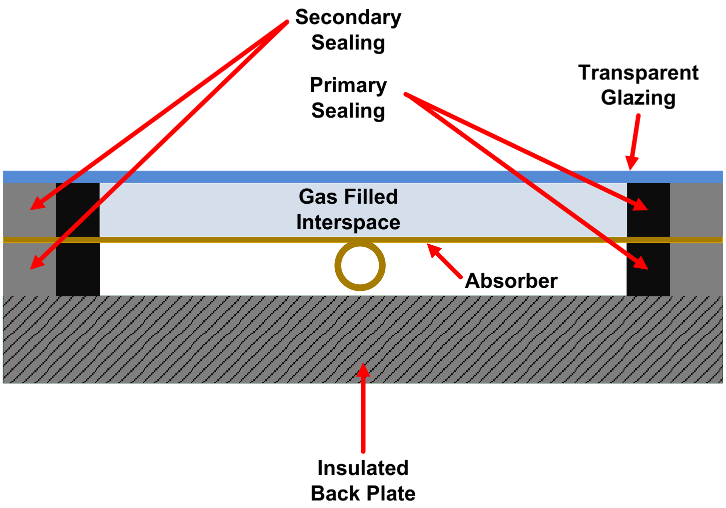


Fig. 7: Cross section of the proposed collector design

Below the production process is described in brief:

Tests showed that the absorber cannot be moved on the pilot plant production line without a jig. The reason to this is the fragile structure of a sheet-pipe absorber which does not allow a precise adhesive application. Therefore, a special jig was used to stabilize the absorber during the production process. At first, the absorber in its jig is put on a conveyor belt by a worker or robot. An airstream keeps a steady distance between the collector component (glazing or absorber) and the production line wall enabling a frictionless transport. The absorber is transferred to the inspection station. After the visual inspection the absorber stops at the first adhesive applicator. The dimensions of the absorber are automatically taken before the glass gets to the primary sealing station. A robot applies the primary sealing in the pre-set design with movement speeds of up to 30 cm•s^{-1}. Due to the computer numerical controlled adhesive application, a very high and repeatable quality is assured at a very low application time (Fig. 8).

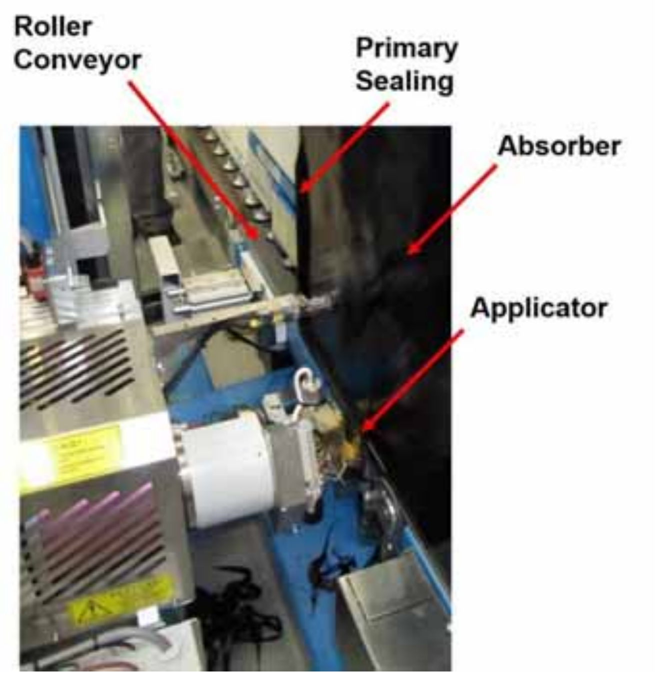


Fig. 8: Application of the primary sealing on a sheet-pipe absorber

At this stage the glazing is already washed and checked at the visual inspection. Both components are transferred to the press without idle periods. The glass and the absorber are simultaneously assembled and gas filled in the press. The final assembly step is the application of the secondary sealing adding the mechanical rigidity. After that, the adhesive needs to cure. The curing times are adjustable to the production speed. The cycle time depends on the automation level of the production. However, a cycle time of less than

60 s for the absorber-glazing-module is intended.

The bonded absorber-glazing-module is then ready to be joined with an insulated back plate. Alternatively, the module can be put in a conventional frame or tray.

4. Proposed collector design

An all-round adhesive supported absorber has several technical advantages over more conventional designs. In this approach, the cavity between absorber and glazing is hermetically sealed which gives the collector significant assets over more conventional collectors. Unlike unsealed collector designs, environmental contaminants such as moisture and dust have no negative effects on the absorber surface of the proposed design. The residual moisture in the hermetically sealed interspace is removed by the primary sealing which contains a desiccant material. Ultimately, this leads to less degradation on a coated glazing or the absorber surface.

Even more important, the interspace is filled with an inert gas (Argon or Krypton) during the assembly of the collector. The gas filled interspace is a promising approach to enhance the thermal efficiency of the collector as the convective heat loss is significantly reduced in contrast to unsealed collectors (Fig. 9).

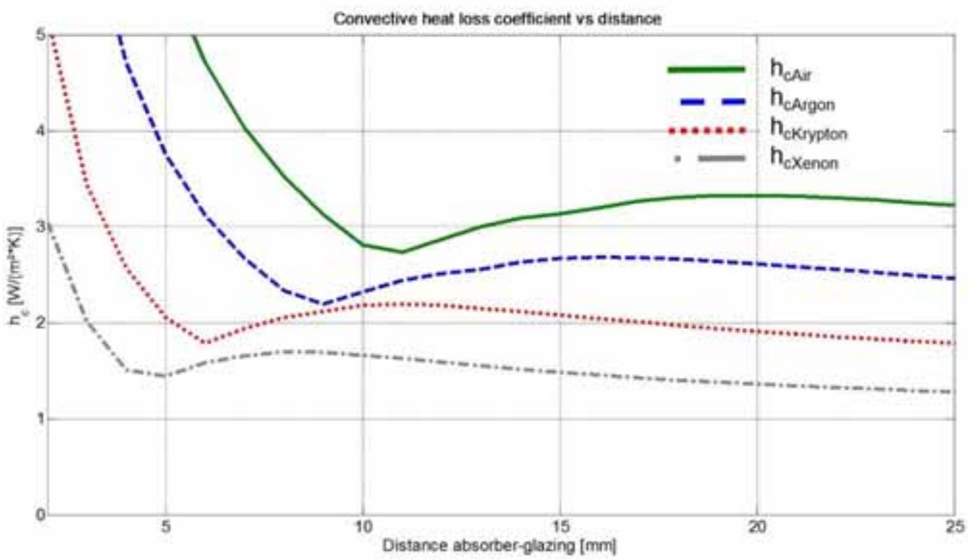


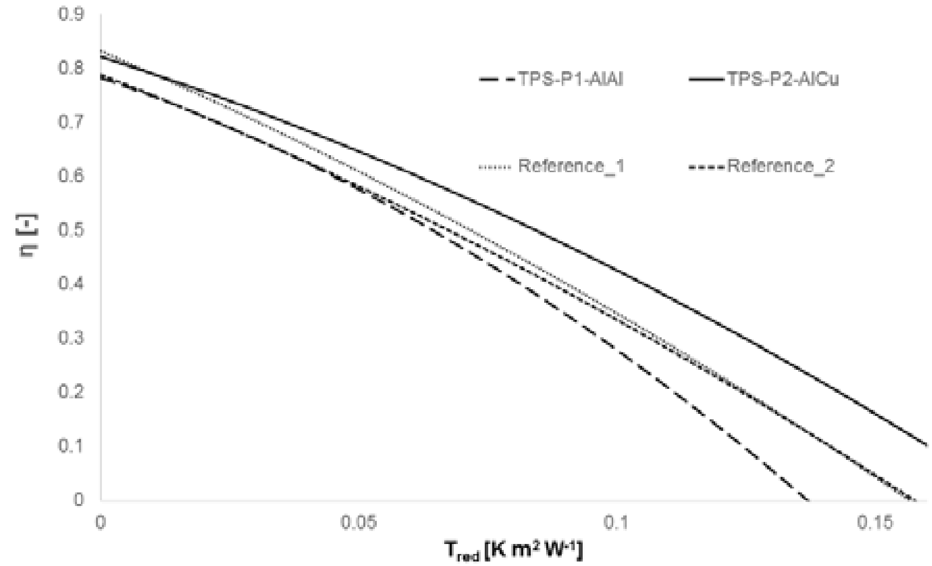
Fig. 9: Convective heat loss coefficient depending on the gap size according to Hollands' convection theory

Beyond that, a gas filled solar collector assembled at ambient pressure can be designed without any additional hardware, such as a perpendicular (e.g. honeycomb insulation) or parallel absorber structure (e.g. double glazing). However, the disadvantage of a sealed interspace is the absorber deflection during collector operation. This is caused by the pressure change in the cavity, the thermal deformation of the absorber and the all-round supported absorber. As the absorber is less rigid than the glazing and facing the highest loads, the absorber experiences the largest deformation. To keep the collector design simple, neither an interspace pressure below ambient pressure nor an additional expansion tank were considered in this research.

5. Outcome

The conducted research presents new knowledge on the use of adhesive technologies for solar flat-plate collectors. Both the collector manufacturing process and the collector design were considered in this work. It was shown that an existing and highly automated IGU production process can be modified and adapted to produce solar collectors. Throughout the research different series of prototypes were produced on the pilot plant production line. Based on the new production technique a new collector design approach was made feasible. The very first samples were designed as a frameless solar collector stabilised only by using the described adhesive technology. For these models full aluminium sheet-pipe absorbers (TPS-P1-AlAl) were used with a distance between absorber and glazing of less than 11 mm. However, these first samples were beyond the expectations based on simulation results. The reason to this was the very high absorber deflection during collector operation. The collision of absorber and glazing magnified the front heat loss and, thus, lowered the thermal efficiency of the collector significantly. Throughout the research programme, several more samples with different properties were produced, such as a roll-bond absorber. The later models showed a very decent performance (Fig. 10). The parameters of the collectors are compiled in Tab. 1.

Fig. 10: Thermal efficiency of 2 prototypes and 2 conventional collectors



Tab. 1: Compilation of the collector parameters (authors own measured data)

Parameter	TPS-P1-AlAl	TPS-P2-AlCu	Reference_1	Reference_2	Unit
η_0	0.782	0.821	0.832	0.787	-
a_1	3.215	3.059	4.060	3.737	$Wm^{-2}K^{-1}$
a_2	0.023	0.011	0.010	0.010	$Wm^{-2}K^{-2}$
Absorber material	Aluminium	Aluminium	Copper	Copper	-
Piping material	Aluminium	Copper	Copper	Copper	-
Absorber type	Harp	Double-Harp	Double-Meander	Double-Harp	
Aperture	1.9	1.9	2.1	1.9	m²
Sealed interspace	Yes	Yes	Yes	No	-
Gas	Argon	Argon	Argon	-	-

6. Outlook

At present the different samples are undergoing thoroughly testing at the institute's own outdoor testing rig. In this context, the temperature loads on the adhesive edge bond and the temperature distribution on the absorber respectively glazing are recorded. Beyond that, the deflection of the absorber is recorded via position sensors which are mounted on the backside of the absorber. Ultimately, this data will be used for a further validation of the simulation. Parallel to this, the final simulation is in progress to identify the most suitable absorber parameters, such as absorber material usage or gap size.

As a final step a comprehensive lifetime prediction of the adhesive as well as on the absorber itself needs to be conducted. This is crucial as the components suffer from a thermal and mechanical load during a collector lifetime of more than 20 years.

7. References

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