HEAT LOSSES OF HIGHLY EFFICIENT FLAT PLATE COLLECTORS WITH A SELECTIVELY COATED DOUBLE GLAZING

S. Föste, F. Limprecht, N. Tiedemann, G. Rockendorf

Institut für Solarenergieforschung Hameln/ Emmerthal (ISFH), Am Ohrberg 1, 31860 Emmerthal, Germany

++49 5151 999 506, foeste@isfh.de.

Abstract

The heat losses of a flat plate collector with a selectively coated double glazing depend among other parameters on the height of the two gas-filled gaps. Within the hermetically sealed glazing cavity inert gases instead of air can be used to decrease the convective heat transfer. To identify the impact of the mentioned parameters, heat loss measurements at a prototype collector were carried out. Therefore the gap sizes were varied and as filling gases of the glazing cavities air, argon and krypton were applied. For each filling gas optimum gap sizes are experimentally identified. These results are in accordance to the Nusselt-equation developed by Hollands [1]. Further the impact of different inclination angles on the heat losses of the collector was determined experimentally.

1. Introduction

Many future applications of solar thermal energy, like central heating with a high solar fraction and solar heat for industrial processes or solar air conditioning will require high collector efficiencies at temperatures above 80°C or at low irradiance levels. Advanced flat plate collectors show a high potential for these applications, as they show low maintenance requirements and they are inexpensive and mechanically simple [2]. Thus ISFH is aiming to raise the performance of flat plate collectors especially for operation at high temperatures by increasing the thermal resistance of the transparent cover while solar transmittance is kept at an acceptable level. This is achieved by adding a second glass pane, which is applied with a low-emitting layer, a so-called low-e coating, in order to reduce the thermal radiation exchange. Furthermore a high solar transmittance must be realized. This requires high quality glass with antireflective coatings and an optimized low-e coating, which is based on a TCO functional layer. Figure 1 shows the basic principle of this collector concept.

Additional measures to raise the efficiency are for example an inert gas filling instead of air. In order to achieve the maximum effect, the low-e coating must be positioned on the upper surface of the lower glass pane (position 3). This ensures, in combination with a selectively coated absorber plate, that in each gap one low emitting coating effectively reduces thermal radiation.

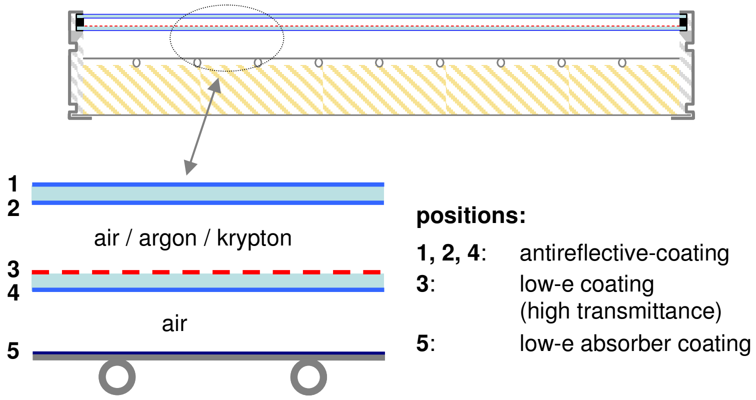

Fig. 1. Schematic collector concept, sectional view

The low-e glazing technology is a standard for windows since more than 15 years. It allowed to reduce the heat losses through windows by approximately 50% if compared to an uncoated double glazing. The objective of our work is to investigate the feasibility to apply this technology for solar thermal collectors and to develop the technological basics of this concept. The project work can be subdivided into three main topics.

One topic is the development of highly transmitting low-e coatings on glass. Low-e coatings on glass are a standard technology for window glazing. But these commercially available coatings show only a high transmittance in the visible spectrum, while they are optimized for a low emissivity of 5% or less, to minimize the heat losses (U-value). For a collector glazing however it is very important to obtain a high solar transmittance, while due to the more complex heat loss paths the emissivity is allowed to be higher than in a window application. According to the current project status we developed a low-e coating system based on a TCO[1] material which reaches a solar transmittance of 85% on a glass substrate with low iron content. This coating system has shown an emissivity of 31% [3]. Besides the optimization of the coating system regarding the optical properties, further investigations concerning the stability against humidity and temperature loads are currently carried out.

Another main topic is the long term reliability of this collector concept. Due to the reduced heat losses through the transparent cover the maximum temperatures in case of stagnation are significantly higher, if compared to a flat plate collector with a single glazing. Particularly the loads on the hermetically sealed double glazing are crucial, as this is a component which is commonly used at moderate temperature levels in windows. If the collector is in case of stagnation the lower glass pane can be heated up to maximum temperatures of approximately 160 °C. The edge bond of the hermetically sealed double-glazing consists of polymers to realize a gas tight joint and is therefore particularly temperature sensitive. Thus the focus of the reliability investigations is directed towards the double glazing. Several load experiments are carried out to investigate the reliability against high temperatures, induced thermo-mechanical loads, UV-radiation, humidity and mechanical loads. Detailed results of these investigations have been presented in different publications [4, 5]

[1] TCO: transparent conductive oxide

The main focus of this paper is aimed at the collector heat losses. The total heat losses are mainly influenced by the heat transfer from the absorber plate through the transparent cover, which is subdivided into two gaps: the air filled gap between absorber-plate and glazing and the air or gas filled gap between the glass panes. This heat transfer depends on different parameters. In each of the gas- or air-filled gaps the heat is transferred in parallel by both convection or conduction and radiation. As the plates are large in relation to the distance, the radiative portion can be calculated very accurately by radiative heat transfer equations, its amount may be minimized using at least one low-e coated surface in each gap. In the gap between the absorber plate and the glazing a commonly used low-e absorber coating decreases heat radiation. In the gap between the two glass panes (glazing cavity) the already discussed highly transmitting low-e coating is applied on the upper side of the lower glass pane.

The convective heat transfer in the two gaps can be described by empirical equations. Usually the Nusselt equation from Hollands [1] is used for flat plate collectors. Beside the temperatures of the opposed surfaces the convective heat transfer depends on the properties of the filling gas in the gap, the gap width and the inclination angle of the gap. To optimize the design parameters for the transparent collector cover with regard to the convective heat losses, extensive series of measurements are carried out. The filling gases of the glazing cavities have been changed as well as the gap width and the distance between absorber plate and glazing. Furthermore the influence of different inclination angles has been investigated.

2. Heat losses

2.1. Experimental setup

For the experimental investigations regarding the heat losses a solar thermal collector with a gross area of 2 m² is used. It is equipped with a standard absorber plate (Cu) and a backside insulation of 10 cm thickness. The construction allows us to vary the distance between absorber plate and glazing. Further the distance between the two glass panes and the filling gas of the glazing cavity can be varied by applying different industrially produced insulating glazings with a hermetically sealed edge bond using a TPS[2]. As up to now the developed high transmittance low-e coating on glass is only produced in laboratory scale, the commercially available Pilkington K Glass™ is applied as a low-e glass. Due to its high absorptance (α = 23%) and reflectance of solar radiation, the solar transmittance of 71% is too low for a solar collector application. The emissivity for thermal radiation of 20% is sufficient.

The high absorptance of the K Glass™ leads to an intense warming of the lower glass pane during collector performance measurements under irradiation. Thus the temperature of the K Glass™ pane is above the absorber temperature if the collector fluid temperature is kept below 65 °C. The self developed high transmittance low-e coating on glass with a low iron content in laboratory scale shows a significantly lower absorptance (α = 8%). Thus the self-heating effect by absorption of solar radiation would be significantly lower if compared to K Glass™.

By performing a heat loss measurement without irradiation the self-heating effect of the K Glass™ due to absorption of solar radiation does not occur. The temperature of the K Glass™ is close to the expected temperature of a glass pane with the self developed ISFH low-e coating under irradiation,

[2] TPS: thermo plastic spacer

what has been stated by a collector simulation. Hence in the following the results of heat loss measurements without irradiation will be presented and discussed.

2.2. Distance between absorber and glazing

Heat loss measurements with different distances between absorber-plate and glazing from 19 mm to 38 mm showed, that a distance of 25 mm causes the lowest collector heat losses, even at high temperatures. This gap is not hermetically sealed and it is therefore open to the ambient air, what is usual for the most commercial flat plate collectors. Hence the use of inert gases in this gap is not possible. In this paper the focus is aimed at the variation of the glazing cavity, while the distance between absorber and glazing is kept constant at 25 mm.

2.3. Glazing cavity

The convective heat transfer through the glazing cavity can be influenced by the design parameters distance between the glass panes and filling gas. Figure 2 shows the convective heat transfer coefficients in an enclosed gap with an inclination angle of 45° for the three filling gases air, argon and krypton according to the equation of Hollands [1].

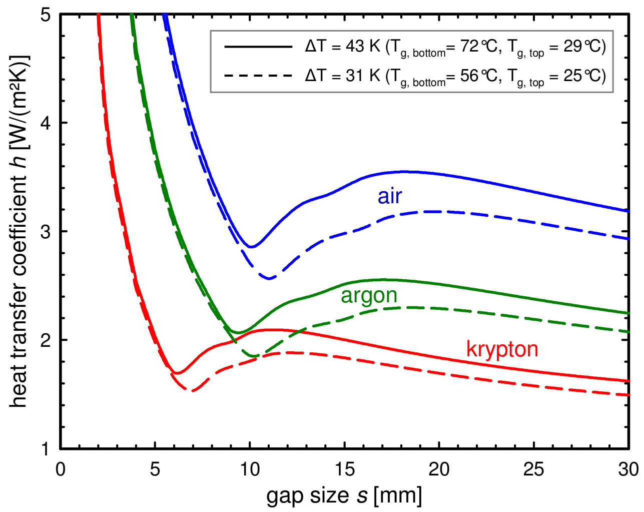

Fig. 2. Heat transfer coefficient across inclined gas layers against gap width for different gases and different temperatures according to [1], inclination angle $\varphi = 45°$.

For each gas type two different temperature differences between upper and lower glass pane are taken, which occur at typical operating conditions of the collector. All curves show similar trends. The heat transfer coefficient decreases strongly until a transient gap size, where a local minimum occurs. If the gap size s is smaller than the transient gap size, no convection takes place; beside the radiation only conduction appears. With increasing gap size s the convection starts, which leads to an increase of the heat loss coefficient until a local maximum. With further increasing gap size the heat transfer coefficient decreases slightly. As figure 2 demonstrates, the non-radiative heat transfer coefficient in the cavity can be reduced by approximately 30% if it is filled with argon instead of air and even by approximately 40% if krypton is used. Furthermore it becomes apparent, that the transient gap size, where the heat loss coefficient has a local minimum, is smaller for the inert gases (argon, krypton) if compared to air.

To experimentally investigate the influence of the gap size for different filling gases, the glazing cavity has been varied by applying different double glazings. The distance between absorber plate and glazing is kept fixed at 25 mm. To evaluate the impact on the heat losses, the total heat loss coefficient U_l of the collector at different fluid temperatures is considered. The total heat loss coefficient is defined by the heat flow $\dot{Q}_l$ between collector and ambient air, and the mean fluid temperature T_f and the ambient air temperature T_a, while $\dot{Q}_l$ is determined by the enthalpy balance between inlet and outlet of the collector fluid:

$$U_l = \frac{\dot{Q}_l}{T_f - T_a} \quad (1)$$

Figure 3 and figure 4 show the total heat loss coefficients U_l for different gap sizes of the glazing cavity versus the temperature difference $\Delta T_{f,a}$ between collector fluid and ambient air.

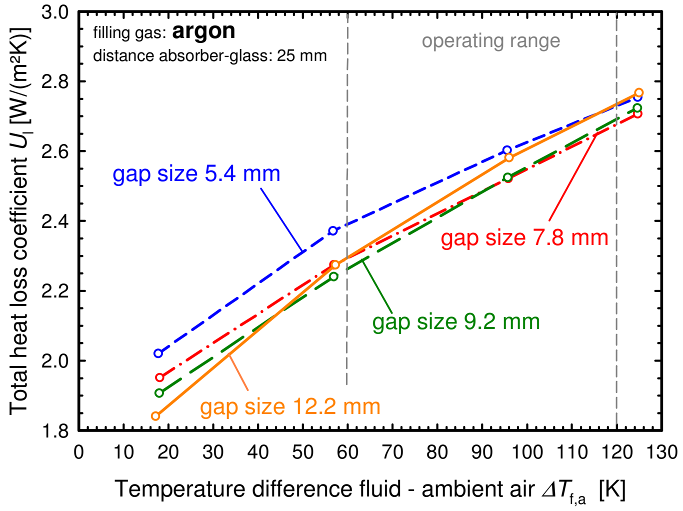

Fig. 3. Total heat loss coefficient U_l for collector configurations with different argon filled glazings versus the temperature difference $\Delta T_{f,a}$ between collector fluid and ambient air

For the investigated configurations with an argon filled glazing (figure 3) the lowest heat losses in the range of operation occur at a glazing cavity of 9.2 mm, at higher temperatures a gap of 7.8 mm also leads to small losses. Compared to that, a larger gap size of the glazing cavity (12.2 mm) as well as a smaller gap size (5.4 mm) leads to higher heat loss coefficients. This trend is conform with the theoretical results given in figure 2.

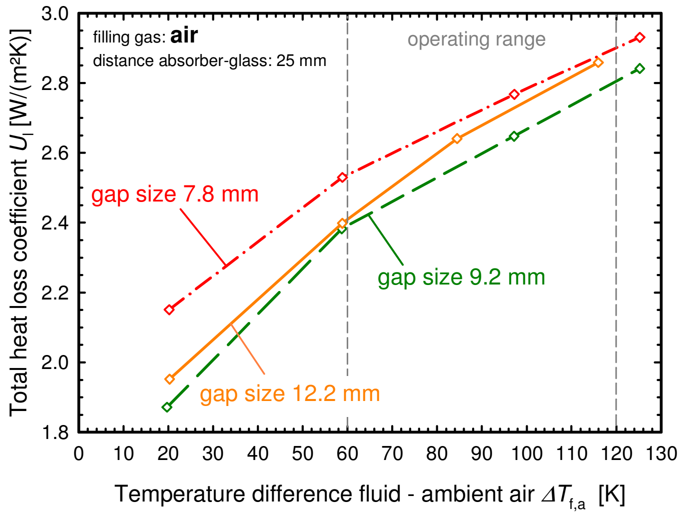

Fig. 4. Total heat loss coefficient U_l for collector configurations with different air filled glazings versus the temperature difference $\Delta T_{f,a}$ between collector fluid and ambient air.

The heat loss coefficients of the configurations with air filled glazings shown in figure 4 give the least heat losses at a gap size of 9.2 mm. This also fits with the theoretical trend in figure 2.

It has to be noted that the gap size of the glazing increases if the gas temperature increases. The gap sizes given in figure 3 and figure 4 are measured at a temperature of 25 °C. At a temperature difference of 120 K between fluid and ambient air the averaged temperature in the glazing cavity is at approximately 60 °C. This leads to an averaged increase of the gap size by 0.8 mm to 1.4 mm, depending on the initial gap size.

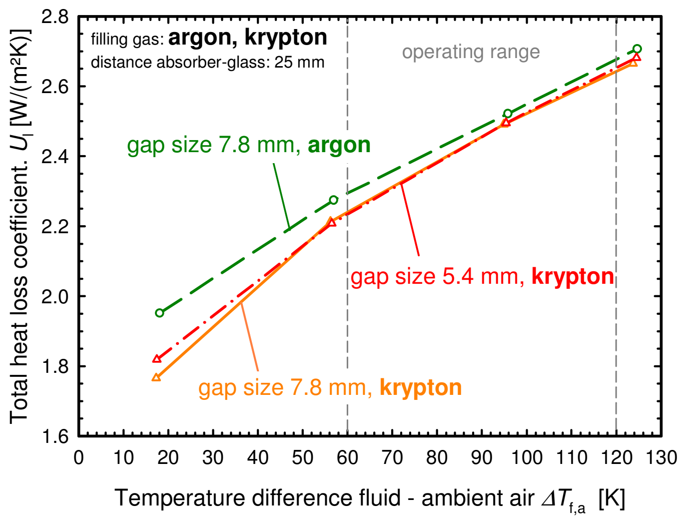

Fig. 5. Total heat loss coefficient U_l for collector configurations with different krypton filled glazings and one argon filled glazing versus the temperature difference $\Delta T_{f,a}$ between collector fluid and ambient air.

If krypton is used in the glazing cavity instead of argon the heat losses of the collector can be further reduced as figure 5 shows. But with increasing $\Delta T_{f,a}$ the advantage of the krypton filling decreases. As figure 2 has already shown, the optimum gap size for a krypton-filled glazing is smaller than the one for an argon- or an air-filled glazing. A smaller gas volume reduces the temperature dependent mechanical load and deformation due to expansion of the gas. This is the main advantage of the krypton-filling. However the smaller volume does not reduce the costs for the gas filling, because krypton is approximately 100 times as expensive as argon.

2.4. Variation of the inclination angle

The inclination angle of the collector also has an impact on the convection in the two gaps of the collector and therewith influences the heat losses. Figure 6 shows the measured total heat loss coefficients U_l at $\Delta T_{f,a}$ = 60 K and $\Delta T_{f,a}$ = 80 K for a collector with an air filled glazing and a collector with an argon-filled glazing. Compared to the heat loss coefficient at an inclination angle φ of 45° the heat loss coefficient can be decreased by approximately 10% if the collector is used in vertical orientation (φ = 90°). If the collector is orientated horizontally (φ = 0°), the heat losses increase by approximately 10% compared to φ = 45°. The inclination angle dependence can be used for system simulations, for example when a collector is tested at φ = 45° and used as a façade collector.

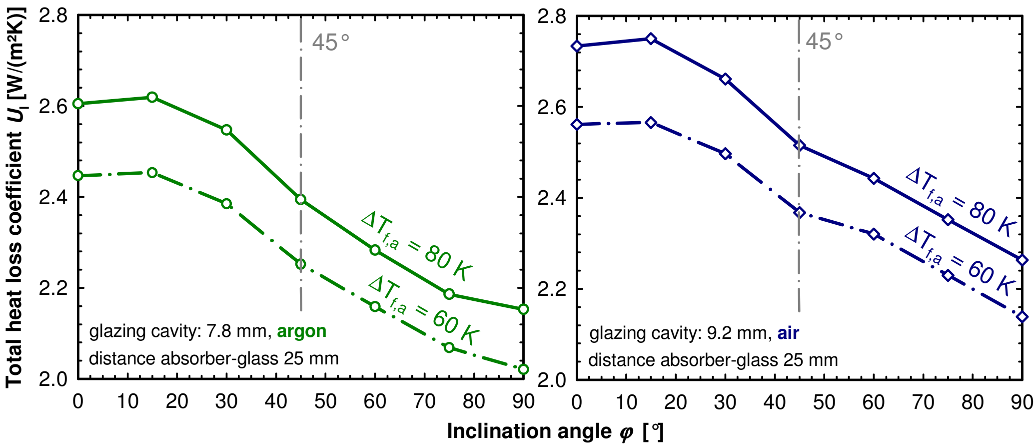

Fig. 6. Total heat loss coefficient U_l for collector configurations with different argon- and air-filled glazings versus the inclination angle φ.

3. Outlook

To be able to evaluate the suitability of the Hollands model for the two gaps of the collector, experimental heat flow balances and temperature measurements at the absorber plate and the glass panes are currently carried out to identify the convective heat transfer coefficients. Therefore the effect of thermal bridges at the edges of the collector frame and the glazing as well as the rear side heat losses have to be determined accurately both by simulations using the finite element method (FEM) and by experimental investigations. The objective is to identify if the Hollands modell is suitable for the two gaps of the collector. If required an advanced model for the convective heat transfer coefficient in the gaps of the collector will be developed, using correction factors for the Hollands equation.

References

[1] K.G.T. Hollands et al.: “Free convective heat transfer across inclined gas layers”, ASME Journal of heat transfer, 98 (1976), pp.189-193

[2] W. Weiß et al.: “Process Heat Collectors. IEA Task 33/IV: Solar Heat for Industrial Processes” Gleisdorf, Austria 2008. Internet: http://www.iea-shc.org/task33/publications/index.html

[3] S. Föste et al.: “High efficiency flat plate solar collector based on a selective double-glazing”, Proceedings of the ISES Solar world Congress 2009, Johannesburg, South Africa

[4] S. Föste et al.: “Verfahren zur Berechnung der temperaturbedingten mechanischen Belastung von Isolierverglasungen in Flachkollektoren“, Tagungsband 19. Symposium Thermische Solarenergie 2009, Bad Staffelstein, Germany, pp.74-79.

[5] S. Föste et al.: „Experimentelle Untersuchungen an Flachkollektoren zur Temperaturverteilung an Absorber und Verglasung im Stagnationsfall“, Tagungsband 19. Symposium Thermische Solarenergie 2009, Bad Staffelstein, Germany, pp.340-345.

Acknowledgement

The results presented in this paper base on the research project “Solarthermie2000plus – Grundlagen für selektiv beschichtete Hochleistungsverglasungen für Flachkollektoren” (*Principles for selectively coated high efficiency glazings to be applied in flat plate collectors)*, which is funded by the German Ministry for Environment, Nature Conservation and Nuclear Safety (FKZ 0329280D).
Furthermore the following industry partners are supporting this research project:

The authors are grateful for this support. The authors alone are responsible for the content of this publication.