

Multiphysics Modeling Studies New Materials that Could Revolutionize Solar Energy

Fundamentally new solar thermal collector designs based on polymeric materials are interesting because they replace metal with plastics and thus offer the potential of far lower costs. In studying these completely new designs, researchers at the Fraunhofer Institute for Solar Energy Systems ISE must consider a variety of interrelated factors including heat transfer due to fluid flow, heat-induced structural deformation and stress plus the mass transport of water through barriers. COMSOL® is a software package which is flexible and comprehensive enough to handle the different physical tasks simultaneously.

BY KARL-ANDERS WEISS, FRAUNHOFER INSTITUTE FOR SOLAR ENERGY SYSTEMS , FREIBURG, GERMANY

An estimated 50% of fossil fuels are used for heating purposes, so there is a huge potential in replacing them with renewable energy sources such as solar collectors. Today's standard collectors use copper or aluminum as the energy-absorbing material, but consider that if we were to meet just 1% of the world's heating energy with conventional solar collectors would require 22 million tons of copper – and that the worldwide output in 2006 was 17.6 million tons. Add to that recent price increases in metals and there's a clear impetus to examine polymers as an alternative.

However, polymers don't have the same ability to withstand high temperatures as metals do, so we need completely new designs for solar collectors using them. Our working group of roughly 30 people focuses on the durability of future solar energy systems, and modeling is a big part of our work with roughly four people using COMSOL on a regular basis.

In studying new concepts we are starting from scratch and use modeling to understand virtually every aspect of an energy system's operation including heat-transfer due to fluid flow, heat-induced structural deformation and stress plus the mass transport of water through barriers. COMSOL Multiphysics provides an excellent platform that allows us to examine all of these within one easy-to-use environment and optimize system operation before we start building prototypes.

Design Optimization for Solar Thermal Collectors

The use of polymeric materials in solar-energy applications has many advantages.

First, of course, is its price compared to today's collector materials. Next, polymers offer great freedom in terms of design – we can develop new collector layouts that would be impossible with conventional materials. For instance, with an extrusion process it might be possible to mass-produce complex geometries in lengths of kilometers and bring the economies of scale. Further, polymers allow the manufacture of collectors that are lighter in weight.

Polymeric materials have a low intrinsic thermal conductivity. This, however, can be compensated by optimized collector geometries with the goal being a layout that assures homogenous flow and maximized

“COMSOL Multiphysics provides an excellent platform that allows us to examine all physics within one easy-to-use environment and optimize system operation before we start building prototypes.”

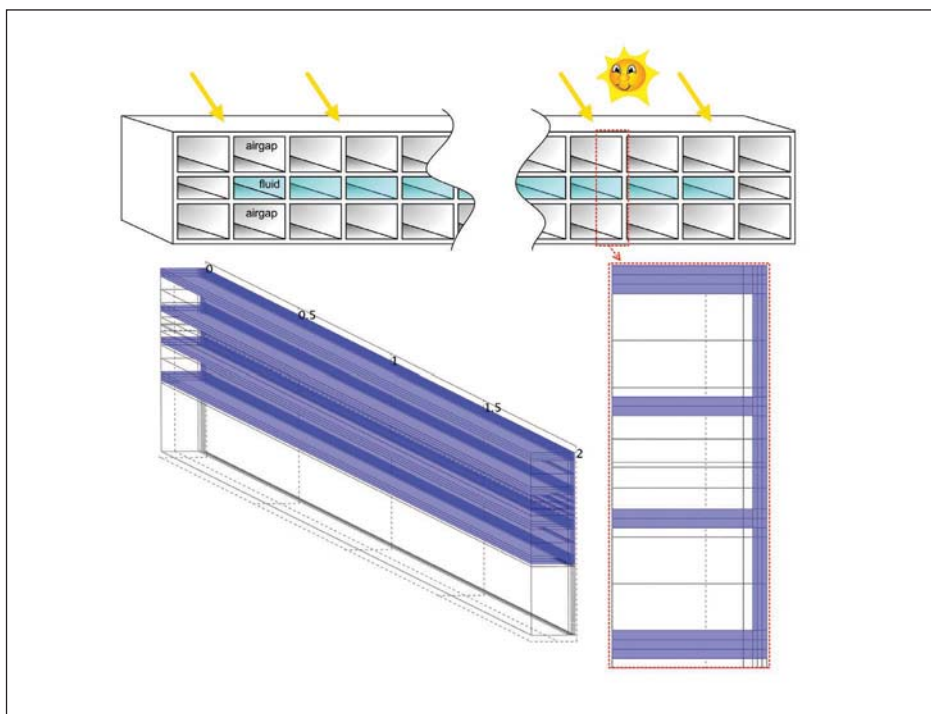


Figure 1: One possible geometry for a solar absorber made of polymer materials.

contact area between the absorber and the heat-transfer fluid. With solar collectors, heat transfer is certainly dependent on a material's thickness and heat conductivity. But an even more predominant effect can be the heat-transfer coefficient between the fluid and the wall, which is determined by the fluid dynamics in the vicinity of the surface, and they depend on the surface's shape. Because polymeric materials can have almost any form, we want to optimize a polymeric absorber's shape so that heat transfer by convection overcomes the lack of heat conductivity.

Advantages of design optimizations are best described by the results of adding an additional plate as absorber into the design, which could increase the internal conductance from 95 W/m²K to 540 W/m²K.

Figure 1 shows one possible layout for a thermal absorber based on multi-wall sheets where the heat-transfer fluid passes through channels that are surrounded by channels filled with air to provide heat insulation from the environment.

Stress Level Analysis of Collector Designs

However, collectors deform when heated, so stress distribution and deformation represent potential risks for their stability and durability, especially at mechanical connection points. We want to estimate a product's useful lifetime due to mechanical stresses that arise not only during normal operation but also during stagnation, the worst-case situation when the energy storage is no longer able to take heat from the collector. We set up a COMSOL model that accounts not only for the tempera-

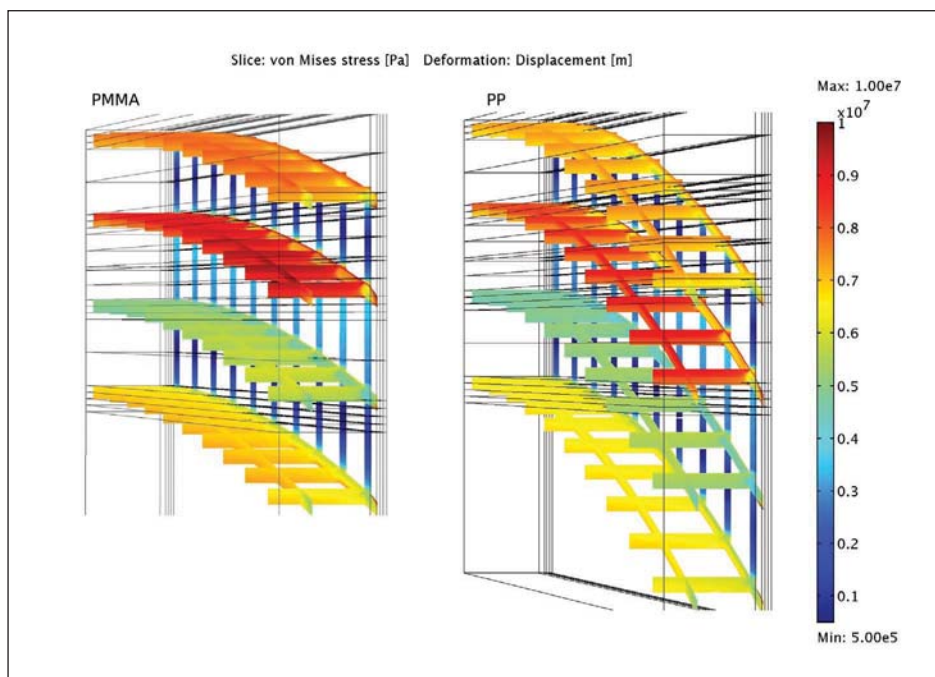


Figure 2: The Von-Mises stresses within a polymer-based solar collector at a normal inlet temperature of 350 K can vary widely depending on the material; here a comparison of the stresses and deformation between polymethyl methacrylate (left) and polypropylene (right) is shown.

ture distribution that varies with the position of the absorber layer but also other factors that affect the temperature level including the amount of irradiance, inlet temperature and the collector's thermal losses. This temperature data enables the determination of the collector's deformation and mechanical failures shortening the service lifetime (Figure 2).

Humidity Transport in PV Modules

While the previous model dealt with solar collectors, polymers also play a role in improving the cost efficiency of photovoltaic (PV) solar modules. These consist of a front cover of glass, encapsulated so-

lar cells and a back-sheet, which is usually made of polymeric materials. These polymeric back-sheets and encapsulants provide a barrier to keep humidity, atmospheric gases and pollutants away from the silicon solar cells and protect them mechanically. The ingress of humidity is a serious reason for their degradation, which can hardly be measured without physically destroying the module. Therefore, we work on developing measurement technologies and the mathematical modeling of the humidity transport.

Modeling Benefits

Thanks to our modeling, we can compare different polymeric collector geometries and materials for various energy carriers to reach an optimized collector design in terms of efficiency and price. We have also confirmed that our design is as efficient as conventional collectors and that the mechanical stability is sufficient if the collector is constructed properly. Our next steps are to model longer time periods to guarantee sufficient durability for our future partners in industry. ■

About the Author

Karl-Anders Weiss earned his degree in physics and economics at the University of Ulm, Germany. Since 2005 he has been with the Fraunhofer Institute for Solar Energy Systems in a group focusing on durability analysis and environmental engineering.



Fraunhofer researchers studying the COMSOL simulation results are (left to right) Georg Mülhörer, Karl-Anders Weiss, Jochen Wirth, and Philip Hülsmann. Steffen Jack is missing.

READ THE RESEARCH PAPER AT:
www.comsol.com/papers/5649/