Air flow and heat exchange simulation of a rotary heat exchanger of polyethylene terephthalate (PET) as a sustainable alternative for aluminum

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Abstract. This paper deals with the simulation of rotary heat exchangers made of polyethylene terephthalates using CFD software. First steps for the simulation of simplified flow processes within a heat exchanger are presented. The aim of the project is the substitution of commercially available materials such as aluminum to plastic. The use of plastic as a storage mass material will create new possibilities which will make the heat exchangers even more efficient than their predecessors made of aluminum. For this purpose, the two materials are compared with each other using simulation models with ANSYS Fluent© and the resulting temperature curve is examined. The results show that PET offers a more suitable temperature profile than aluminum for heat exchanger.

1 Introduction and Objectives of the project

The PET rotary heat exchanger research project is being carried out in cooperation between the Gesellschaft zur Förderung technischen Nachwuchses GFTN e.V., Darmstadt, and Klingenburg GmbH, Gladbeck. The main focus of the research project is the substitution of the aluminum by PET for the production of the storage mass. The PET shall use the advantages of plastic and increase the efficiency of the rotary heat exchanger up to 90% by a geometrically optimized shaft structure. The design options for aluminum are limited by the yield strength. This leads to a maximum efficiency of 85%. A further advantage is the recyclability of the PET. The reuse of the material leads to a sustainable and future-oriented alternative to the existing heat exchangers. The aim of the project is to develop the complete production cycle in a process chain. The process chain is to include extrusion, embossing and deep-drawing as well as the joining of the films with subsequent winding. Once the life of the heat exchanger has been reached, it will be taken back and recycled by Klingenburg GmbH.

2 Operating principle of a rotary heat exchanger

Rotary heat exchangers are used with permitted circulating air. The main task is the supply and removal of heat energy in computer centers, office buildings, factory halls and cruise ships. Due to the large surface area and the associated large air volume, rotary heat exchangers are considered to be the most effective heat exchangers. During operation, two air streams flow through the storage mass, the supply air stream from the outside and the exhaust air stream from the inside. Each of these two flows transfers its heat energy to the storage mass. The energy absorbed is released again and the heat is transferred by the rotation in the respective other stream. [1] The functional principle of the rotary heat exchanger is shown in Figure 1. In the further course of this abstract, the function of a rotary heat exchanger made of aluminum is compared with one made of PET on the basis of simulation results.

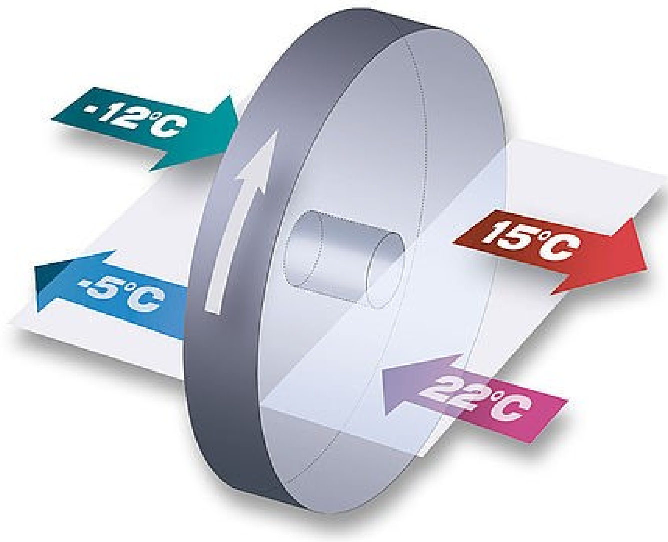

Fig. 1. Functional principle of the rotary heat exchanger

3 Thermal basics of the model

In counterflow heat exchangers, the air flows are guided through a series of parallel plates. Figure 2 shows the simplified principle of the heat exchanger as a volume body in CATIA V5R20®. The arrows indicate the direction of flow of the two air streams. The warm air flow directs the energy through the plate into the cold air flow, resulting in heat exchange. The shown model was calculated under the theoretical basis of single-layer walls.

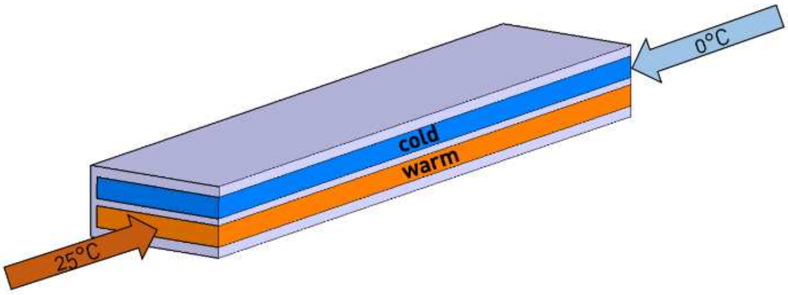

Fig. 2. Used simulation model in half section with displayed flow directions

The proportion of the heat flow absorbed depends on the design of the heat exchanger, the size of the effective heat transfer surface and the material of the transfer surface. The cooperation company Klingenburg GmbH has already carried out the first practical tests in this field, in which the material of the heat exchanger mass was changed from aluminum to PET. It has been shown that PET leads to a better efficiency as soon as the layer thickness becomes very thin.

If the stationary heat conduction is considered in a single-layer wall, the following relationship applies to the heat flow for a plate [2]:

$$\dot{Q} = \frac{(T_{warm} - T_{cold})}{R_\lambda \cdot t} \tag{1}$$

R_λ	=	thermal resistance
$T_{warm/cold}$	=	temperature warm/cold
t	=	time

with the thermal resistance:

$$R_\lambda = \frac{s}{\lambda \cdot A} \tag{2}$$

s	=	wall thickness
λ	=	thermal conductivity
A	=	trea flowed through

If the layer thickness in equation 2 is continuously smaller with the same denominator, the thermal resistance also becomes arbitrarily low. This means that the significantly higher thermal conductivity of aluminum (approx. factor 1000 better than PET) continuously has a considerable influence.

4 Simulation of a counterflow heat exchanger with ANSYS Fluent©

The first simulations were created with ANSYS 18.2 Fluent© CFD software. The geometry used for this was 2.1 mm wide, 0.5 mm high and 5 mm long. Two channels were provided with a height of 0.15 mm and a width of 2 mm over the entire length of this geometry. The dividing wall between them had a continuous thickness of 0.05 mm (50 µm).

In Fluent©, a stationary state was simulated with an air velocity of 1 m/s flowing through both channels. The temperature of the supply air flow duct is 0°C and the temperature of the exhaust air flow is 25°C. The thermal boundary conditions on the outer walls were defined as adiabatic and the material properties varied between aluminum and PET.

Looking at the results in Figure 3, it can be seen that PET has a more favourable temperature profile for heat exchangers. In the case of aluminum, a constant temperature has been set over the entire cross-section, while the PET volume body has a higher temperature difference in the air flow channels.

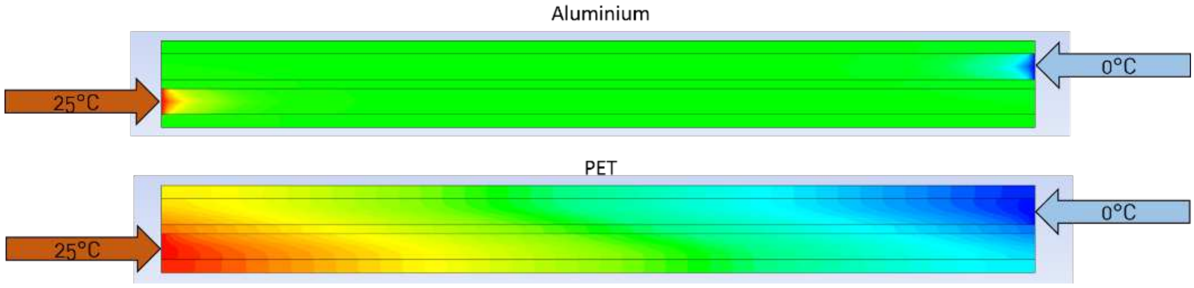

Fig. 3. Temperature curve in the middle of the body for aluminum (top) and PET (bottom)

5 Inference

This simulation is a first comparison of the two materials, aluminum and PET, with a simplified model. The results obtained are similar to the practical tests carried out by Klingenburg GmbH. In order to verify the simulation results, the model will be simulated in practice in the next phase of the project.

6 Acknowledgement

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7 Bibliography

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