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Analysis and optimization of a Puffer-type water heater

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Abstract

In this paper we present the design optimization of a Puffer-type water heater for sanitary water production in residential buildings. The optimization study is performed with the aim to fulfill the design requirements of the heater, i.e. the provided mass flow rate and the outlet water temperature, while minimizing the surface area of the coil characterizing the Puffer and thus reducing the overall cost of the device. The coil diameter and pitch and the diameter of the pipe composing the coil are analyzed in the optimization study. Starting from available correlations providing the heat transfer rate between the sanitary water and the heated water surrounding the coil, a simplified thermal resistance model of the heat transfer process within the heater is developed. The analysis show a significant impact on the overall heat transfer rate between the sanitary water and the heated water when the geometrical parameters of the coil are varied. Using an optimal value of the pitch to pipe diameter of the coil for a given coil diameter in particular, it is possible to maximize the heat transfer rate and thus minimize the size of the coil. As a first step, the optimization study is performed by introducing sizing constraints allowing for sharing the same coil among several types of water heaters. In this case, a reduction as high as 14% of the coil surface area can be obtained, whereas a reduction as high as 23% can be achieved if the optimization is performed free of such constraints.

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Keywords: Puffer; Water heater; Optimization; Helicoid; Thermal model

1. Introduction

The use of renewable resources such as solar radiation and geothermal energy is becoming increasingly popular in the heating of residential buildings, as they allow for a significant reduction of energy consumption costs as well as for a reduction of traditional (fossil) resources usage, thereby limiting the environmental impact.

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In a residential heating system, whether renewable resources are used or not, a water heater is always present. The water heater is used for hot sanitary water production as well as for the heating system of the envelope and they rely on a primary source of energy. Water heaters suitable to the use of renewable energy sources can be classified in plate heat exchangers, shell and tube heat exchangers, “Tank in Tank” and Puffer-type heaters. Among these, the Puffer-type water heater is the one employed most frequently in residential heating systems, thanks to its specific design allowing for accumulating the hot water provided by the energy sources until the sanitary hot water is requested by the users.

In this work, an optimization study of a Puffer-type water heater based on the modeling of the heat transfer process between the hot water provided by the energy sources and the sanitary water is presented. The analysis is focused on the coil-type heat exchanger characterizing the Puffer, where the heat transfer between the hot water and the sanitary water takes place. Aim of the study is to fulfill the design requirements of the heater, minimizing at the same time the volume of the coil, thereby reducing the overall production cost of the heater.

Nomenclature

d_e	Coil pipe outer diameter (m)
d_i	Coil pipe inner diameter (m)
d_b	Coil diameter (m)`
g	Gravitational acceleration (m/s^2)
h_e	Convective heat transfer coefficient between the hot water and the coil (W/m^{2}K)
h_i	Convective heat transfer coefficient between the sanitary water and the coil (W/m^{2}K)
k	Thermal conductivity of the coil pipe (W/mK)
A_e	Heat transfer surface referred to the coil pipe outer diameter (m^2)
D_e	Dean number
F	Correction factor for the heat transfer between the hot and the sanitary water
H	Coil pitch (m)
H_b	Coil height (m)
L	Coil length (m)
Pr	Prandtl number
R_c	Conductive thermal resistance across the coil pipe (K/W)
Ra	Rayleigh number
Re	Reynolds number
R_{he}	Convective thermal resistance between the hot water and the coil (K/W)
R_{hi}	Convective thermal resistance between the sanitary water and the coil (K/W)
U_e	Global heat transfer coefficient referred to the coil outer surface (W/m^{2}K)
α	Thermal diffusivity (m^2/s)
β	Thermal expansion coefficient of water (1/K)
λ	Curvature ratio
ν	Kinematic viscosity (m^2/s)
ΔT_{lm}	Logarithmic temperature difference between the hot and the sanitary water (K)
HRW	Hot Reservoir Water
SHW	Sanitary Hot Water
CFD	Computational Fluid Dynamics

2. Heat transfer inside the Puffer and thermal model

In Fig. 1, the main components of the Puffer and a sketch of the heat transfer process inside the heater are shown. The heater consists of an insulated tank where the hot reservoir water (HRW) provided by the thermal sources (solar panels, boilers, heat pumps, etc.) is accumulated. The coil-shaped heat exchanger can be noted in the section shown