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Thermo-fluid dynamic model for horizontal packed bed thermal energy storages

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Abstract

An asymmetrical thermo-fluid dynamic model for horizontal packed bed thermal energy storages is developed and implemented. The model can account for void fraction distributions and different thermal insulation materials surrounding the storage tank. A first simulation study is performed to investigate the influence of the thermal insulation properties and height to width ratio of the storage on the temperature profile progression and overall performance of the thermal storage. During the first charge and discharge cycle the non-symmetric thermal insulation has a considerable influence on the temperature profile progression. Thermal insulation properties and the height to width ratio can affect the efficiency of the thermal storage.

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Keywords: packed bed; porous media; thermal energy storage; horizontal; thermo-fluid dynamics; modeling.

1. Introduction

The interest in sensible thermal energy storages for various applications, e.g. Concentrated Solar Power plants, has grown steadily in recent years. Apart from molten salt and concrete energy storages, packed rock beds with natural rocks seem to have the potential to be robust, easy to operate and costworthy, as Tiskatine et al. point out [1]

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Modeling of rock bed storages is a key task for the design of the devices. For this reason, researchers like Hänchen et al. [2] or Opitz et al. [3] have focused on formulating two-phase energy and mass conservation based equations for the simulation of these storages.

Nomenclature

Latin letters

a	Volumetric surface area
A	Cross section
c_p	Specific heat capacity
d_p	Particle diameter
E	Energy
h	Specific enthalpy
H	Height
k	Number of radial elements
L	Length
m	Mass
$\dot{m}$	Mass flow
n	Number of axial elements
Nu	Nusselt-number
Δp	Pressure drop
Pr	Prandtl-number
$\dot{Q}$	Heat flow
Re_p	Particle-Reynolds-number
Δt	Time step
ΔT	Temperature change
V	Volume
v_{sup}	Superficial velocity
W	Width

Greek letters

α	Heat transfer coefficient
δ	Thickness
ε	Void fraction
η	Efficiency
λ	Thermal conductivity
μ	Kinematic viscosity
ρ	Density

Subscripts

b	bottom
c	core
cond	conduction
eff	effective
f	fluid
fs	fluid-solid
fw	fluid-wall
i	i-th element
j	j-th element
l	left
r	right
rad	radial
s	solid
t	top
w	wall
wa	wall-ambient

The main advantage of these models compared to the computational fluid dynamic (CFD) approach is the significantly lower simulation time.

The current state of the art layout of thermal storages is a vertical tank, which is operated as described by Hatte et al. [4]. During charging mode hot heat transfer fluid (HTF) enters the thermal storage at the top, while cold HTF exits the bottom of the tank. The flow direction is reversed for discharge operation. This design and operation concept results in a hot region at the top and a cold region at the bottom. They are separated by a thermocline region.

The vertical layout is beneficial for the preservation of thermal stratification within the tank, especially during standstill phases. The degree of thermal stratification strongly influences the storage efficiency.

Nonetheless, with increasing storage capacities the vertical layout might reach limits in regards of mechanical stability and visual impact on the landscape.

Despite the advantages in thermal stratification of the vertical layout, a horizontal design can be a solution to these challenges because of a higher mechanical stability and the possibility to build the storage underground.

Vertical designs are typically of symmetrical built and thus surrounded by only one type of thermal insulation material with a uniform heat transfer coefficient between the thermal insulation and ambient air. For horizontal packed bed storages the thermal insulation at the bottom requires different physical parameters compared to the