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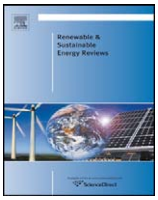

Review of study on solid particle solar receivers

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ABSTRACT

The solid particle solar receiver (SPSR) is a direct absorption central receiver that uses solid particles enclosed in a cavity to absorb concentrated solar radiation. The SPSR is a candidate for applications of solar energy in a thermo-chemical water-splitting process to produce hydrogen. This paper presents a review of the study on SPSRs, including the idea originality, design concepts, advantages and disadvantages, the solid particle identification, a conceptual design in Sandia National Laboratories and detailed studies performed on this design. The geometry, particle size, calculating domain selection, the wind effect, the aerowindow and other factors which influence the cavity efficiency have been studied and the results are presented.

Contents

1. Introduction

The study on solid particle solar receivers (SPSR) has been years an important research topic for the developing of renewable

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Nomenclature

C_D	drag coefficient
d_p	particle diameter
$I(\vec{r},\vec{s}')$	total intensity
$I_{b,\lambda}$	black body intensity
n	refractive index
Nu	Nusselt number
Pr	Prandtl number of gas flow
$\vec{r}$	position vector
Re_p	relative particle Reynolds number
$\vec{s}$	direction vector
u_j	velocity of air flow (m/s)
U_j	mean velocity of air flow (m/s)
u'_j	fluctuant velocity of air flow (m/s)
$u_{p,i}$	particle velocity
T	temperature
$\bar{T}$	mean temperature
X,Y,Z	coordinates

Greek symbols

α	thermal conductivity
α_λ	spectral absorption coefficient
ε_p	particle emissivity
λ	wavelength
μ	viscosity
μ_t	turbulent viscosity
ν	kinematic viscosity
ρ	density
ρ_p	density of particle
σ	Stefan-Boltzmann constant
σ_s	scattering coefficient

energy systems. The idea originality of an SPSR is to design an efficient receiver as an important part in a water-splitting (WS) thermo-chemical (TC) process to produce hydrogen, which is a promising energy carrier for the future energy supplies. An SPSR is a direct absorption central receiver that uses solid particles enclosed in a cavity to absorb concentrated solar radiation. An SPSR is an ideal candidate for applications of solar energy including fuels and chemicals production, Brayton cycle electricity generation, or industrial process heat applications. The solid particles are heated in an SPSR and serve as a heat transfer and storage medium or as a substrate on which chemical reaction may be performed directly in solar WSTC processes.

This paper presents a review of the study on SPSRs, including the idea originality, the experimental work and numerical studies, and the milestones achievements. Furthermore, the detailed studies of a US DOE funded project on a conceptual design of an SPSR have been reviewed, which is a part of the Solar Thermo-Chemical Hydrogen (STCH) project based on the cooperation of Sandia National Laboratories (SNL) and University of Nevada, Las Vegas (UNLV) [1]. The review will include the conceptual design of an SPSR in the STCH project, the geometry, the particle properties, the calculating domain selection, the wind effect, the protection of an aerowindow and other factors which influence the cavity efficiency. The physical model and mathematical models are analyzed and the solution schemes are presented with the parametric study on different operating conditions and model parameters [2].

2. Hydrogen as an energy carrier

The drawbacks to the fossil fuel use include limited reserves, and carbon dioxide emissions, which is a greenhouse gas responsible for the global warming and environmental pollutions. Hydrogen is a promising and clean energy carrier, which could potentially replace the use of fossil fuels in the transportation sector in the future. The US president George W. Bush's Hydrogen Fuel Initiative [3], announced in 2003, envisions the transformation of the nation's transportation fleet from a near total reliance on petroleum based products to steadily increasing use of clean-burning hydrogen. America's energy security can be dramatically improved with the promising hydrogen projects by significantly reducing the reliance on imported oil, as well as reducing greenhouse gas emissions and helping to clean the air.

Life cycles assessment (LCA) of hydrogen production was first considered by Koroneos in Ref. [4]. LCA is a powerful tool to help evaluate the impact from a process or from production and use of a product. It consists of goal definition and scoping which defines the product, process or activity; inventory analysis which identifies material usage and environmental releases; impact analysis which assesses the human and ecological effects of energy, water and material usage; and last interpretation, which evaluates the results of each analysis. Hydrogen production methods have been compared among natural gas, renewable energy, electrolysis, and fuel in the research. The use of wind, hydropower, and solar thermal energy were proved to be the most environmentally friendly and efficient methods [4].

Hydrogen has much more advantages, as a promising future energy carrier, particularly when coupled with fuel cells. However, there is no environmentally attractive, large-scale, low-cost, and high-efficiency hydrogen production process available for commercialization currently [5]. Hydrogen can be manufactured from a range of energy sources such as fossil fuels, biofuels, renewable energy, nuclear energy via electricity [6–8]. Hydrogen can also readily be produced from synthesized hydrogen carriers such as methanol, ammonia and synfuels. The hydrogen production is mainly based on fossil fuels and most specifically on natural gas at present [4]. There are no environmental benefits if the hydrogen is derived from natural gas or fossil fuel reforming, because of the emissions of CO_2 from these production routes. In addition, hydrogen produced from fossil fuel contains trace contaminants (CO) that are poisons for catalysts used in PEM fuel cells electrodes [1]. A detailed review of the renewably driven hydrogen systems and the modeling approaches have been presented by Deshmukh [7]. The use of wind, hydropower and solar thermal energy for the production of hydrogen are the most environmental friendly methods. Among which, the WSTC cycle is one of the most promising methods to produce hydrogen, especially when it is driven by solar energy.

3. Solar-driven water-splitting thermo-chemical (WSTC) cycles for hydrogen producing

Electrolysis produces pure hydrogen but suffers from thermodynamics inefficiencies. The projected efficiency for the electrolytic path is about 36%. However, the current combined efficiency does not exceed 20–25%. The overall efficiencies of the most investigated WSTC cycles are in the range of 45–50% [1,5]. Therefore, a WSTC cycle is one of the most promising methods to produce hydrogen from the point view of efficiency. In a WSTC cycle, water and heat are the inputs, and hydrogen and oxygen are the only outputs. The other chemical and reagents are recycled in a closed WSTC.

As the opposite beneficial aspect of the oil crisis, the interest in WSTC processes boomed in the late 1970s and early 1980s [9–11].