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Wind dependence of energy losses from a solar gas reformer

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HIGHLIGHTS

- Energy losses analysed as functions of wind, internal receiver wall temperature.
- Energy loss predictions match reasonably well with most relevant documented correlations.
- Results useful for solar receiver design, solar thermal process operation.

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ABSTRACT

The thermal performance of a cavity receiver design for the CSIRO solar gas reformer is studied using transient Computational Fluid Dynamics (CFD) simulations. Under process control-induced operating conditions targeting constant internal wall temperatures, energy losses from the cavity nearly double for high-wind conditions as compared to no-wind conditions. Receiver geometry, inner cavity wall temperature and wind interact to result in differences in energy losses under steady wind velocities that can differ up to 40 percent depending on wind direction. The findings in this paper are useful for targeting improvements in receiver design and solar flux control during solar reactor operation.

1. Introduction

A key issue in the harnessing of solar energy using solar thermal (ST) technologies is the ability to store the energy for use away from the site of the solar energy capture. One approach to storing the thermal energy is to embed it in combustible fuel, through a process known as solar thermal reforming. The key gas-phase reaction in solar thermal reforming is

$$CH_4 + H_2O \rightarrow CO + 3H_2 \quad \Delta H_{25\,^\circ C} = 206\ \mathrm{kJ/mol}, \tag{1}$$

with the SynGas product featuring 26 percent embodiment (conversion) of solar energy as chemical energy. The methane/steam mixture requires moderately high temperatures (>800 °C) for the gas reforming reaction to be thermodynamically favoured over competing reactions such as water-gas shift reactions. [It should be noted that gas reforming can feature other reactions such as dry reforming, as well as carbon-producing side reactions that foul catalysts such as methane cracking [1]]. Temperatures to favour the steam reforming reaction require the use of point receivers to adequately trap the focused solar energy from the heliostat field. In this spirit, the cavity-shaped solar receiver is the preferred concept adopted by CSIRO for solar thermal reforming.

The CSIRO solar reactor system investigated here is a demonstration plant located at the CSIRO Energy Centre in Newcastle, on Australia's Pacific east coast. The solar reactor concept features a field of heliostats at ground level focussing solar radiation up to a cavity receiver that is mounted on a support structure, as shown in Fig. 1. The heating achieved within the cavity provides the necessary temperature conditions to host the endothermic gas reforming reaction in a continuous manner within the reactor tube array inside the cavity. The reactor tube array is mounted high within the cavity, to enable the cavity to trap the hot air under its own buoyancy to envelope the array.

Noting that the tube array must stay properly heated for thermodynamically favourable high-throughput operation of the CSIRO solar reactor, the effect of wind on cavity energy losses is a concern

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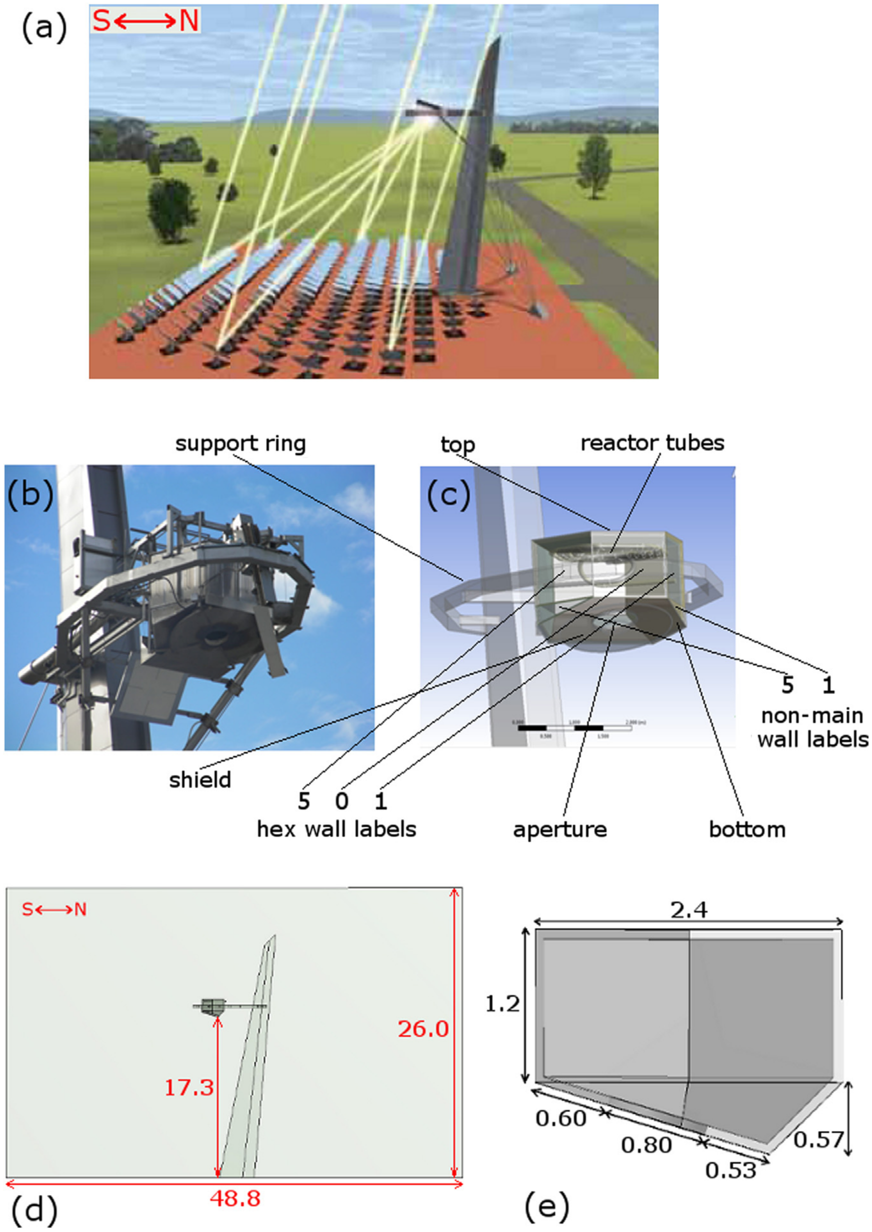

Fig. 1. CSIRO "Solar reactor" concept. (a) On-site configuration of solar reactor plant. (b) Photograph of solar reactor cavity on tower at CSIRO Newcastle site. (c) CAD reconstruction showing the reactor tube array within the cavity. (d) CAD of the overall geometry, showing the open-air site, the support structure (tower + support ring) and the cavity receiver. (e) CAD close-up of the cavity receiver shape. In the CAD, the upper vertical walls are labelled Hex0–Hex5, the lower vertical walls surrounding the bottom face are labelled NonMain1–NonMain5, with the remaining walls labelled Top and Bottom. Important length dimensions in the problem setup are in metres.

that must be designed around. Minimizing heat loss from the receiver is promoted by the use of a full cavity receiver where an aperture for incoming radiation is as small as practicable to minimize aperture losses. On the other hand, focal image width is a major motivator for considering more open receiver concepts such as the semi-cavity and the modified cavity [2]. For solar gas reforming using a tubular reactor, the cavity receiver must be big enough to fully contain a tube array that will allow for sufficiently long residence times to enable target conversion levels to be achieved. Increased heliostat field size to ensure reactor throughput (yet often underutilized), and the use of more exotic and heavier materials of construction, are just some of the consequences that process designers have to deal with if energy losses from the cavity receiver are poorly understood.

In this paper, temperature distributions elucidated from production runs generated from a validated Computational Fluid Dynamics (CFD) model, and energy loss analysis of typical steady-state operation of the CSIRO solar reactor, are presented. A key feature of the paper is an energy loss analysis for different wind conditions, to elucidate how thermal performance of the cavity receiver is affected by the interaction of the wind with temperature non-uniformities within the receiver.

2. Demonstration plant measurements

Validation of the numerical model proposed in this paper is facilitated by historical data that has been retained for the operation of the CSIRO solar reactor demonstration plant in Newcastle,