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Dynamics of a solar-thermal transport-tube reactor

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HIGHLIGHTS

- ▶ A dynamic model of a solar thermal reactor was developed for control purposes.
- ▶ A simplification strategy was applied to the model to reduce computational time.
- ▶ The model was validated with experimental data obtained on sun.
- ▶ Error in model is less than 5% in terms of steady state temperatures.
- ▶ Model was applied to a reflective and to an absorbing cavity receiver.

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ABSTRACT

Solar-thermal reactors make use of concentrated solar irradiation to drive endothermic reactions. One example of processes that can be carried out in solar-thermal reactors is the solar-thermal conversion of biomass into synthesis gas (H_2, CO and CO_2). The operation of these reactors is dependent on available sunlight and is affected by the presence of clouds, which act as disturbances. During a partly cloudy day, operation of solar-thermal reactors is still possible but flow rate adjustment is required in order to maintain consistent operation. Thus, a robust control system that will allow continuous high performance operation of the reactor is required in order to make the process financially viable. A model predictive control system (MPC) is proposed, which uses a model of the process to determine the required control signal. The first step in the development of the control system is the formulation of a dynamic mathematical model that describes process behavior adequately yet can be solved in real time. A simplified dynamic model for a solar-thermal transport-tube reactor has been developed based on unsteady mass and energy balances. The model was solved using MATLAB™ and validated with experimental data. Model validation was carried out at the High Flux Solar Furnace (HFSF) at the National Renewable Energy Laboratory (NREL) in Golden, CO, using different solar power level inputs. In this work, a description of the model and a comparison with the experimental results are presented. Simulations of the model were performed for a reflective and an absorbing cavity. The former allows for faster heating during experimental runs, while the latter is more representative of an industrial setting.

1. Introduction

Increasing energy consumption and the inevitable fact that fossil fuels are a limited resource have led humankind to the search for alternative energy resources. Solar energy is the most abundant source, but its availability is not uniform with higher direct normal irradiation in equatorial regions of the Earth [1]. As a result, many efforts have been dedicated to the development of technologies that can transform solar energy into chemical energy, i.e., into a fuel that can be stored and transported to places outside the earth's sunbelt [2]. One such process is the solar-thermal conversion of biomass into synthesis gas (H_2, CO and CO_2), which can be catalytically reformed to fungible liquid fuels and transported for use throughout the world [3].

A transport-tube reactor uses concentrated solar irradiation in order to drive the endothermic biomass gasification reaction for the production of synthesis gas [3]. As in any solar-thermal process, the intermittent nature of solar irradiation presents a challenge. Changes in solar irradiation can directly affect the performance of solar-thermal reactors, possibly causing unnecessary shutdowns and start-ups, complications in the purification processes downstream of the reactor, and damage to the reactor

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