

SOLAR FUELS PRODUCTION USING HIGH TEMPERATURE SOLAR REACTORS UNDER TRANSIENT THERMAL RESPONSE

by

Nesrin Ozalp

Mechanical and Civil Engineering Department
Purdue University Northwest, Hammond, USA

Abstract:

Solar thermal production of hydrogen and carbon black via methane cracking is a promising process for charging fuel cells (HFC and CFC) with efficiencies of 50–60% and 70–75%, respectively. This method has the potential to double the current commercial solar conversion efficiencies as most of the CSP plants implement the Rankine cycle to convert heat to electricity with typical efficiencies of 35–40%. However, higher efficiencies may be reached via solar cracking of the natural gas coupled with HFC and CFC for a combined efficiency of 60–70%. This presentation describes a promising novel combined system featuring a solar reactor, HFC and a CFC. The combined solar reactor with fuel cells has the flexibility of working strictly as an electricity production unit by keeping both fuel cells explicitly for power generation and excluding the reactor when sufficient carbon and hydrogen are produced. However, the major challenge to make this system work involves particle agglomeration and deposits that can clog the solar reactor. The main reason behind the deposition is diffusion and convection in addition to the strong influence of external and colloidal interaction forces. Such particle deposition may occur in two steps: (1) transport phenomenon sweeping particles nearby surfaces, and (2) attachment phenomenon responsible for the interface chemistry between particles and the walls, and particles and particles. Eddy diffusion can enhance particle transportation between high concentration areas of the gas stream and low concentration areas. It should be noted that when particles move from a more concentrated medium to a less concentrated medium, diffusion becomes dominant on particles that have diameters between 10 nm and 50 nm. On the other hand, the carbon particle deposition rate would be lower than the deposition due to thermophoretic force. It should also be noted that larger particles transported in the gas are challenged moving laden with the gas stream due to inertia, resulting in collisions with the walls. Smaller particles that have diameters in the range between 1 nm and 200 nm, such as carbon black, can smoothly move laden with the gas stream, which leads to less deposition. Particles transported near walls attach to these surfaces or onto deposited particles. In this phenomenon, interface chemistry is the leading driving cause. The interface chemistry is often explained using the Derjaguin-Landau-Verwey-Overbeek (DLVO) theory, which explains particle deposition and aggregation and predicts the experimental observations quantitatively. It is possible to explain the interface chemistry between particle-wall and particle-particle by combining the DLVO theory with the van der Waals (VDW) forces and the electrostatic double layer (EDL) forces. This presentation demonstrates an approach to address this problem systematically, including reactor design based on multi-physics/multi-scale tools, the influence of flow dynamics on convective and radiative heat transfer, and concluding with the impact of carbonaceous catalysts on heat transfer and fuel production efficiency. An example “self-cleaning reactor” design will be presented describing the design evolution and the heat transfer analysis based on the forced internal convective heat transfer from the gas flow to the exhaust walls of the design and the heat transfer fluid to the cooling channels.



Nesrin Ozalp Nesrin Ozalp is a Professor of Mechanical Engineering at Purdue University Northwest, a Full Professor by Courtesy at the School of Mechanical Engineering of Purdue University West Lafayette, and Editor-in-Chief of Thermopedia by Begell House. She received her Ph.D. from the University of Washington's Mechanical Engineering Department and her MSc in Mechanical Engineering from Stanford University. Dr. Ozalp specializes in the areas of designing novel solar reactors for emission-free generation of fuels. She is the Lead Principal Investigator of research projects totaling \$5M+, the corresponding author of 120+ peer reviewed journal, book chapter, and conference papers, Co-PI of completed Phase I of Solar Carbon Black commercialization with Fraunhofer, supervised 25 graduate students' theses. She has given 40+ invited/keynote/plenary talks on her research. She is the chair of ASME Solar Energy Executive Committee, chair of ASME Heat Transfer and Thermal Sciences Education technical committee, member of the American Society of Thermal Fluids Engineers Inaugural Executive Committee, and the recipient of many research and teaching awards including the Outstanding Reviewer Award by the ASME Heat Transfer Division, and the College-Level Distinguished Teaching Award by the Texas A&M Association of Former Students. Dr. Ozalp is an ASME Fellow.