Title
DIRECT RADIANT HEATING OF PARTICLE SUSPENSIONS

Author
Hunt, A.

Publication Date
1985-03-01

Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

APPLIED SCIENCE DIVISION

Presented at the Solar Thermal Research Program Annual Conference, Lakewood, CO, February 20-22, 1985

DIRECT RADIANT HEATING OF PARTICLE SUSPENSIONS

A. Hunt, J. Ayer, P. Hull, F. Miller, and R. Russo

March 1985

APPLIED SCIENCE DIVISION

Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

DIRECT RADIANT HEATING OF PARTICLE SUSPENSIONS*

Arlon Hunt, Jackie Ayer, Patricia Hull,
Fletcher Miller, Rick Russo

Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

ABSTRACT

This paper describes recent advances in the research program at LBL in understanding the behavior of radiantly heated gas-particle suspensions. In particular, we are investigating the use of gas-particle suspensions to absorb concentrated sunlight to supply energy for endothermic chemical reactions. Our goal is to understand the optical, thermodynamic, and chemical processes in solar heated particle suspensions through a balanced program of analytical and experimental investigations. This work is aimed at establishing a technology base supporting new applications of concentrated sunlight for the production of useful fuels and chemicals.

INTRODUCTION

Since sunlight originates from a 6000°K black body source, extremely high temperatures can be achieved in solar furnaces. Traditional energy conversion methods were developed for much cooler sources where radiation is less important, and they are not necessarily the best solar conversion methods. It is important to match the energy conversion method to the unique characteristics of the solar resource. In absorbing materials, radiation is converted to heat in distances less than the wavelength of light. Therefore, absorbers in the form of small particles can collect the solar radiation efficiently. Moreover, the amount of absorbing material is small, because small particles have high surface area per unit mass. In addition to the advantages small particle offer as a solar absorbing media, they may also (when used to provide the solar heat transfer for a chemical process) function efficiently as microsites for a chemical reaction.

*This Work was supported by the Solar Thermal Fuels and Chemicals Program Managed by the San Francisco Operations Office under the Assistant Secretary for Conservation and Renewable Energy of the U.S. Department of Energy under Contract No. DE-AC03-76SFO0098.

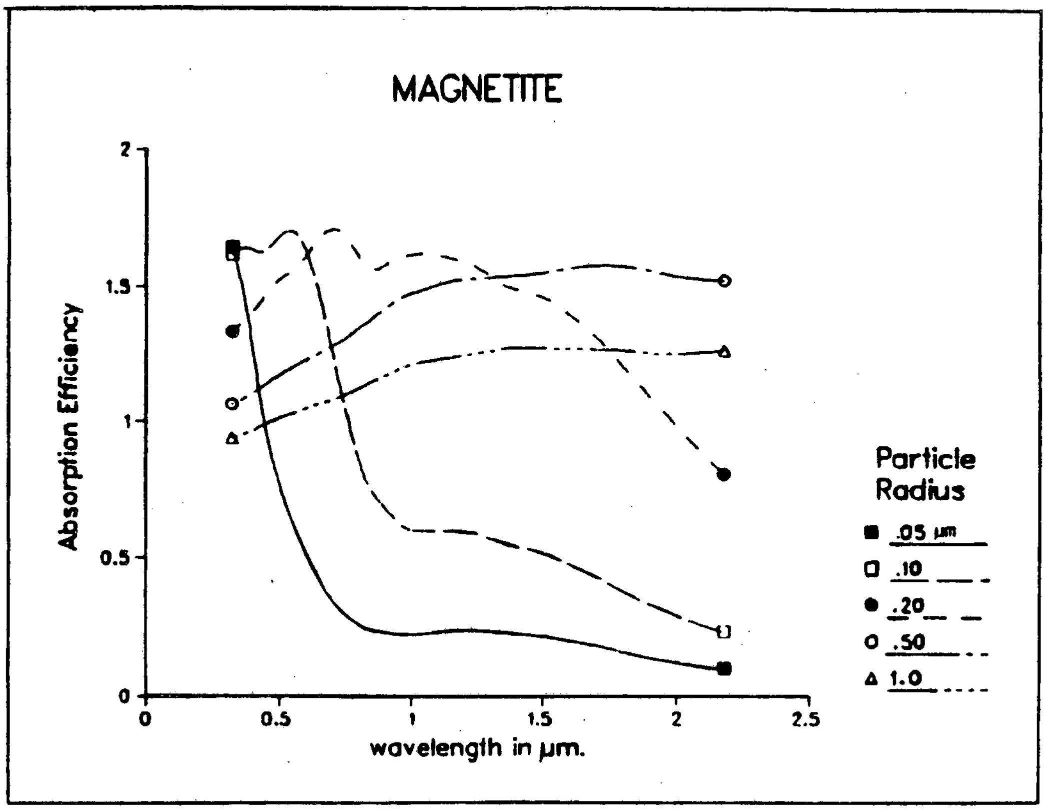
Since 1978, LBL has been involved in the development of solar thermal receivers that utilize suspended particles as solar absorbers and heat exchangers to heat gases for power and industrial process heat applications.[1] This program resulted in the design, construction,[2] and successful testing [3,4] of the Mark I, Small Particle Heat Exchange Receiver (SPHER) in 1982 at the Georgia Institute of Technology solar test facility.

Our present research extends the earlier work to new methods of initiating chemical reactions. This paper discusses research into several key elements of direct radiant heating of small particle suspensions. The analytical section includes the description of a chemical survey, the results of optical calculations, and a summary of our heat transfer studies. The experimental section outlines the current laboratory studies of direct radiant heating that utilize a high intensity radiant source to simulate concentrated sunlight.

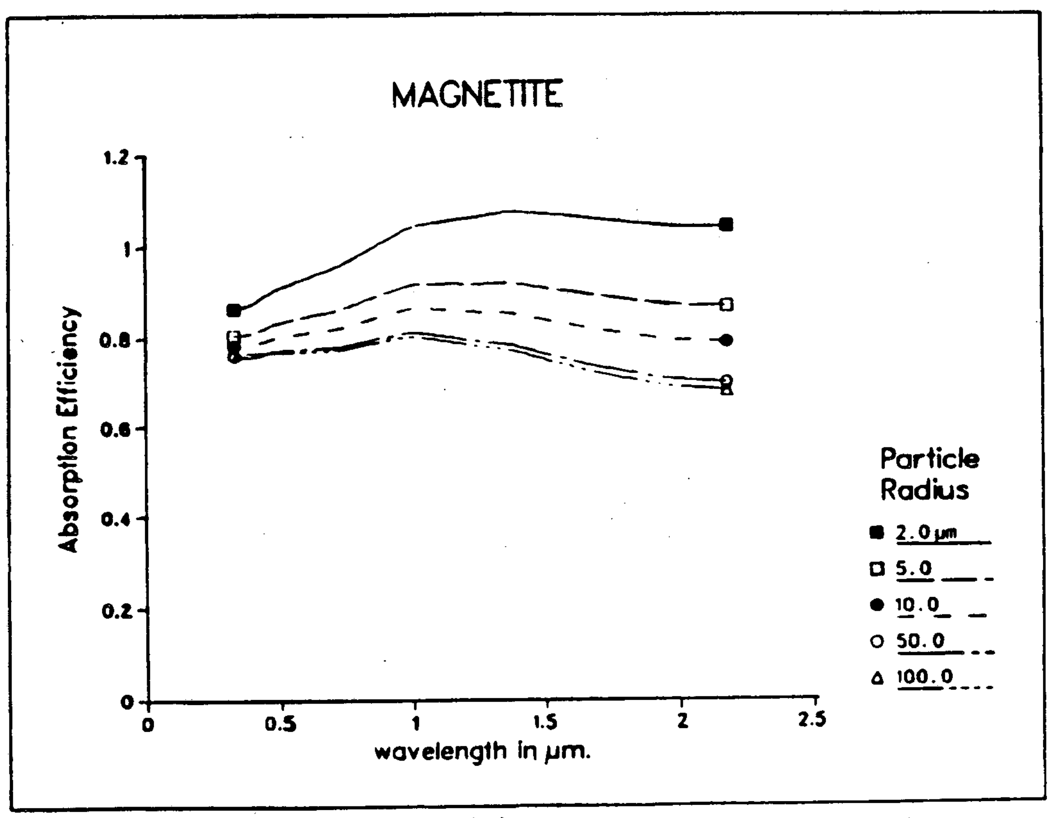
ANALYTICAL STUDIES

To initiate the study of chemistry in radiantly heated gas-particle suspensions, a survey of chemical reactions in or between gases and absorbing solids was performed. A number of suitable reactions were identified and optical, physical, and chemical data were obtained for the compounds involved. A computer program using a Mie subroutine was written to calculate the energy absorbed from a radiant source possessing a broad spectral distribution by a suspension of particles with a known size distribution. Figures 1a and 1b illustrate the dramatic effects of particle size on the ability of a gas-particle suspension to absorb sunlight.

An analytic expression for conductive heat transfer from a particle to the surrounding gas was developed for arbitrary Knudsen number (ratio of the gas molecule mean free path to the characteristic dimension of the particle). This was especially important for intermediate Knudsen numbers where a useful expression with an analytic basis was not previously in use.[5] Our calculations for the rate of heat transfer agree with experimental data from research in rarefied gas dynamics.[6,7] An energy balance on a particle in a radiant environment shows that the temperature difference between the particle and gas during the heating process has a theoretical maximum for a given particle size. [8] A graph of this maximum temperature difference between a particle and surrounding gas as a function of the particle radius for different solar concentration factors and gas temperatures is shown in figure 2. The maximum gas heating rate for a given mass loading and heat input as a function of particle radius is shown in figure 3.

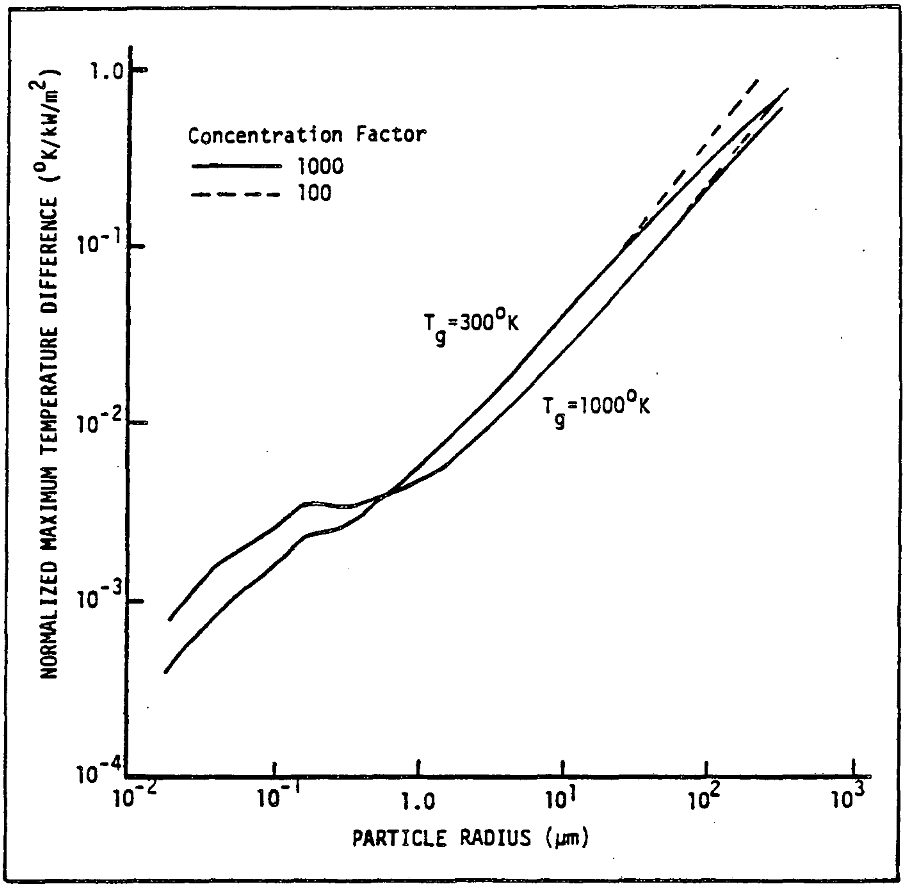


(a)



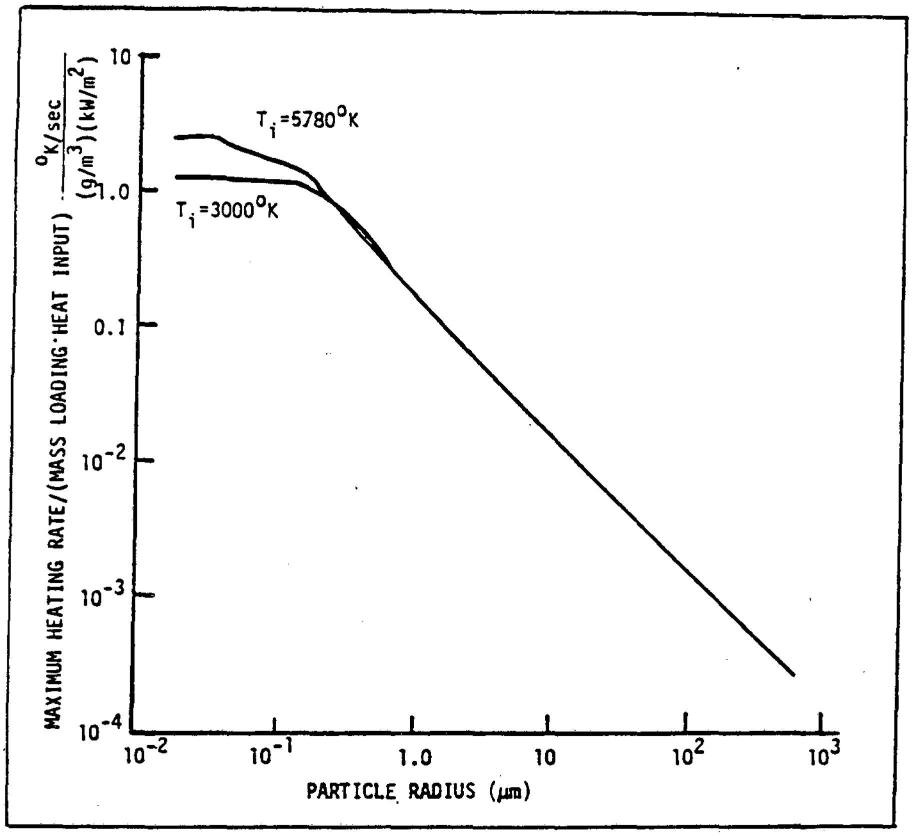
(b)

Figure 1. Absorption efficiency for a suspension of magnetite particles as a function of wavelength.



XBL 855-2572

Figure 2. Normalized maximum temperature difference between particles and gas as a function of the particle radius at different concentration factors and gas temperatures.



XBL 855-2571

Figure 3. Normalized maximum heating rate as a function of particle radius for different source temperatures.

EXPERIMENTAL PROGRAM

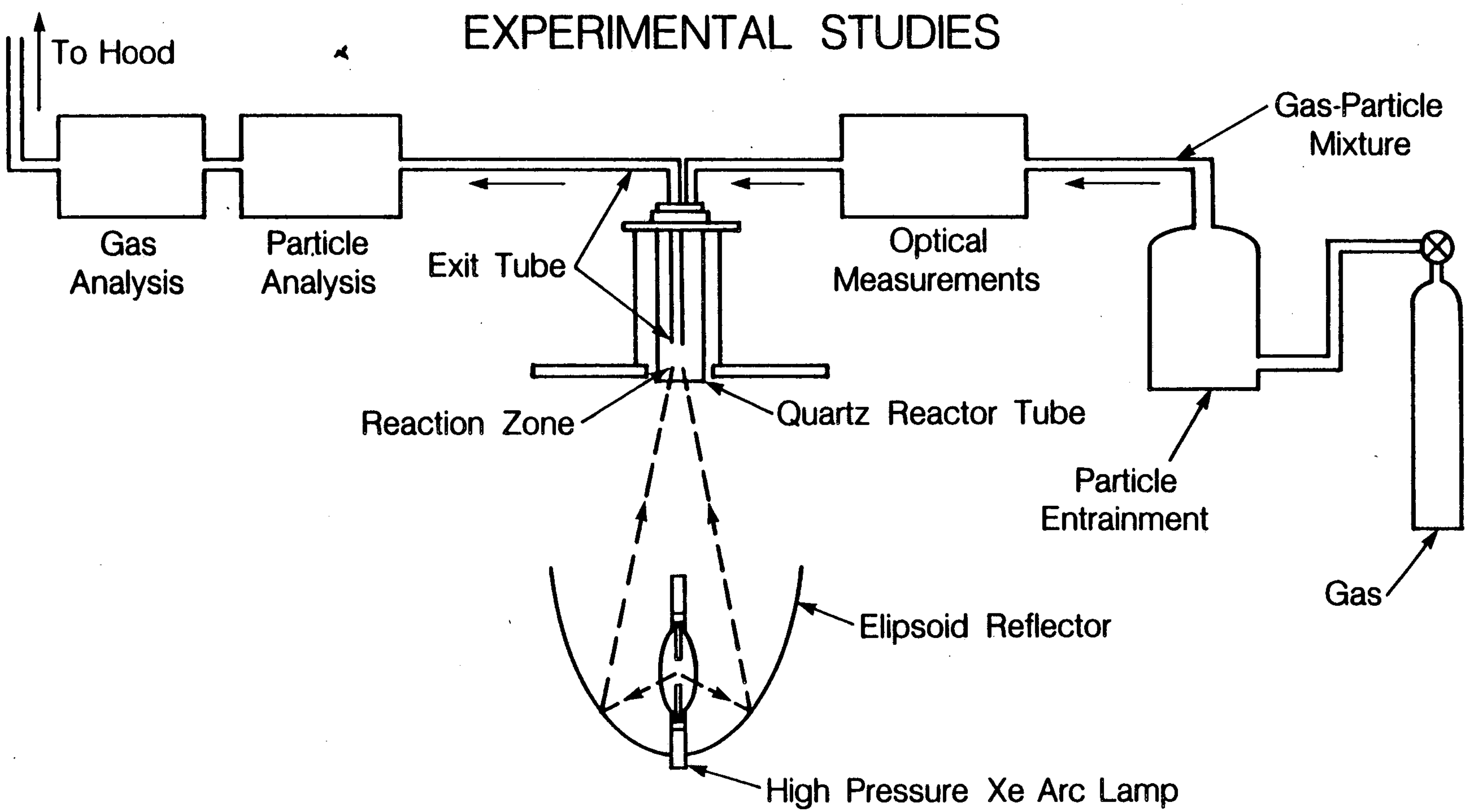
A mechanical shaker and cyclone chamber was constructed for entraining small particles in a gas stream. Commercially available powders of carbon, hematite, and magnetite were successfully entrained in a gas stream and optical extinction measurements made of the particle suspensions. The mass loading of the particle suspensions from the cyclone shaker were determined by drawing a known volume of the particle-gas mixture through a filter and weighing the filter. Small samples were then cut from the filter and scanning electron micrographs were made of these samples. The size distribution of the particles was determined from these micrographs.

In order to simulate concentrated solar radiation in the laboratory, a high intensity xenon arc lamp was mounted at one focus of a ellipsoidal reflector. Light from the arc is reflected to the other focus of the ellipsoid. The region about this focus containing the measurable radiant flux defines the limits of the reaction zone. A scanning calorimeter was used to measure the radiant flux in this region, and a spatial integration of these measurements determined the total power available in the reaction zone. These measurements indicate a peak flux density on the order of 4000 kW/m^2 and a total input power to the reactor of 490 Watts, assuming an 8% reflection due to the vessel window.

The spatial characteristics of the radiant flux are critical in determining the size and shape of the receiver/reactor. In the current design, the gas-particle mixture enters a quartz reactor vessel at the top, and is exhausted through a central tube. Light from the solar simulator passes through the bottom of the vessel and is focussed just below the exhaust tube to ensure that all particles pass through the high intensity portion of the beam. A number of experiments were made to observe the heating of gas-particle mixtures in the reactor, and temperatures in excess of 1200°K were measured. A schematic diagram of the experimental apparatus is shown in figure 4.

SUMMARY

The use of a gas-particle mixture as a solar absorption medium for heating gas has already been demonstrated. In this paper we have discussed research directed towards extending the small particle absorption concept to other applications, including the solar production of fuels and chemicals. The field is entirely new and many issues still need to be addressed. We have begun addressing these issues by identifying and gathering data on possible reactions, calculating absorption characteristics of particle suspensions, developing a satisfactory particle to gas heat transfer model, and constructing a laboratory system that will allow these reactions to be studied experimentally.



XBL 856-10000

Figure 4. Schematic diagram of laboratory apparatus for study of direct radiant heating of particle suspensions.

FUTURE PLANS

The modeling capabilities to predict the optical and thermal performance of direct flux reactors for a wide range of particle sizes, mass loadings, and compositions will be expanded. Additional instrumentation will be developed and experimental data obtained on the operation of direct flux chemical reactors. The theoretical predictions of the performance and operating parameters will enable a rational choice to be made about which direct flux processes make sense for producing useful fuels and chemicals with sunlight. Special attention will be paid to reactions in which the particle absorber may also act as a chemical catalyst. It is this case that offers the highest potential for a photo-assisted reaction or a "solar unique" process. When a basic understanding of the optical, physical, and chemical processes is achieved, one or more reactions will be identified and analyzed for technical suitability for fuels or chemicals production.

REFERENCES

1. A.J. Hunt, "Small Particle Heat Exchangers," Lawrence Berkeley Laboratory Report LBL-7841 (1978).
2. A.J. Hunt and D. Evans, "The Design and Construction of a High Temperature Gas Receiver Utilizing Small Particles as the Heat Exchanger (SPHER) Phase I Report ", LBL-13755 (1981).
3. A.J. Hunt and C.T. Brown, "Solar Testing of the Small Particle Heat Exchange Receiver (SPHER), Phase II Report," LBL-15756 (1983).
4. A.J. Hunt and C.T. Brown, "Solar Test Results of an Advanced Direct Absorption High Temperature Gas Receiver (SPHER)," presented at the 1983 Solar World Congress, International Solar Energy Society, Perth, Australia, August 15–19, LBL-16497 (1983).
5. W.W. Yuen, F.J. Miller, and A.J. Hunt, "A Two-Zone Model for Conduction Heat Transfer from a Particle to a Surrounding Gas at Arbitrary Knudsen Number", Submitted to the *International Journal of Heat and Mass Transfer* LBL-18449 (1984).
6. F. S. Sherman, "A Survey of Experimental Results and Methods for the Transition Regime of Rarefied Gas Dynamics," *Rarefied Gas Dynamics* 3rd Symposium Vol. II, Academic Press, New York (1963).
7. K. Takao, "Heat Transfer from a Sphere in a Rarefied Gas," *Rarefied Gas Dynamics* 3rd Symposium Vol. II, Academic Press, New York (1963).
8. W.W. Yuen and A.J. Hunt, "On the Heat Transfer from Particles to Surrounding Gas," submitted to *International Communications of Heat and Mass Transfer*.