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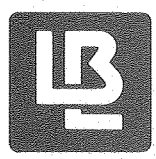
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Publication Date

1979-11-01



Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

ENERGY & ENVIRONMENT DIVISION

Presented at the Solar Fuels Workshop, organized by the Solar Thermal Test Facilities Users Association, Albuquerque, NM, November 28-29, 1979

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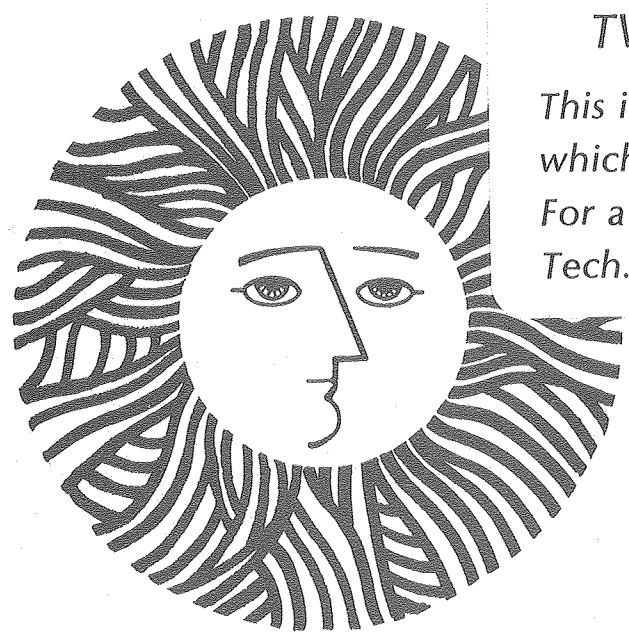
Arlon Hunt

November 1979

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Presented at the Solar Fuels Workshop, November 28 and 29, 1979 Albuquerque, New Mexico, Organized by the Solar Thermal Test Facilities Users Association.

A High Temperature Gas Receiver Utilizing Small Particles*

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INTRODUCTION

Solar energy is being considered as a practical source of high temperatures to provide heat for a variety of solar applications including industrial process heat and the operation of efficient heat engines. Many current concepts for conversion of sunlight to heat are based on traditional, non-solar technologies. The work discussed here involves a novel approach that matches the characteristics of concentrated sunlight to the requirement of heating a gas.

The purpose of the work is to develop a new type of solar thermal receiver that utilizes a dispersion of very small particles suspended in a gas to absorb the radiant energy from concentrated sunlight^{1,2}. The Small Particle Heat Exchange Receiver (SPHER) operates by injecting a very small mass of fine, light-absorbing particles into the gas stream. The gas-particle mixture then enters a transparent heating chamber into which the concentrated solar flux is directed. The particles absorb the radiation and because of their very large surface area, quickly transfer the heat to the surrounding gas. The gas-particle mixture continues to heat until the particles oxidize or vaporize. The gas may be heated to medium or high temperatures as suitable for a variety of industrial process heat or thermal power requirements. In particular it can be used as a high efficiency receiver to supply hot air or gas to operate a chemical or fuel production process.

The starting point for the concept of the small particle heat exchanger is the desire to maximize the transfer of solar radiant energy to sensible heat in the gas. The fundamental difference in the approach results in significant advantages over other types of high temperature gas receiver designs.

The most important characteristic of these small particles is the extremely large surface area per unit mass of absorber material. (One gram of particles for this application has a surface area of approximately 100 square meters.) Thus, as light traverses the chamber, it encounters an absorbing surface that has an area many times larger than the chamber opening. This results in a high absorption coefficient for the incoming sunlight and a high optical efficiency for the receiver.

Since the infrared reradiation from the heated particle-gas mixture will be inhibited from leaving the chamber by the window, the receiver will have a high overall efficiency. One consequence of this is that the receiver is not restricted to a cavity type, but may be built to be illuminated from all sides.

The combination of the large surface area and the small size of the particles insures that the particle temperature stays to within a fraction of a degree of the gas temperature. Thus, the highest temperature present in the receiver is essentially that of the working gas. This results in considerably lower radiant temperatures in the chamber compared to other solar receivers that produce gas of the same temperature.

There are several other important advantages to the use of small particles as heat exchanger elements. There is no need for heavy and complex heat exchanger elements, since the receiver basically consists of a hollow chamber with a window, resulting in a very light weight structure.

Because the heat exchanger is uniformly distributed throughout the chamber, it is not necessary to pump the gas through pipes or small orifices. This has the effect of considerably reducing the amount of energy required to overcome pressure losses.

Since the heat exchanger is vaporized in the process of performing its function, there are no problems associated with maintenance, failures, heat stress, or corrosion that occur with conventional heat exchanger elements.

Since there are no temperature limitations on the heat exchanger in the usual sense, there are applications to the field of high temperature solar process heat. The ultimate temperatures achievable are limited only by the chamber walls, the window (if pressurized operation is desired) and the second law of thermodynamics. It appears that temperatures in excess of 2000°C are achievable.

The basic concept of the small particle gas receiver can be scaled from the size suitable for a parabolic dish to much larger sizes. The upper size limitations are determined by window design. By the use of multiple windows, a matrix of transparent quartz tubes or other modular designs, the technique is applicable to the sizes characteristic of the central receiver program.

The feasibility of the concept has been under study for the past two years at LBL. During this period, calculations were performed to quantify the optical and physical processes of absorption and heating of the particles. A variety of related considerations were investigated, including particle production methods, window and chamber designs, hybrid fossil-solar compatibility, as well as environmental and safety factors. The analysis confirmed that the operating parameters are flexible and suitable to a variety of solar applications. A modest laboratory apparatus was built earlier that successfully demonstrated the concept.

The approach is to study the optical and physical processes of absorption and heating of the particles, investigate the particle production methods, formulate chamber designs, and determine the optimum operating conditions. Laboratory bench tests will be used to demonstrate the operation of the system and to gain the experience necessary to build an experimental receiver for use with a solar collector.

RECENT DEVELOPMENTS

In the past year the operation of the various subsystems was investigated and the overall efficiency and system parameters were determined. Theoretical work was performed to determine the efficiency and operating conditions of a high temperature receiver utilizing a transparent window. Two different window designs were evaluated, material and sealing considerations were addressed, and window costs were determined. An experimental program was initiated to produce and characterize the particle suspensions. A patent application was filed on the SPHER concept with the rights held by DOE³.

Windowed Receiver Studies

A study of the optical and thermodynamic efficiencies of single and double windowed high temperature gas receivers was carried out⁴. The two window design utilized a cooling gas flow between the windows. The method used to calculate the receiver performance is based on a detailed window energy balance that includes the energy flows resulting from both radiative and convective transfer to and from the window(s). Equations governing the energy flows were written using conservative estimates for the quantities involved. The parameters were varied by an iterative process until a self consistent solution was obtained. Once the window temperatures were determined by this process, the total energy loss and the receiver collection efficiency were calculated.

The analysis is based on the assumption that the receiver is sized to 4 MW_t per module operating at a pressure of four atmospheres. In the double window design, the cooling air flowing between the windows comes directly from the compressor. The efficiencies are very high, and by the use of the solar antireflection coatings of the type reported by Minot⁵, the losses usually associated with windowed receivers can be minimized. The receiver efficiencies obtained for a gas temperature of 1000⁰ C using fused silica type windows that span a 1.7 meter opening were 93.8% and 95.4% for the single and double window designs respectively. The losses due to each mechanism were computed and their relative contributions were assessed.

Sensitivity studies were performed by varying each parameter from a baseline design to determine the effects on the efficiency. The techniques used in this analysis are not restricted to receivers of the SPHER type but are general enough to be applied to a number of windowed receiver designs.

Experimental Program

The experimental program presently has three main thrusts: particle production, particle characterization, and the determination of the performance of the particle-gas mixture as a heat exchanger. Once good candidates for particle generation are obtained, measurements will be performed to characterize the particles and determine their operating parameters in a receiver.

A laboratory has been obtained, equipped, and is in operation. Work has begun on two alternative methods of producing carbon particles suitable for high temperature receiver work. One method utilizes an enclosed diffusion flame and has successfully produced very dense particle streams. The second method relies on a high intensity arc in an inert gas atmosphere. Work is under way on the experimental chamber and a set of remotely controlled electrode holders are being fabricated.

Opacity measurements will be performed on the particle-gas mixture as well as on collected samples of the particles. Oxidation properties will be determined by optical measurements on particle samples in a high temperature furnace. Electron microscopy will be used to determine the size, size distribution and shape of the particles.

An analytical program will be used for guidance and interpretation of the laboratory work. Computer codes to analyse the optical and thermodynamic properties of the system will be written.

A chamber will be constructed to determine the temperature rise and energy exchange to a particle-gas stream. It will utilize a tungsten halogen light source to simulate the sun. The goal is to gain enough experience to design a test receiver to operate with a solar collector. Long range plans call for a larger SPHER to be fabricated and tested at a National Solar Thermal Test Facility.

FOOTNOTES AND REFERENCES

*This work has been supported by the U.S. Department of Energy under contract No. W-7405-ENG-48.

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