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THE SERI SOLAR-ENERGY-STORAGE PROGRAM

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ABSTRACT

The SERI Solar Energy Storage Program is summarized. The program provides research, systems analyses, and assessments of thermal energy storage and transport in support of the Thermal Energy Storage Program of the DOE Division of Energy Storage Technology; emphasis is on thermal energy storage for solar thermal power and process heat applications and on thermal energy transport. Currently, research is in progress on direct-contact thermal energy storage and thermochemical energy storage and transport. In addition, SERI is directing the definition of new concepts for thermal energy storage and supporting research on thermal energy transport by sensible and latent heat media. SERI is performing systems analyses of thermal energy storage for solar thermal applications and coordinating thermal energy storage activities for solar applications.

INTRODUCTION

As part of the Thermal Energy Storage Program of the DOE Division of Energy Storage Technology, thermal energy storage technologies are developed for identified application areas by the laboratories assigned the lead responsibilities. The SERI Solar Energy Storage Program supports the DOE program by researching thermal storage and transport technologies and by performing analyses and assessments of thermal storage for solar thermal power and process heat applications. Research, analyses, and assessments are also conducted for thermal energy transport systems (Fig. 1).

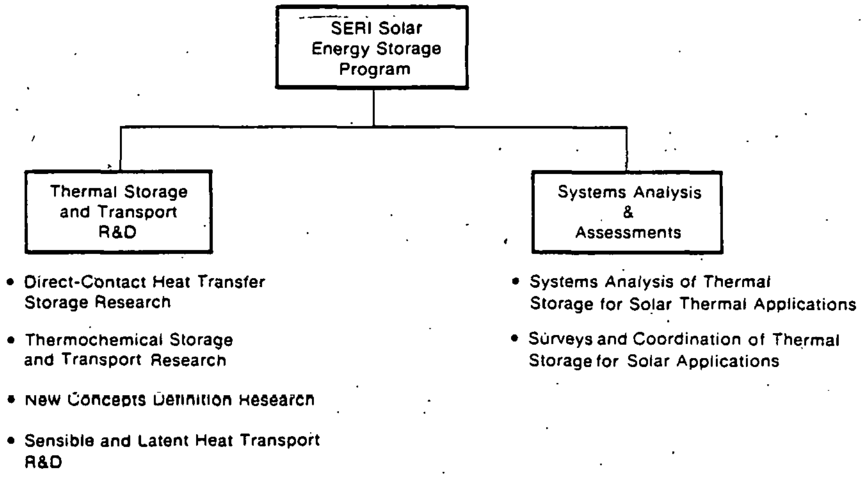

Figure 1. The FY 1981 SERI Solar Energy Storage Program

The objectives of the SERI Solar Energy Storage Program are to develop a better understanding of thermal energy storage and transport technologies and to obtain information that allows designers to select promising thermal storage and transport technologies for specific applications. We research thermal energy storage options to resolve technical and economic uncertainties that hinder their development. For example, SERI is investigating the storage and transport of thermal energy in chemical bonds (thermochemical energy storage and transport) and studying direct contact between immiscible fluids for latent heat storage. SERI also supports research on innovative thermal energy storage and transport concepts as part of this effort. SERI conducts systems analyses for defined applications to determine thermal storage requirements and to aid in selecting thermal storage technologies. Surveys and assessments also are performed to examine the matches of thermal energy storage technologies with applications. Figure 1 lists the activities now included in the SERI Solar Energy Storage Program.

For FY 1981, the emphasis of these activities is to support the joint plan of the DOE Division of Energy Storage Technology and the Division of Solar Thermal Energy Systems for developing thermal energy storage for solar thermal applications (described in reference 1). The SERI FY 1981 solar energy storage activities are discussed briefly in the following narrative; several of the areas are presented in more detail in other papers at this meeting.

THERMAL STORAGE AND TRANSPORT R&D

SERI performs and subcontracts research on advanced thermal energy storage technologies. As shown in Fig. 1, research on direct-contact heat transfer between the thermal storage media and an immiscible heat transfer fluid is an important element in the SERI program because of the potential to reduce heat transfer costs appreciably. SERI is investigating thermochemical reactions as a low cost means of thermal energy storage and transport. Subcontractors are being supported to research innovative thermal energy storage and transport ideas. In all cases, the research will provide new information on these technologies which will allow assessment of their potential by developers.

SERI continued research on direct-contact heat transfer for thermal energy storage because the cost and performance penalties of conventional heat exchangers render many otherwise promising thermal storage concepts noncompetitive. Direct-contact heat transfer is particularly attractive for latent heat storage media or phase change materials (PCMs). PCMs have long been regarded as attractive for thermal energy storage because the storage volume required is much less than that for sensible heat storage. However, extensive heat-transfer area must be provided to overcome the thermal resistance of the storage medium during the energy extraction (freezing) cycle, and the cost of the heat exchange system must be reduced significantly for it to be competitive with conventional technology. Furthermore, the latent heat storage system must be capable of working with a heat transfer liquid since over 90% of the low- and medium-temperature solar thermal systems rely on liquid-based collectors. Finally, the volume for passage of the heat transfer liquid must be kept to a minimum to preserve the volume reduction of latent heat storage.

One possible means of meeting these requirements is to use bulk containment of the latent heat storage medium and direct-contact heat exchange between the storage medium and an immiscible heat transfer fluid to add heat to and remove heat from storage. In one such system, a tank holds the storage medium (Fig. 2). To add energy, hot oil is bubbled through the tank, melting the storage material. After rising through the PCM, the drops coalesce into a floating layer of oil. The oil is then pumped to the heat source and recycled through storage. To discharge the unit, drops of cold oil enter the bottom of the tank and absorb heat as they rise. After coalescing at the top, the warm oil is pumped to the load to deliver heat. As heat is extracted, flakes of solid PCM form, grow, and settle to the bottom of the tank.

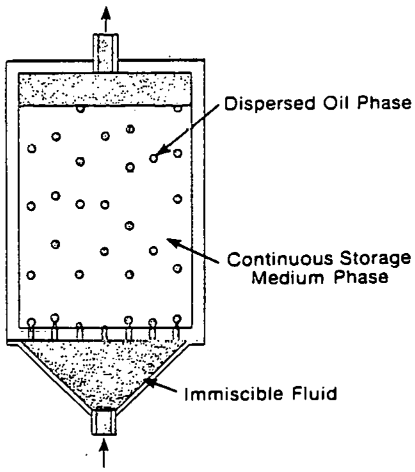

Figure 2. Direct-Contact Thermal Storage System for Heat Transfer Between a Latent Heat Storage Medium and an Immiscible Fluid

Despite the intriguing potential of direct-contact thermal storage, substantial uncertainties hinder the development and commercialization of the technology. Questions exist in the ability to reliably inject heat transfer oils into a freezing latent heat storage material. Also, the storage media may be carried out of the tank by the heat transfer oil and may freeze on external heat exchangers, thereby plugging the system. Finally, criteria are not available for designing a reliable heat exchange system.

The objective of the SERI direct-contact thermal storage research is to develop methods to ensure reliable distribution of the heat transfer fluid and to prevent carryover of the storage media. If these operational problems can be effectively overcome, design criteria will be determined for direct-contact thermal storage. As a result of this work, sufficient knowledge will be provided to the private sector to allow development of latent heat storage systems that cost less than existing systems and require about one-third the volume. In FY 1981, SERI is emphasizing research for low temperature storage because the technology has immediate application potential for home heating and domestic hot water uses and the experimental difficulties are less. However, the techology is applicable to high temperature applications as well; SERI will shift the research emphasis to high temperature direct-contact systems in FY 1982.

In FY 1981, SERI tested several different distributors in the low temperature, direct-contact storage experiment. A variety of difficulties were encountered in the operation of the distributors, but a distributor was found that reliably injected oil into a salt hydrate. After running through several freeze-thaw cycles with the design, the storage column was allowed to freeze overnight; no evidence of distributor flow blockage was observed when the system was started the next morning. A procedure was also developed to accurately measure continuous phase carryover, and experiments are now in progress to determine the extent of the carryover problem, factors affecting carryover, and methods to minimize the problem. Data are also being gathered to characterize the thermal performance of the unit.

In relation to the direct-contact research, the SERI Systems Analysis Task has identified the direct-contact latent heat storage concept being developed by Grumman Aerospace Corp. for high temperature applications as one of the three most promising storage concepts for water/steam central receivers. In the Grumman system, heat is extracted from a molten inorganic salt by bubbling drops of the salt through a cooler column of molten metal. As the salt rises, it solidifies into solid spheres, overflows at the top, and falls into the storage bin. Research into the operational characteristics of the unit is being carried out by Grumman under subcontract to SERI. Areas requiring further study include heat transfer and fluid flow phenomena within the heat exchanger, and heat transfer and freeze-up during droplet formation.

In another area, SERI has continued research on thermochemical energy storage and transport (TEST). This method of storage and transport involves absorption of energy by a reversible endothermic chemical reaction, with subsequent cooling to allow transport and/or storage at near-ambient temperatures. Upon demand, the energy stored in the chemicals is recovered by carrying out the reverse exothermic chemical reaction, with regeneration and recycling of the original chemicals.

Potentially, TEST systems can provide low cost, long-term thermal energy storage and long-distance thermal energy transport. However, previous studies have raised questions about the efficiency and costs of TEST (see reference 2). The major goal of the SERI task is to define TEST sufficiently to allow assessment of its long-term potential and identification of important research issues. The TEST definition involves thorough examination of both technical and economic aspects, as well as comparison with studies reported in the literature. Primary TEST systems are being designed, and cost consultants experienced in the costing of commercial reactor systems are estimating the price of the systems. Several independent groups are involved in this effort to provide a careful check of the results. The results will be integrated with applications to determine the delivered energy costs for the overall systems. Research will then be performed to clarify key assumptions in the analysis if promise is shown for TEST, and the analysis will be upgraded, if appropriate. The definition of TEST must be in sufficient detail so that if the outcome is favorable, the economic incentives will be obvious for private industrial firms and/or utilities to continue TEST R&D and commercialize the technology.

Currently, thermal energy storage concepts are being developed for several high temperature solar thermal applications. These so-called second-generation technologies offer cost and/or performance advantages over existing first-generation thermal energy storage options for six selected key applications. As part of the joint program plan between the DOE Division of Energy Storage Technology and the Division of Solar Thermal Energy Systems, SERI is subcontracting research on advanced storage technologies to significantly improve the cost and/or performance of thermal energy storage for high temperature solar thermal applications. Subcontractors were chosen competitively for this research. Research and analyses are being undertaken to determine the cost and performance potential of innovative thermal energy storage concepts so that judgment can be made as to whether these concepts can be effectively developed further. Since revolutionary approaches must be explored to significantly lower the cost of thermal energy storage, substantial risk is involved in this effort. The advanced storage technologies to be explored through this joint plan provide a basis for future focused thermal storage development efforts.

As one of the subcontractors in this effort, the University of Washington is investigating the phase conversion of small beads of a refracting oxide to a liquid in a solar furnace; silica, which is very stable at high temperatures, is an example of such an oxide. The liquid is stored until energy is needed; at this time, the molten material is injected into a heat exchanger under pressure as small-diameter streams, which break up into drops. The drops fall through a counterflowing, high pressure working gas, giving up their heat and solidifying into beads again.

In another innovative thermal storage study, the Institute of Gas Technology is studying a heat exchanger concept in which a composite sensible/latent heat storage media is maintained in direct contact with the high temperature air working fluid. A molten carbonate, phase change material is immobilized in porous refractories or particulate ceramic structures by capillary action, thus yielding a composite storage media.

As shown in Fig. 1, SERI is directing research on the transport of thermal energy. Thermal energy transport is important for supplying process heat from large central solar, coal, or nuclear plants to distributed users. Thermal transport is also essential for transmitting heat from distributed solar collectors to the centralized applications. For distances up to at least 50 km, thermal transport as sensible heat appears economically attractive, and this technology could service a significant market. Thermal transport by phase change materials may also have promise. For greater distances, advanced technologies such as thermochemical pipelines are more attractive.

In the thermal energy transport research area, SERI is initiating a subcontract to study the technical and economic merits of internal insulation of high temperature (120°-560°C) steam and hot water pipes. There is a strong economic incentive to develop cost-beneficial internal insulation in long-distance thermal energy transport systems. High temperature steam pipelines currently require expensive alloy steels and many expansion bends because of their high wall temperatures. For buried hot water systems, reinforced plastic pipes are economically advantageous in several important respects, but their present range of applications is severely temperature limited. Both sets of problems could be resolved by insulating the pipe walls from the high fluid temperatures.

The internal insulation study is the first phase of a wide-ranging SERI program planned in thermal energy transport research. Under SERI direction, the most economical thermal transport concepts will be optimized to refine the analysis and design system components. Research will be carried out to identify and develop the most cost-effective materials for transport, containment, and insulation. This activity will include definition of techniques to measure and retard system degradation. Alternate piping and insulation approaches will be explored, and materials and fluids will be evaluated to identify the most cost-effective options. Code qualification will be undertaken of the least costly containment materials capable of providing safe service in transport systems. In addition, efforts will be made to modify the codes to allow use of the least expensive, safe materials. Research and development will be performed on heat exchange concepts to reduce heat transfer costs. Advanced concepts identified in the cost analysis will be pursued. All of these activities will be performed in both the low and high temperature ranges with the objective of providing low cost thermal energy transport. The outcome of these activities will be a thermal transport technology base that can be used by industry and business to develop systems that will allow replacement of expensive oil and gas by low cost energy options.

SYSTEMS ANALYSIS AND ASSESSMENTS

A wide range of thermal energy storage and transport technologies have been researched. Systems analyses allow the technologies to be judged on a consistent basis for important applications. As a result, important technical and cost uncertainties can be identified for further research. In addition, nonpromising thermal energy storage and transport systems can be eliminated from the research program and the focus shifted to the most promising options.

SERI is continuing to perform systems analyses of thermal energy storage to support decision points in the Thermal Energy Storage for Solar Thermal Applications Program (TESSTA). In the TESSTA program, second- and third-generation thermal storage technologies will be developed to provide lower cost and/or improved performance over the first-generation technologies currently being deployed in solar thermal large-scale experiments (LSE). SERI is conducting the systems analysis of thermal storage to provide the information necessary to select thermal storage technologies for research development for specific solar thermal applications. The criteria to be met in this process are the following:

- The program cost goals defined in the plan must be met or surpassed.
- The advanced concepts must be more cost-effective than thermal storage technologies currently under development.

The program cost goals of the first criterion are based on the costs of the alternative energy systems, which establish the value of a solar thermal technology competing in the open market (see reference 3). Meeting these value-based goals ensures that there will be a market for the developed technologies. The second criterion requires comparison of the various thermal storage concepts (see reference 4).

During FY 1981, Stearns-Roger, under subcontract to SERI, completed cost and performance estimates of thermal energy storage for water/steam, organic fluid, and gas-cooled solar thermal receivers. Prior to completion of the work, Stearns-Roger presented the data to the developers of thermal energy storage technologies; 26 people representing 14 organizations attended the review. The data were generally well received, and only some fine tuning of the data was required to resolve the issues raised. The data was in good agreement with some independent assessments conducted by Combustion Engineering and Babcock and Wilcox under subcontract to Sandia National Laboratory, Livermore.

SERI integrated Stearns-Roger results with the solar thermal application to determine the impact of thermal energy storage on delivered energy cost. SERI also examined the sensitivity of the results to the following factors in the Stearns-Roger data: storage efficiency, cost of money, size and distribution of indirect cost factors, operation and maintenance cost assumptions, and cost uncertainties. The cost data had the largest effect, but the conclusions were unaffected within the range of uncertainties. The data were also compared with the cost goals for thermal energy storage. Based on the results, recommendations were made to the DOE Division of Energy Storage Technology on promising thermal energy storage concepts for continued study.

SERI also performs systems analyses of innovative thermal energy storage and transport concepts for solar thermal applications. The studies describe a system, estimate its cost, and compare the cost to the value. In this way, SERI identifies promising new concepts for existing and potential solar thermal applications. In FY 1981, mechanical transport of high temperature thermal energy was examined for ground-mounted thermal storage for solar thermal dish collector applications. Storage was evaluated for solar-powered air conditioning using trough collectors. These activities are reported in more detail in other papers presented at this meeting.

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