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THERMAL ENERGY STORAGE FOR BUILDING HEATING AND COOLING APPLICATIONS

QUARTERLY PROGRESS REPORT APRIL–JUNE 1976

H. W. HOFFMAN
R. J. KEDL

MASTER

OAK RIDGE NATIONAL LABORATORY
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H. W. Hoffman and R. J. Kedl

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SUMMARY

This document is the first in a series of quarterly progress reports covering activities funded at ORNL by the ERDA Division of Energy Storage Systems to develop thermal energy storage (TES) technology applicable to building heating and cooling. Studies to be carried out will emphasize latent heat storage in that sensible heat storage is held to be an essentially existing technology.

Development of a time-dependent analytical model of a TES system charged with a phase-change material was started. A report on TES subsystems for application to solar energy sources is nearing completion. Studies into the physical chemistry of TES materials were initiated. Preliminary data were obtained on the melt-freeze cycle behavior and viscosities of sodium thiosulfate pentahydrate and a mixture of Glauber's salt and Borax; limited melt-freeze data were obtained on two paraffin waxes.

A subcontract was signed with Monsanto Research Corporation for studies on form-stable crystalline polymer pellets for TES; subcontracts are being negotiated with four other organizations (Clemson University, Dow Chemical Company, Franklin Institute, and Suntek Research Associates). Review of 10 of 13 unsolicited proposals received was completed by the end of June 1976.

THERMAL ENERGY STORAGE FOR BUILDING HEATING AND COOLING APPLICATIONS QUARTERLY PROGRESS REPORT FOR PERIOD APRIL-JUNE 1976

H. W. Hoffman and R. J. Kedl

1. INTRODUCTION

This is the first in a series of quarterly reports covering activities funded at ORNL by the ERDA Division of Energy Storage Systems (DESS) to develop thermal energy storage (TES) technology applicable to building heating and cooling. The low funding level during the first three quarters of FY 1976 severely constrained the technical effort; however, much was accomplished during this early period in assisting ERDA with defining overall program goals, reviewing proposals, and outlining ORNL responsibilities. To provide some tie with this earlier work, the present report covers activities for the larger period January-June 1976.

2. PROGRAM OBJECTIVE

This program provides management and technical support to ERDA in developing thermal energy storage (TES) systems for use with solar or waste heat energy sources and for peak shaving by the consumer in building heating and cooling. This objective will be pursued with the general guideline that engineering feasibility and concept demonstration will be the province of industrial participants and concept feasibility and long-term generic R&D, of universities and national laboratories. Studies performed will emphasize latent and chemical reaction heat storage in that sensible heat storage is held to be an essentially existing technology (albeit with commercialization problems and low-energy density limitations).

3. ORNL TECHNICAL STUDIES (TASK 2)

3.1 Mathematical and Physical Modeling — Task 2.1 (M. E. LaVerne)

Development of a time-dependent analytical model of a TES system charged with a phase-change material was started. Current effort is directed to defining the problem and obtaining background information. The moving boundary problem (Stefan problem), as in the melting or freezing of a PCM, is difficult but important and is receiving a great deal of attention by applied mathematicians. Our approach here is to utilize existing solutions to describe the behavior of a TES system. The TES model will be coupled analytically to existing overall performance models of solar collectors and applications; thus a realistic appraisal of the entire Solar/TES/Application system will be available.

3.2 Subsystems for Solar Application — Task 2.2 (C. L. Segaser)

This study, initiated at the request of OTA (see Section 5.5), is being extended to include an economic evaluation of TES subsystems. The compass of the report is broad and should provide significant rationale for TES application with the solar energy source. Considered are loads ranging from single-family residences to cities of 30,000, including 100-unit apartment buildings, storage capacities from 60 to 3.6×10^6 Kw · hrs, and storage temperatures from 100 to 1000°F. The report should be completed by the end of the transition period.

3.3 Thermodynamic Properties and Interactions — Task 2.4 (S. Cantor and D. E. Heatherly)

Studies were initiated into the physical chemistry of materials that can be used to store thermal energy in individual homes and such larger buildings as apartment houses, department stores, etc.

Two materials currently being investigated for phase-change storage — sodium thoisulfate pentahydrate ($Na_2S_2O_3 \cdot 5H_2O$) for heat storage and a mixture of $Na_2SO_4 \cdot 10H_2O$-NaCl-NH_4Cl-$Na_2B_4O_7 \cdot 10H_2O$-thickener (70-11-10-3-6 wt%) for cold storage — were studied in regard to melting and freezing behavior. Neither material behaved as favorably as reported.[1] Reagent grade $Na_2S_2O_3 \cdot 5H_2O$ melted over a range of 46.5°C to above 66°C rather than congruently; supercooling of the molten material was observed in all 12 of the temperature cycles. The coolness medium (without thickener) showed supercooling to ∿5°C in quiescent liquid and to ∿9.6°C in stirred liquid; the freezing temperature was 10.6°C vs the 12.8°C reported by Telkes.[1]

Paraffin waxes are also being examined as heat storage materials. Two waxes, supplied by Quaker State Corporation, were studied with the following results:

Designation	Melting Temp. (°C)	Freezing Temp. (°C)
IP Petrolatum	65.6	--
IP-2 Slack Wax	44.4-51.7	48.4-46.2

Changes in enthalpy of fusion and melting temperature under melt-freeze cycling conditions will be determined when a differential scanning calorimeter (DSC) becomes available.

Preliminary measurements on the viscosity of $Na_2S_2O_3 \cdot 5H_2O$ over the temperature range 36 to 66°C indicate viscosities about 20% higher than reported by Moynihan.[2] This property is needed in calculations of thermal performance and may help in correlating super-cooling behavior.

4. INDUSTRIAL PARTICIPATION (TASK 3)

The following subcontracts are being developed:

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[1] M. Telkes, <u>ASHRAE J.</u>, 38-44 (September 1974).

[2] C. T. Moynihan, J. Phys. Chem., 70, 3399 (1966).

Organization	Subcontract Title
1. Clemson University	Immiscible Fluid-Heat of Fusion Heat Storage System
2. Dow Chemical Company	Macro-Encapsulation of Heat Storage Phase-Change Materials for Use in Residential Buildings
3. Franklin Institute	Thermal Energy Storage with Saturated Aqueous Solutions
4. Monsanto Research Corporation	Form-Stable Crystalline Polymer Pellets for Thermal Energy Storage
5. Suntek Research Associates	Thermocrete, A Thermal Energy Storage Material with Structural and Thermostatic Properties

Plans are being made to visit each of these subcontractors as the contracts are completed to meet personnel assigned, discuss the technical approach, view equipment and facilities, establish appropriate communication channels, and clarify technical and administrative relationships. As currently understood, ORNL will follow and advise on the work being done but will suggest changes in scope, schedules, or budgets only through ESS — Thermal & Chemical Storage Branch.

5. PROGRAM MANAGEMENT (TASK 1)

5.1 Subcontracts

Procurement packages were processed by ERDA-ORO for the subcontracts listed above under Task 3 (Section 4). The Monsanto contract has been signed; the other four are still being negotiated, and signing early in the TQ is anticipated.

5.2 Proposal Reviews

During the period January-June 1976, 13 unsolicited proposals were received for review. Detailed comments and recommendations were provided on ten of these; review remains incomplete on three others. These proposals are listed in Table 76-6.1.

Table 76-6.1 Unsolicited Proposals Reviewed, January-June 1976

Submitting Organization	Proposal Title	Review Status
1. Chemical Energy Specialists	The Chemical Heat Pump: A Simple Means to Conserve Energy	Review completed; letter to ERDA 2/19/76
2. Dow Chemical Company	Development of Thermal Storage Systems for the Heating and Cooling of Residential Buildings: (a) Macroencapsulation (b) High-Temperature Storage for Absorption Air Conditioners (c) Dispersed Storage	
3. EXXON Research and Engineering Company	Water in Oil Liquid Emulsions — A Novel Technology for Energy Conservation and Storage in Air-Conditioning Applications	Review completed; letter to ERDA 6/10/76
4. Lockheed Missiles and Space Company, Incorporated	Development of Standardized Tests of Energy Storage Materials (EMS's) Performance	
5. Monsanto Research Corporation	High-Temperature Thermal Energy Storage System, $Na_2SO_4 + SO_3 \rightleftarrows Na_2S_2O_7$	Review completed; letter to ERDA 6/8/76
6. Pioneer Rural Electric Coop, Incorporated	Adapting Off-Peak Banked Heat for Residential Use	Review completed; letter to ERDA 3/15/76
7. Science Applications, Incorporated	Energy Storage in Reversible Decomposition Oxides	Review completed; letter to ERDA 6/9/76
8. Southwest Research Institute	An Investigation of Thermal Energy Storage in Phase-Change Materials	Review completed; letter to ERDA 3/11/76
9. Standun, Incorporated	The Use of Supercooled Fluids for Energy Storage in Solar Heating Applications	
10. State University of New York at Binghamton	Search for Chemical Additives that Will Increase the Heat Capacity of Water	Review completed; letter to ERDA 2/6/76
11. UOP, Incorporated	Dispersed Salts Thermal Energy Storage	Review completed; letter to ERDA 6/22/76
12. University of Delaware	Research in Energy Storage Materials and Systems	Review completed; letter to ERDA 3/22/76
13. Westinghouse Research Laboratories	Development of a Fluidized-Bed Device to Evaluate Experimental Encapsulated Phase-Change Materials	Review completed; letter to ERDA 6/17/76

On February 25-27, 1976, H. W. Hoffman assisted the Solar Heating and Cooling Branch (Division of Solar Energy) in the review of proposals for TES applicable to the solar heat source. During the following week, R. J. Kedl worked with C. J. Swet to prepare procurement packages for a number of the proposals found acceptable from this review (see listing in Section 4 above).

On March 30, 1976, H. W. Hoffman participated (as Program Area Manager for Building Heating and Cooling Applications) in a review of the ANL program: Ammonia-Water Absorption System and Thermal Energy Storage. It was concluded that storage in the working fluid of an adsorption heating/cooling system was not the most cost-effective process.

5.3 Meetings

Program staff participated during the last six months in a number of meetings relevant to the TES area:

a. Conference on Thermal Energy Storage. H. W. Hoffman was an invited participant in this conference sponsored by the NATO Science Committee at Turnberry, Scotland, on March 1-5, 1976. The final report of this meeting has just been published (E. G. Kovach, Editor, Thermal Energy Storage, Scientific Affairs Division, North Atlantic Treaty Organization, Brussels, Belgium). The Summary from this report is appended (A-1); additional copies of the full report have been ordered.

b. Advanced TES Technologies for Solar Applications. R. J. Kedl participated in this workshop held in Baton Rouge, Louisiana, on April 23-24, 1976, chairing discussion in the area of storage for solar space heating and cooling. (This workshop — organized by the TES Branch, CONRT — immediately followed the Second Southeastern Conference on Application of Solar Energy co-sponsored by ERDA.) A summary of this duscussion area has been prepared by Kedl and forwarded to Professor Ozer Arnas (LSU) for inclusion in a report documenting the workshop results; a draft of this report is expected by early August.

c. Molten Salt Technology. H. W. Hoffman participated as one of four lecturers in a short course on Molten Salt Technology offered by the Center for Professional Development, East Brunswick, New Jersey, May 24-26,

1976. These lectures covered the areas of engineering thermophysical properties, molten salt heat transfer and flow characteristics, and systems and components. One thrust was the application of molten salts as storage and heat transfer media for high-temperature TES. No formal documentation is planned.

5.4 Visits

Program staff members were involved in the following visits during this reporting period:

a. March 8-11, 1976. H. W. Hoffman — in the company of P. A. Lowe (ERDA-CONRT) and D. R. Glenn (GE-Valley Forge Space Center) — visited a number of European laboratories engaged in TES studies. These visits, made in the week following the NATO Conference discussed above (Section 5.3), were to the Philips Research Laboratories in Aachen, Germany, and Eindhoven, Netherlands, and to Electricité de France (EDF) in Chatou, France. Meetings were also held with U.S. Embassy staff, ERDA office personnel, and European Economic Community staff in Brussels, Belgium.

Summaries of these visits are contained in a trip report prepared by H. W. Hoffman.

b. April 27-28, 1976. S. Cantor (ORNL Chemistry Division) and J. R. Engel (ORNL Reactor Division) participated in a technical review by ERDA-DSE of the TES subsystem in the Honeywell, Incorporated, concept of a solar thermal-electric power station. Immediately prior to this review, the concept was discussed with Honeywell staff in Minneapolis.

These visits are documented in a trip report by Cantor and Engel.

5.5 Publications

There were no formal publications during this reporting period.

The draft of a report on solar TES subsystems was forwarded (in early February) through CONRT-TES to the Congressional Office of Technology Assessment. This report was prepared in partial response to OTA's request for information on TES systems to support their study on solar energy utilization status and prospects (see Section 3.2).

5.6 Program Plan

Preparation was started on a program plan for "Development of Advanced Thermal Energy Storage Systems for Building Heating and Cooling Applications." This plan supplements the national program plan on TES (preliminary draft of February 16, 1976) by filling in the details of technical activities proposed by ORNL to accomplish the national goals in the area of building heating and cooling.

A draft of this plan will be submitted for ERDA review and comment in the transition quarter.

Appendix A-1

Excerpt from "Thermal Energy Storage," a report of a NATO Science Committee Conference at Turnberry, Scotland, March 1-5, 1976.

Summary

The following is not meant as a complete summary of these findings. Rather, it represents general conclusions reached by the Organizing Committee.

1. It is clear that TES is far from new. In many instances it has been practiced for centuries. However, the concerted application of TES as a large-scale means of energy conservation has only been studied for the past few years, and no really new experimental results are yet available. This Conference was immensely useful in that it came at a most opportune time and served to order and clarify the thoughts of many responsible for directing future progress.

2. There are a large number of present and potential applications of TES; e.g., uses were identified in:

(a) Domestic heating

(b) Commercial heating (apartment houses, shopping centers, office buildings, etc.)

(c) Energy conservation in a large array of industrial applications

(d) Load leveling in the power generating industry.

3. In many instances the technologies involved in TES are well known and can be applied economically at present. This is particularly true for TES at temperatures below 100°C but also applies to sensible heat storage using water at higher temperatures and pressures.

4. All Working Groups identified applications where the technology was known but acceptance of the principle would require pilot-scale development units. The initiation of such projects should be encouraged.

5. Long-range developments in materials for sensible heat and latent heat storage as well as for chemical storage, especially at higher temperatures, offer exciting possibilities.

6. The scale of storage both in terms of time and volume (or mass) of material is very important. Nearly all applications today are for hourly, diurnal or weekly storage and have immediate application in energy conservation, particularly in industry but also in domestic and commercial heating, and in the electric utilities for load leveling. However, there is a great need for seasonal storage — i.e., over many months — and the use of large lakes, ponds, or underground aquifers should be developed as rapidly as possible. This is mainly a low-to-moderate temperature application, and the "pay-off" in terms of energy savings is large.

7. While energy storage may be useful for electric utilities, especially for load leveling, it is mandatory for the development of solar heat and solar power applications.

8. It is clear that the impact of TES on various systems is a most complex matter in which the economic answer depends on not only on technology but also on social and political considerations. It was unanimously agreed that while general guidelines were apparent it was impossible to examine specific cases because the optimum application for a given instance depended strongly on the particular circumstances; the recommended procedure could be diametrically opposite for another case.

9. As a consequence, it was strongly recommended that detailed economic investigations of individual cases be made before taking decisions. These should consider all variables, and the use of proven mathematical models would be a useful and indeed necessary prerequisite.

10. Although this conference concentrated on the needs of industrially advanced nations, many participants expressed the view that TES would play a significant role in those countries in which technological development is underway.

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