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SYSTEMS ANALYSIS OF THERMAL STORAGE

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Abstract

During FY80 analyses were conducted on thermal storage concepts for solar thermal applications. These studies include both estimates of the obtainable costs of thermal storage concepts and their worth to a user (i.e., value). Based on obtainable costs and performance, promising thermal storage concepts are being identified. A preliminary screening was completed in FY80 and a more in-depth study was initiated. Value studies are being conducted to establish cost goals. A ranking of storage concepts based on value in solar thermal electric plants was conducted for both diurnal and long duration applications. Ground mounted thermal storage concepts for a parabolic dish/Stirling system are also being evaluated.

Introduction

The systems analysis of thermal storage effort is being conducted to identify promising thermal storage concepts for development. The criteria to be met in this process are:

1. The obtainable cost must be less than or equal to program cost goals.
2. The concept must be more cost effective than alternative thermal storage technologies.

The program cost goals are being established to assure a market place for the developed technologies. This requires an understanding of the potential market places, the potential size of each market, the locations, user economic criteria, and alternative energy systems. From this knowledge the cost of the alternative energy systems are employed as a measure of what the user is willing to pay for a new energy system; i.e., the value. The value of thermal storage is that part of the system value which is due to storage or which can be allocated to storage. The program cost goals for thermal storage are established based on that later value.

The second criterion requires a direct comparison of the various thermal storage concepts. This analysis must be conducted with a consistent cost data base and for a specified application. Furthermore, to assure a fair comparison each technology must perform the same mission. Each storage is not required to have the same efficiency, but there must be a way of accounting for differences. A ranking methodology for conducting the comparisons has been developed by SERI,[1] and SERI is employing that methodology in the analysis of the thermal storage concepts.

In FY80 this effort has focused on thermal storage for solar thermal applications. Cost trade-off analyses are being conducted for water/steam receivers, organic fluid receivers, and gas/Brayton systems. The potential for ground-mounted thermal storage with a parabolic dish/Stirling system is being assessed. The value of thermal storage in solar thermal process heat applications is being analyzed, and a ranking of thermal storage concepts based on value in solar thermal electric power plants was completed. Each of these activities is discussed in the following paragraphs.

Obtainable Cost Analyses

Thermal storage concepts are being developed for solar thermal applications; a plan has been prepared as a cooperative effort of the Solar Thermal Program and the Thermal and Chemical Energy Storage Program.[2] SERI is supporting decision points in that program by conducting comparative rankings of thermal storage concepts for identified applications. The first of these decision points will occur in the spring of 1981 when thermal storage concepts will be selected to develop for the following solar thermal systems:

Water/Steam Central Receiver System

1. Electric power plant; diurnal storage with a second generation receiver.
2. Process heat; diurnal storage with dry saturated steam delivered to the load.

Organic Fluid Receiver System

3. Co-generation system; week-end storage
   3-A) Syltherm transfer fluid
   3-B) Caloria transfer fluid.
4. Process heat; week-end storage with dry saturated steam delivered to the load.

Air Cooled Receiver System

5. Large Brayton cycle; diurnal storage.

The analyses are being done in a two-step manner as described below:

I. Preliminary Screening
   This analysis was conducted by SERI to understand the importance of various performance

parameters and to provide some early guidance to the program managers. Because of the limited scope, the analysis was done in a generic manner.

II. Decision Data

Stearns-Roger under contract to SERI is generating consistently calculated cost and performance data. SERI will analyze the impact of thermal storage on system-delivered energy cost (using the Stearns-Roger data) and recommend specific concepts for development. The Stearns-Roger work is described in another paper being given at this meeting.

Table 1 summarizes the results of SERI's in-house study. The study has been documented[3] and each of the concepts is described. Each of the concepts was compared on a consistent basis with a first-generation thermal storage technology (i.e., reference system). The conclusions were based upon the delivered energy costs of the storage-coupled solar thermal system with the alternative thermal storage as compared to the reference thermal storage for that same condition. The program goals require a 24% or more lowering of the thermal storage cost relative to the first-generation concept. The concepts with that potential are noted in Table 1.

Table 1. RESULTS OF THE PRELIMINARY SCREENING

Concepts with the Potential of Meeting Program Goals

- Water/Steam Collector/Receiver (1)
  - K-Salt/Glass (Buffer Storage Applications)
  - Two Stage: Draw Salt/Glass and Oil/Rock (Diurnal Storage Applications)
- Organic Fluid Collector/Receiver (2)
  - Trickle Charge Syltherm/Glass

Concepts That Would Increase the Energy System Costs

- Water/Steam Collector/Receiver
  - Draw Salt
  - Two-Stage Draw Salt/Glass and Oil/Rock
  - $NaNO_3$ Phase Change
- Organic Fluid Collector/Receiver
  - NaOH, Phase Change
  - K-Salt (3)

Concepts with Little or No Advantage or Penalty

- Water/Steam Collector/Receiver
  - Improved Phase Change, $NaNO_3$
  - Two-Stage Draw Salt/Glass and K-Salt/Glass
- Organic Fluid Collector/Receiver
  - K-Salt/Glass

(1) For water/stream receivers system, (Barstow Technology), electric power only, oil/rock reference storage concept.

(2) For organic fluid receiver, (Shennandoah Technology), cogeneration only; trickle-charge syltherm/taconite reference storage.

(3) K-salt is similar to Hitec and consists of 50% $NaNO_3$, 35% KNO_3, and 15% $NaNO_2$.

The analysis was conducted in a generic manner. Not all concepts currently being developed were studied; instead, the analysis was configured to study each of the major types of technologies: sensible heat (both organic and inorganic storage media in both single- and two-stage systems) and latent heat. Only one phase change concept was studied, which was described by Honeywell[4] but modified for use in the specific applications. The list of sensible heat concepts was also limited and the ones listed were considered as generically representative of other sensible heat systems. The data in Table 1 are obviously preliminary. While the data are indicative of the type of results anticipated in the Stearns-Roger study, the later effort will study more concepts for more applications and in greater depth.

Value Studies

The value of thermal storage is being analyzed for solar thermal applications. Value data for electric power applications were presented at the last year's annual meeting.[5] Values of thermal storage in process heat applications are currently being generated, but the results are not available as of this writing. The electric power value data were employed to rank thermal storage for diurnal and long-duration storage.

Diurnal Storage

Table 2 presents the results of the ranking of thermal storage concepts based upon value. First-generation thermal storage concepts are those currently being built in large-scale experiments. The first-generation storage for each solar thermal collector/receiver system is noted in Table 2. For areas of high insolation (i.e., Barstow, Albuquerque, Phoenix) all of these first-generation storage meet the value-delivered goal. However, the large markets of storage-coupled solar thermal systems are anticipated to be in medium insolation sites. These areas include most of Texas, Colorado, Utah, Nevada, California, and some of Oklahoma. In that area only molten salt storage with molten salt collector/receivers could meet the value. Table 2 presents the required improvement in the first-generation storage to meet value in the medium insolation sites. Fortunately, development of second generation is in progress.[2] The cost reductions considered obtainable in the current plan are also noted in Table 2. The overall situation is very healthy; a second-generation development effort is needed and concepts have been identified which can meet the need.

Table 2. RECOMMENDED GOALS FOR SECOND-GENERATION DIURNAL THERMAL STORAGE (1)

Collector/Receiver	% Improvement in First-Generation Subsystem Cost for Storage Capacity of:			
	3 Hours	6 Hours	9 Hours	Current Plan (3)
Water/Steam (Oil/rock)	30	30	30	24
Molten Salt (2) (Dual tank, salt external insulation)	√	√	√	50
Liquid Metal (Dual tank, sodium, external insulation)	55	65	70	57
Gas Cooled (Ceramic brick)	50	55	60	31

(1) To meet value at medium insolation sites (most of Texas, Colorado, Utah, Nevada, California, and some of Oklahoma and Kansas). The data are the needed improvements including O&M costs.

(2) Second-generation storage (i.e., internally insulated tanks) are anticipated to meet the value even at low insolation sites. √ = First-generation costs are less than value.

(3) From DOE, 1979. Thermal Energy Storage for Solar Thermal Applications, Multiyear Program Plan," Draft. Oct. 25, 1979.

Long Duration Storage

Third-generation thermal storage developments are to provide a technology base for future solar thermal applications. One of those frequently discussed applications is long-duration storage for base-load electric power plants (i.e., 24 hr/day operation, day after day, regardless of weather). Value for the long-duration storage use has been calculated. The value was found to be a strong function of the thermal storage efficiency (i.e., the ratio of the actual work produced with thermal storage to the amount of work which could have been produced if the thermal energy has not been stored). The effect of location (high, medium, or low insolation) was small. Table 3 presents the results of the study. The cost data were taken directly from the literature. No modifications to the reported data were made except those necessary to place all data in the same format (i.e., same-year money and the power- and energy-related terms). Contingency and spares, interest during construction, or indirects have not been added by this author since the referenced paper may or may not have included those factors. Unfortunately, the references fail to mention which factors are included.

The long-duration value data were derived for a truly base-load application. To meet such load, a very large quantity of storage is needed—on the order of 1000 hours[6]. For an overall capacity factor equal to a coal-fired plant (i.e., equipment outages only), the availability factor need be only 94%, requiring from 250 hours to 830 hours of storage (say a nominal 360 hours). If the availability factor were reduced to 90%, the overall value would be slightly reduced; but the quantity of storage is reduced to only 40 to 100 hours (say a nominal 72 hours). The quantity of storage necessary to achieve the value has not been determined. The quantity of storage will be variable due to differences in insolation and loads at various sites and in different time frames. Thus, the obtainable cost data are compared to the same value for two nominal storage capacities.

The data in Table 3 indicate that only the air/rock and $Ca(OH)_2$ concepts have the potential of meeting their value. The air/rock system has a very high efficiency and thus value. For the $Ca(OH)_2$ concept, the efficiency can be high and also the value. However, the power-related cost for that concept might be very high. Research currently in progress at SERI is examining the issues of both efficiency- and power-related cost. Improvements in efficiency of $Ca(OH)_2$ over previous work have been found. As currently defined, the other concepts examined have both efficiency and cost problems. As the current work at SERI* is demonstrating for calcium hydroxide, improvements might be made. Revision of the SO_2/SO_3, NH_4HSO_4, and oil/rock concepts may alter both the cost and value (i.e., efficiency) data of the currently defined concepts. In the future, other concepts might be found which are also low cost and have high efficiency.

Ground Mounted Thermal Storage

Thermal storage placed on the ground with a Stirling engine is being studied. The objective is to assess the potential as an advanced system. Preliminary data indicate that cost and efficiency of transporting the thermal energy to the ground are major factors. Innovative concepts are being identified to solve the problems; the final results are not available now.

Closure

The systems analysis of thermal storage is analyzing the cost and value of thermal storage in solar thermal applications. The ranking of thermal storage based on value has

Table 3. COMPARISON OF OBTAINABLE COSTS AND VALUE FOR LONG-DURATION THERMAL STORAGE (1978 Dollars)

	Concept Reference	Efficiency [3]	Cost Data [1] C_P $/kW$_e$	Cost Data [1] C_S $/kWh$_e$	Total Cost [2] $/kW$_e$: 72 Hours $C_S \cdot H$	72 Hours C_T	360 Hours $C_S \cdot H$	360 Hours C_T	Value $/kW$_e$ [4]
THERMOCHEMICAL	SO_2/SO_3								
	Minimum	0.41	300	17.0	1224	1524	6120	6420	-35/+2
	Maximum	0.52	NE	NE	NE	NE	NE	NE	110/120
	$Ca(OH)_2$								
	Minimum	0.42	450	0.5	36	486	180	630	-35/+2
	Maximum	0.76	NE	0.3 [7]	22	NE	108	NE	360/480
	NH_4HSO_4 [6]								
	Minimum	0.44	600	6.0	432	1032	2592	3192	0/40
	Maximum	0.55	NE	1.5 [7]	108	NE	540	NE	130/165
SENSIBLE & LATENT	Air/Rock								
	Nominal	0.9	81	1.7	122	203	612	693	500/700
	Underground Oil/Rock								
	Nominal	0.7	300	5.0	360	660	1800	2100	300/400
	Latent Heat Mixed Chlorides								
	Nominal	0.62	Modular	50.0	3600	3600	18,000	18,000	210/280
	Media Only	0.62	[5]	6.0	432	NE	2160	NE	210/280

[1] NE: Data not estimated
[2] $C_T = C_P + C_S \cdot H$; sum of power-related and energy-related costs
[3] Work out/work equivalent into storage
[4] Minimum value/maximum value
[5] Storage tanks are modular, each including its own heat transfer system
[6] This author generated all efficiency and "media only" cost data.
[7] Media only, materials cost from Chemical Marketing Reporter, June 1980

shown that the development of second-generation technologies is needed and that the current program can meet that need. Long-duration thermal storage must be both low cost and have higher efficiency. Identified sensible and thermochemical storage concepts have the potential of meeting the long-duration value. In the future other low-cost concepts may also be identified.

A preliminary screening of thermal storage concepts was completed for water/steam and organic fluid receivers. Because of the preliminary and generic nature of that data, the results should not be applied to other concepts unless they are similar. A more in-depth study was initiated; the later effort is being supported by Stearns-Roger and will be employed to recommend specific thermal storage concepts for development.

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