SYSTEMS ANALYSIS OF THERMAL STORAGE

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AUGUST 1980

5TH ANNUAL THERMAL STORAGE MEETING
TYSONS WEST PARK HOTEL
MCLEAN, VA.
OCTOBER 10-15, 1980

PREPARED UNDER TASK No. 3528.10

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Prepared for the
U.S. Department of Energy
Contract No. EG-77-C-01-4042

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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, 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. 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) Sytherm 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:

1. **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

Steama-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 Steama-Roger data) and recommend specific concepts for development. The Steama-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 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.

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 but modified for use in the specific applications. The list of sensible heat concepts was also limited and the ones listed were considered as generally 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 Steama-Roger study, the later effort will study more concepts for more applications and in greater depth.

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 units are noted. 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

<table>
<thead>
<tr>
<th>Collector/Receiver</th>
<th>% Improvement in First-Generation System</th>
<th>Cost for Storage Capacity of 1,000 Hours Plan (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water/Steam</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>Molten Salt (2)</td>
<td>75%</td>
<td></td>
</tr>
<tr>
<td>Lime/Active Carbon</td>
<td>50%</td>
<td></td>
</tr>
<tr>
<td>Ceramic</td>
<td>25%</td>
<td></td>
</tr>
</tbody>
</table>

(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 median improvements including O&M costs.

(2) Second-generation storage (i.e., internally insulated tank) are anticipated to meet the value even at low insolation sites. A 25% improvement can be met that value.


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. 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 units are noted. 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.

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-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. For an overall capacity factor equal to a coal-fired plant (i.e., equipment outages only), the availability factor needed would 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 in 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 SO₂/SO₃, NH₄HSO₄, 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.

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

<table>
<thead>
<tr>
<th>Concept Reference</th>
<th>Efficiency [3]</th>
<th>C_p $/kW_h</th>
<th>C_s $/kW_h</th>
<th>Total Cost [2] $/kW_h</th>
<th>Value (72 Hours)</th>
<th>Value (360 Hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>C_s H</td>
<td>C_T</td>
<td>C_s H</td>
<td>C_T</td>
<td>Value</td>
</tr>
<tr>
<td>THERMOCHEMICAL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SO₂/SO₃</td>
<td>Minimum</td>
<td>0.41</td>
<td>300</td>
<td>17.0</td>
<td>1224</td>
<td>1524</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>0.52</td>
<td>NE</td>
<td>NE</td>
<td>NE</td>
<td>NE</td>
</tr>
<tr>
<td>Ca(OH)₂</td>
<td>Minimum</td>
<td>0.42</td>
<td>450</td>
<td>0.5</td>
<td>26</td>
<td>486</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>0.76</td>
<td>NE</td>
<td>0.3 [7]</td>
<td>22</td>
<td>NE</td>
</tr>
<tr>
<td>NH₄HSO₄ [6]</td>
<td>Minimum</td>
<td>0.44</td>
<td>600</td>
<td>6.0</td>
<td>432</td>
<td>1032</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>0.55</td>
<td>NE</td>
<td>1.5 [7]</td>
<td>108</td>
<td>NE</td>
</tr>
<tr>
<td>SENSIBLE &amp; LATENT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air/Rock</td>
<td>Nominal</td>
<td>0.9</td>
<td>81</td>
<td>1.7</td>
<td>122</td>
<td>203</td>
</tr>
<tr>
<td>Underground Oil/ Rock</td>
<td>Nominal</td>
<td>0.7</td>
<td>300</td>
<td>5.0</td>
<td>360</td>
<td>660</td>
</tr>
<tr>
<td>Latent Heat Mixed</td>
<td>Chlorides</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Nominal</td>
<td>0.62</td>
<td>Modular</td>
<td>50.0</td>
<td>3600</td>
<td>3600</td>
</tr>
<tr>
<td></td>
<td>Media Only</td>
<td>0.62</td>
<td>[5]</td>
<td>6.0</td>
<td>432</td>
<td>NE</td>
</tr>
</tbody>
</table>

[1] NE: Data not estimated
[2] C_T = C_p + C_s * H; sum of power-related and energy-related costs
[3] Work out/work equivalent into storage
[5] Storage tanks are modular, each including its own heat transfer system
[6] This author generated all efficiency and "media only" cost data.
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 Stema-Roger and will be employed to recommend specific thermal storage concepts for development.

References


