IEA ECES
Annex 30
Subtask 1

Process Analysis Guidelines Retrofit and Greenfield Projects

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Institute	DLR, Institute of Engineering Thermodynamics Danish Technological Institute (Greenfield adaptation)
Compiled by	Maike Johnson (DLR) Lars Reinholdt (DTI)
Participants	Annex 30
Checked by	Duncan Gibb
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1. Document summary and goals

The goal of the document is the development of process analysis guidelines and the testing of these analysis steps with work conducted by researchers in Annex 30.

The goals of the guidelines are twofold. On the one hand, these guidelines can serve as guidance for researchers developing thermal energy storages (TES) for industrial processes and upscaling from the laboratory setting. On the other hand, the process analysis guidelines can be a first step in assisting process customers or partners in assessing the necessity and depth of information required at the various steps of the evaluation and design.

Referring to the structure of the Annex 30, the combination of the process analysis conducted here in Subtask 1 and the storage unit analyses conducted in Subtask 2 *Technical Parameters* and Subtask 3 *Economic Parameters* results in a combination of factors that can be used for evaluating the integration potential of a storage unit. This is analyzed in Subtask 5 *Key Performance Indicators*.

These guidelines have been developed with a focus on industrial processes and power plants, with an initial focus on retrofit (RF) applications, which was expanded to incorporate greenfield (GF) scenarios. Retrofit examines an existing process and the storage must be designed to fit the needs of this already dimensioned and built system. In a greenfield analysis, the storage parameters are designed with the rest of the system. This results in a different viewpoint while applying the process analysis guidelines. The information and values from the process analysis are used to design the storage system.

These guidelines can be used for processes other than industrial or power plants, but some adjustment may be necessary.

2. Process analysis guidelines

For designing thermal energy storage units, various aspects must be considered. Some of the considerations are only relevant if the storage is to be physically integrated and not solely theoretically evaluated for integration.

The main step in this procedure is the collection and analysis of process information. Following that, a storage concept can be evaluated, roughly planned and thereafter, the aspects of detailed engineering become relevant. Realistically, the concept and integration are evaluated in parallel.

For the process analysis, different types of information are necessary and/or beneficial. Sometimes, however, the optimum information is not available and secondary sources have to be used. The information sources discussed within the subtask are listed in Table 2-1.

Measured transient data
Average system values
Database information
Fuel use extrapolation
Piping and instrumentation diagram analysis
Commercial information
Extrapolation from CO_2 emissions
Company experts
Industry experts

Table 2-1: Information sources for process data.

The process analysis guidelines can be broken down into six steps:

- Step 1: Overall goal(s) for the thermal energy storage system integration
- Step 2: Define process and boundaries
- Step 3: Identify thermal sinks
- Step 4: Identify thermal sources
- Step 5: Quantify the sink and source
    - Step 5.1: Thermodynamics
    - Step 5.2: Physical properties
- Step 6: Analyze general factors
- Step 7: Summarize analysis

Step 1: Overall goal(s) for the thermal energy storage system integration

The overall goal for the thermal energy storage (TES) system integration needs to be identified. To some extent, the goal can first be determined through the analysis, especially in a retrofit system. In a greenfield design, it is possible that the goals can be more clearly quantified in advance. This is because the process may be designed for a certain number of solar hours of operation, for example, and all of the components will be designed for this. In a retrofit integration, it may only become clear through the process analysis how much more efficient a system can become, for example.

The overall goals could be the following, and there can be more than one goal for a TES system integration.

1. Lower cost of energy supply
   - Higher share of heat recovery
   - Off peak tariffs
   - Higher utilization of fluctuating lower cost fuels (solar, wind)
   - Peak limitation of supply (e.g. district heating)
   - Tax optimization
2. Lower environmental impact
   - Implementation of (more) renewable energy
   - Tax optimization
3. Higher productivity in the same production system
   - Handling bottlenecks (incl. boiler or heat pump capacity through peak shaving)
   - Quicker start up
   - More even load/supply
4. Lowering production loss
   - More stable process parameters
5. Maximizing value of energy (for heat suppliers)
   - Decoupling of time of heat production and heat delivery
   - Selling heat at peak time (= high price) / storing at low load hours (Peak saving)

<u>Questions</u>

1. What is the expected goal of the TES integration?
2. What are the required results in achieving this goal?

Step 2: Define process and boundaries

In order to analyze a process for storage integration, the process has to be defined or selected and the process boundaries for analysis clarified.

Process definition is a part of project preparation and/or research work, and typically entails a partner discussing process aspects with consultants or research institutions. If only parts of the process are analyzed, it helps to clarify this limitation regarding which parts of the process are analyzed.

In some cases the introduction of TES makes further process optimization possible by cooperation of other systems, e.g. boiler and heat pump. In a retrofit application, this may only become clear through the process analysis.

At this step, possible future changes of the process characteristics (both source and sink) have to be addressed, as the return on the investment in a TES can be highly affected by this (e.g. change of operating temperatures, duration, power level etc.).

Questions

1. What is the process or part of the process being analyzed? If only a part of the process is being considered, how does this part relate to the whole process?
2. Are future changes to the process, source and/or sink to be expected?

Step 3: Identify thermal sinks

As the impact of a TES is often to replace heat needed for the process, the first step is to identify the thermal sinks. Focus should be on the overall goals of thermal energy storage integration.

This identification can be done via discussion with (industry) specialists, analysis of piping and instrumentation diagrams, process database analysis, estimation via extrapolation of fuel usage or measurement. The integration of a TES should consider the opportunity of exploring external thermal sinks, i.e., providing heat to nearby processes.

This information should be gathered in two steps – an initial estimation to preliminarily determine the benefit of pursuing more detailed information, followed by the more detailed information itself. Some of this information may be confidential.

Typical sinks can be preheating or electricity generation and as such can be external to original process boundaries. Sinks collected within this subtask are listed in Table 2-2.

Organic Rankine cycle (ORC) Process
Steam turbine
Steam main
Heat pump
Process heat (direct integration)
Water main
Space heating
Upgraded heat at a higher temperature by heat transformation
Thermal Electric Generator
Environment (esp. cold storage)
Back to source

Table 2-2: Analyzed thermal energy sinks.

Questions

1. What thermal sink(s) was/were selected?
2. Why was/were this/these selected?
3. What sinks were considered?

Step 4: Identify thermal sources

As a second step, thermal sources have to be identified. This has to be done based on the chosen heat sink (especially temperature level) as well as overall integration goals and again can be done via discussion with (industry) specialists, analysis of piping and instrumentation diagrams, process database analysis, estimation via extrapolation of fuel usage or measurement.

This information should be gathered in two steps – an initial estimation to preliminarily determine the benefit of pursuing more detailed information, followed by the more detailed information itself. Some of this information may be confidential.

Typical sources can be waste heat or heat flows within the process. Sources collected within this subtask are listed in Table 2-3. If there is no heat source found within a process, there is no need for a storage system. However, when also considering Power-to-Heat systems, excess electricity can also be seen as a heat source.

Waste heat
Heat provided directly for charging – i.e. steam from heat recovery steam generator
Electricity
Direct combustion
Heat transfer fluid from solar field in concentrating solar power (CSP) plants
Heat transfer fluid from solar field for solar process heating / cooling
Cooling water / exhaust gas
Lake water, ambient air

Table 2-3: Analyzed thermal energy sources.

<u>Questions</u>

1. What sources were considered overall?
2. What thermal source(s) was/were selected?
3. For each source selected, why was it chosen?
4. Can the source be utilized directly, or is a temperature upgrade needed (e.g. heat pump, mixing, or electrical heating)?

Step 5: Quantify the sink and source

Sources and sinks must first be quantified in order to evaluate their potential applicability for TES integration. There are three major groups of parameters in this quantification – general factors, thermodynamics, and physical properties.

5.1. General factors

With the topic of general factors, an initial energy-based analysis can be completed, not yet regarding temperature levels and other critical thermodynamic properties. The factors that need to be analyzed here are the following, and the answers are possibly more qualitative in nature. In following sections, the answers would be more quantitative in nature.

- Availability: Are the sink and the source regularly available, is there a constant profile?
- Seasonal characteristics: Even for short-term storages, seasonal fluctuations in either source or sink may play a significant role in the supply or demand of energy.
- What overall energy level is available at the source? Is required at the sink?

Questions

1. Are the required or available thermal sources and sinks compatible? This refers to the temperature levels and quantities.
2. Do the sources and sinks have a comparable availability? This refers to profiles and intermittencies.
3. Are the sources or sinks dispatchable, i.e. manageable, in their profile?
4. Do either the source or the sink have seasonal characteristics?

5.2. Thermodynamics

Thermodynamic data can be analyzed independently of the physical factory or environment, though without consideration of the physical properties, a full analysis is not possible. Thermodynamic data are, however, most critical for the storage concept development.

The following distinctions are clarified for liquid energy sources. If electricity is used as the energy source, the transient supply characteristics must be determined. The other parameters detailed here are then only necessary for the sink.

a) Medium

The medium of the source or sink influences the heat transfer rate, piping, types of containment and materials used and applicable storage concepts. In some cases, an additional heat transfer fluid will need to be introduced into the system as a heat transfer medium. Media collected within this subtask are listed in Table 2-4.

Fluid	Source?	Sink?	Additional?
Thermal oil	X	X	X
Water (and water mixtures)	X	X	X
Air (Ambient)	X	X	X
Air (Flue gas)	X		
Steam	X	X	X
Molten salt	X	X	X
Molten metal	X	X	X
Refrigerants			X
Emulsions and slurries			X
Gases	X	X	X

Table 2-4: Heat transfer fluids

Questions

1. Which medium(s) is/are used as the thermal source?
2. Which medium(s) is/are used as the thermal sink?
3. Is there an internal loop involved, in which the heat transfer fluid is separated from the rest of the process and interacts via heat exchanger?

b) Temperature levels and dynamic profiles

The temperature levels and dynamic profiles of the source and/or the sink are key for the development of a thermal energy storage concept, its power level and its capacity (in combination with further characteristics). Information about the temperature level or temperature range can help establish the motivation and usefulness of storage integration. For detailed development, access to the dynamic temperature profiles is necessary.

If electricity is used as the energy source, then the transient profiles of this availability are necessary as well.

The mass flow rates and the dynamic character of the source and sink are critical for the power level and capacity determination.

The pressure, as well as the dynamic profile thereof, determines the phase of the heat transfer medium and therefore also the heat transfer characteristics. In addition, the material and containment aspects are directly affected by the pressure levels of the source, sink and possible intermediate heat transfer fluids.

For a better understanding of the depth of the information available, it is helpful to know if this information is available solely for this process analysis or is known for this specific process or this type of process.

Questions

1. How were temperature levels, dynamic profiles, mass flow rates, pressure levels determined?
2. Were measurements needed especially for this analysis or are these values known in the process anyway?

c) General Thermodynamics

The following questions regarding the heat transfer fluid, temperature gradients and cycle characteristics need to be clarified for the analysis of the given process for thermal energy storage integration.

Questions

1. Is the heat transfer fluid between the source and the sink the same?
    a. If yes – are the in the same phase state (liquid, gaseous)?
2. Are temperature gradients, profiles or levels currently used in the process adjustable in any way?
3. Are there any limitations in the thermodynamics for the sources or sinks, i.e. condensation or formation of toxins in specific temperature ranges?

In some systems, cycle length, as in the length of time energy is available for charging and needed for discharging a storage, and cycle frequency, as in the rate or interval during which a storage is cycled, are directly coupled to one another. In others, these characteristics are more independent of one another, depending on the source(s) and sink(s). There are also systems in which several sources or sinks are considered, resulting in a combination of cycle lengths and frequencies. If the sources and sinks operate independently, an evaluation of fully regular or irregular cycles is necessary – are full charging and discharging cycles likely, or is some kind of bypass and partial charge or discharge likely? The following questions address this potential combination of sources and sinks.

Questions

1. When the source and sink are connected via a storage system, what is the resulting cycle length? The cycle length here refers to the length of time energy is available for charging a storage and for discharging a storage if charging and discharging are conducted directly back-to-back. For example, in a CSP integration, consider 12h charge and 6h discharge: 18h cycle length.
2. Do multiple cycle lengths need to be considered (i.e. seasonal and daily)?
3. Are the source and sink operating in a regular or full cycle, and independently? This means:
    a. Are full discharging and charging cycles possible?
    b. Is the source sometimes available at the same time that the sink has a demand? This would require either a closed loop or bypass over a possible storage, two storages or some other system solution.
4. When the source and sink are connected via a storage system, do multiple cycle frequencies need to the considered? How often would charging and/or discharging of the storage occur, in theory? The cycle frequency in a continuously charging and discharging system is related to the cycle length. Taking the CSP storage above, the cycle frequency is 1/day.
5. When the source and sink are connected via a storage system, what is the maximum energy that can theoretically be transferred and/or saved?
6. What is the required response time of a storage system for charging? How quickly does a storage unit need to respond to charging requirements, in theory?

7. What is the required response time of a storage system for discharging? How quickly does a theoretical storage unit need to respond to discharging requirements?
8. Are charging/discharging times controlled by the system or result from less foreseeable factors?

5.3. Physical plant/process properties

Some processes are very large so that physical distance can be a critical factor. In very small processes or integrating a storage system in an existing site, the same can be true. When analyzing a mobile storage system, the source and sink may not even be in the same area. The physical distance between the source, the sink and a possible location for the storage system can therefore directly affect the feasibility of the integration.

Questions

1. What physical is space available for a storage system?
2. What physical distance and hindrances are between the source, sink and space for a storage system?
3. What integration infrastructure exists and what needs to be considered? This includes basics such as necessary foundations or fork-lifts to various control technologies.
4. Can the storage be integrated without affecting the regular operation of the process?
5. Do regularly scheduled shut-down times (e.g. Cleaning In Place, CIP) need to be incorporated into the planning?

Step 6: Analyze overarching factors

In this step, the overall process is considered. These questions and their answers are related to the process and process type, regardless of the storage system that may or may not be developed for integration. These questions are somewhat related to the research nature of the integration of storage units and the continuing development and changes in the policies and economics in different countries regarding energy efficiency. The questions can be grouped into two basic categories: company/type and legal/specific.

Company/process type questions:

1. How often does this process exist? With these conditions?
2. What is the life cycle/-span of the analyzed process? Here, the life cycle or life span denotes how long the process is expected to exist for. Have possible future changes/adjustments to the process parameters been considered?
3. Are company goals related to the following being pursued?
   a. CO_2 reductions?
   b. Greenwashing?
   c. Policy changes?
   d. Energy reliability or flexibility?

Specific/legal questions

1. Would the storage be integral to the process? Here, integral means: can the storage be 'turned off' and the system still operates? → If yes, the storage is not integral. If no, and the storage is fully a serial part of the process, then yes.
2. What developmental grade of research is acceptable (TRL level for the suggested TES)?
3. What environmental/health restrictions exist at the site or in the process? These can relate to safety issues such as legionnaires or dioxins specific to the process or to factors such as critical permits regarding noise or emissions during commissioning.
4. What rules and regulations need to be adhered to?

Economics

1. Are there tax considerations that need to be taken into account?
2. Is there a clearly defined economic goal that needs to be met?

Step 7: Summarize analysis

In this step, the guideline summarizes the answers with some basic questions.

Questions

1. Can the expected goal of the TES integration, determined in Step 1, be met?
2. Are the required results determined in Step 1 feasible?
3. Is this process considered suitable for a TES in general?
    a. If yes, why? If no, why not?
4. If yes: Are there clear indications which storage concepts or types are better suited to the process? Why?
5. If yes: Are there clear indications which storage concepts or types are NOT suited to the process? Why? What is the process or part of the process being analyzed?
6. Will integrating a TES system make new improvements by cooperation of other systems possible? In greenfield applications, the answer to this question may be more clear than in retrofit applications.