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THE ROLE OF THERMAL ENERGY STORAGE IN INDUSTRIAL ENERGY CONSERVATION

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ABSTRACT

Thermal Energy Storage for Industrial Applications is a major thrust of the Department of Energy's Thermal Energy Storage Program. Utilizing Thermal Energy Storage (TES) with process or reject heat recovery systems has been shown to be extremely beneficial for several applications. Recent system studies resulting from contracts awarded by the Department of Energy (DOE) have identified four especially significant industries where TES appears attractive - food processing, paper and pulp, iron and steel, and cement. Potential annual fuel savings with large scale implementation of near term TES systems for these industries is over 9 x 10^6 bbl of oil. This savings is due to recuperation and storage in the food processing industry, direct fuel substitution in the paper and pulp industry and reduction in electric utility peak fuel use through in-plant production of electricity from utilization of reject heat in the steel and cement industries.

INTRODUCTION

One of the many responsibilities of the Department of Energy (DOE) is administering the Voluntary Business Energy Conservation Program. This program, under the guidelines of the 1975 Energy Policy and Conservation Act, requires major energy consuming firms within industries for which energy efficiency improvement targets have been set to report directly to DOE on their energy efficiency. The fact that industrial production uses about 40% of the total energy consumed in the United States indicates the tremendous potential that exists for significant energy savings through a concerted effort by all concerned.

Significant conservation benefits and the substitution of domestic fuels for petroleum and natural gas are possible through the use of thermal energy storage of industrial process and reject heat for subsequent in-plant use. Recognizing the increased importance of waste heat recovery and use, the former Energy Research and Development Administration (ERDA) funded a study to determine the economic and technical feasibility of thermal energy storage (TES) in conjunction with waste heat recovery (1). This study was directed toward identifying industrial processes characterized by fluctuating energy availability and/or demand, a key criterion for TES applicability.

At least 20 industries were identified as areas where thermal energy storage had potential application to some degree. Responses to a Program Research and Development Announcement (PRDA) issued by ERDA shortly after the conclusion of the feasibility study program resulted in contract awards by DOE's Division of Energy Storage Systems to study four industries with potential significant energy savings through the use of TES systems. These industries were paper and pulp, food processing, iron and steel, and cement. Major emphasis was given to TES systems and applications that have potential for early commercialization within each specific industry.

PAPER AND PULP

The forest products industry, as a whole, is one of the largest users of fossil fuels for in-plant process steam generation. Boeing Engineering and Construction, with team members Weyerhaeuser Corp. and SRI International, investigated the application of process heat storage and recovery in the paper and pulp industry (2). For this investigation, Weyerhaeuser's paper and pulp mill at Longview, Washington was selected to assess the potential energy savings and to evaluate the effectiveness of thermal energy storage in achieving these savings.

The paper and pulp operation at Longview consists of process systems and a power plant which supplies steam to the processes and the power generation turbines. Figure 1 shows schematically the energy supply characteristics without energy storage. The recovery (liquor-kraft black and sulfite from conventional chemical and wood pulping) and waste (hog fuel-wood waste produced by the various machining processes) boilers provide a base load of steam generation while the oil/gas boilers provide the time dependent load. The primary goal of using thermal energy storage at Longview (and similar paper and pulp mills throughout the industry) is to substitute usage of more hog fuel for the oil/gas fossil fuels.

The inability to follow rapidly changing steam demands with hog fuel boilers requires the reduction of hog fuel firing in favor of increased fossil fuel firing. However, this can be overcome by the use of thermal energy storage. The hog fuel boiler would be operated at a higher base load, the excess steam would be stored when the demand is low, and storage would be discharged when the demand is high. The economics of steam swing smoothing in the paper and pulp industry depends on the capacity of the swing smoothing system and the number of hours per year the system will allow hog fuel substitution for fossil fuel.

Daily operational data from the Longview plant was used to evaluate the effectiveness of thermal energy storage. This plant was considered representative of paper and pulp mills where the potential exists for the economic use of thermal energy storage. The analyses using this typical mill data indicated that for a system as shown on Figure 2, a storage time of about 0.5 hour with a steaming rate capacity of 100,000 lb/hr would result in 60,000 lb/hr of steam load transfer from fossil fuel boilers to the hog fuel boiler. This corresponds to about 50% reduction in fossil fuel consumption for load following.

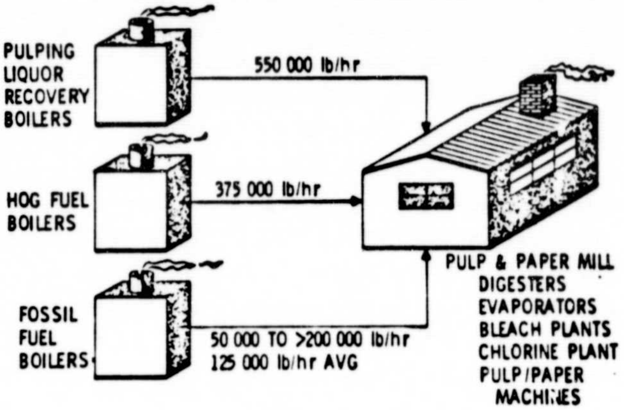

Figure 1. - Paper and Pulp Energy Supply Characteristics

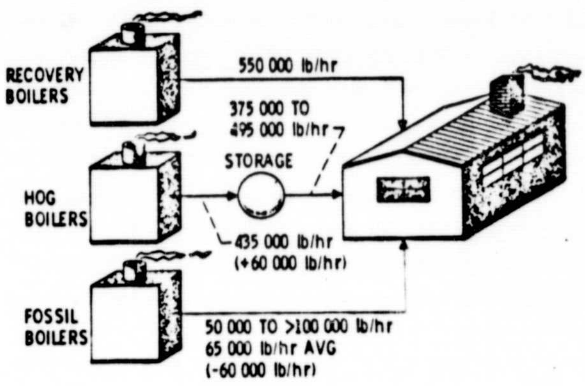

Figure 2. - Energy Supply with Thermal Energy Storage

Initial sizing and cost estimates for storage system concepts were generated for a range of steaming rates and storage times. The results indicated that for storage times less than one hour, direct storage of steam using steam accumulators was more economically attractive than indirect sensible heat storage using media such as rock/oil or rock/glycol combinations. Steam accumulators store steam by transferring the latent heat of vaporization to water and can be either variable pressure or constant pressure type.

Figure 3 shows the variable pressure accumulator TES concept. Steam used for charging storage from either the high pressure or intermediate pressure header bubbles through the saturated water contained under pressure in the vessel. The steam condenses and transfers energy to the water, raising the water's temperature and pressure. Upon discharging to the low pressure header, the vapor pressure above the water surface is reduced causing the water to evaporate, supplying steam but lowering the water's temperature and pressure.

Figure 4 shows the constant pressure accumulator TES concept. Again, steam for charging storage can come from either the high pressure or low pressure header. The accumulator is charged during low demand periods by preheating in the deaerating heater more feedwater than required for boiler feed. This excess preheated water is then stored in the accumulator vessel at constant temperature and pressure. During periods of peak steam demand, feedwater heating is slowed or stopped, most or all of the boiler steam is used to meet the increased process load, and boiler feed is maintained from the preheated water stored in the accumulator.

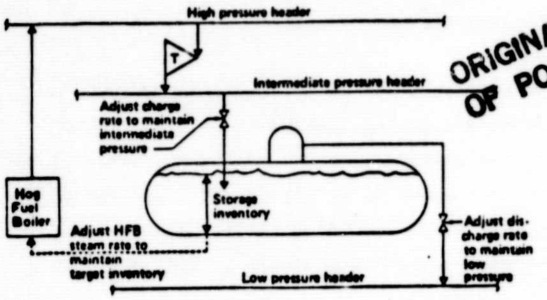

Figure 3. - Variable Pressure Accumulator Concept

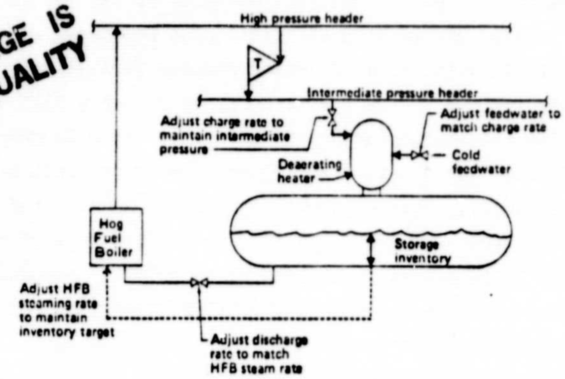

Figure 4. - Constant Pressure Accumulator Concept

Oil savings estimated for the Longview plant is 100,000 bbl/yr based on the transfer of 60,000 lb/hr of steam load from the fossil fuel boilers to the hog fuel boiler. A survey performed using data supplied by the American Paper Institute indicated that there are 30 candidate mills that either have now or will have by 1980, operating characteristics similar to the Longview plant. Therefore, potential near-term (1985) fossil fuel savings are projected as being 3×10^6 bbl/yr.

Energy resource and environmental impact studies completed by SRI International indicate potential long-term (2000) fuel savings of 18×10^6 bbl/yr based on a 10% shift in steam generation from gas and oil to hog fuel and coal due to TES use. This also takes into account the additional cogeneration accompanying this shift and the resultant decrease in purchased electricity.

Preliminary economic evaluation shows a potential annual return on investment (ROI) for this TES system in excess of 30% over a 15-year return and depreciation period. The conceptual system using a steam accumulator appears technically and economically feasible. Results of this study showed that installation at full scale in one of the candidate mills utilizing commercially available equipment could be accomplished within a two-year time period for a cost of less than one million dollars.

A decision was made to proceed with a technology demonstration in an operating paper and pulp mill. This decision was based on the following factors: (1) technical feasibility; (2) economic feasibility; (3) significant conservation benefits; (4) early commercialization potential; (5) high benefits to R&D costs ratio; and (6) a visible, low-risk activity to demonstrate the near-term actual conservation and cost benefits.

In the course of finalizing the plans for this demonstration investigations uncovered a pulp mill that was using a recently installed constant pressure accumulator for steam demand smoothing. To date details of this system have not been publicly available. Current plans are to obtain information on the operation of this TES system, evaluate the benefits of this system, compare results with results of the previous system study, and disseminate the information to the paper and pulp industry. Included in this dissemination will be similar information obtained from international mills. There are mills operating in both Finland and Sweden with steam accumulators. However, there is also no readily available information on the operation of these systems.

The anticipated net result of disseminating the information after it is obtained and evaluated will be to stimulate the rest of the industry to utilize this information. Where applicable, it is hoped that enough TES systems will be installed to appreciably effect the energy conservation program in the paper and pulp industry.

FOOD PROCESSING

The food processing industry is a major user of low-temperature (below 250°F) process heat. It is estimated that 85% of the fuel utilized by the industry produces process steam and hot water for cooking, sterilizing, and washing and sanitizing equipment and work areas. Westinghouse Electric Corporation in cooperation with the H. J. Heinz Company (USA Division) investigated the use of waste heat recovery and storage systems in the food processing industry (3).

The Pittsburgh Factory of the H. J. Heinz Company was made available for analysis of the various food processing operations. The factory's main products are baby foods and juices, canned soups, and canned bean products. Thermal energy is applied to the product during the cooking process and leaves primarily as hot water down the drain system. The main method of heating process water is by the direct injection of steam. Since process water is not recycled to eliminate the possibility of product contamination, condensate losses are high and must be matched by make-up. Therefore, preheating make-up water would be one excellent use of waste heat resulting in direct conservation of energy.

Figures 5, 6, and 7 are schematics of typical operations that were analyzed for waste heat availability. As shown in Figure 5, empty cans are washed by hot water sprays (generally 170-190°F) as they approach the filling system and are washed again after filling and sealing. Figure 6 shows the continuous cooker/cooling operation. As the product enters the cooker its contact with the steam atmosphere raises the product temperature to approximately 240°F which is required for cooking and sterilization. The cooling process is accomplished in two stages during which the cooler pressure is controlled to prevent can deformation. Figure 7 shows the continuous cooler process whereby hot products are cooled as they exit the canning operation. Heat is transferred from the moving product to a counter-flowing stream of cooling water. Typical waste water temperatures and flow rates are noted on each figure.

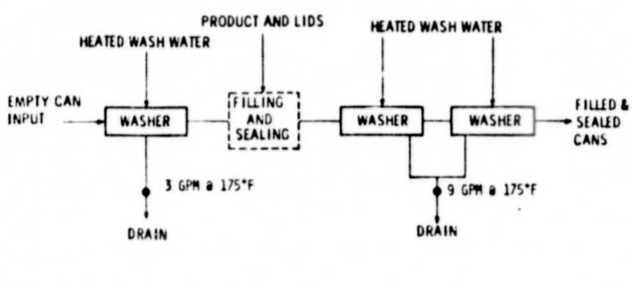

Figure 5. - Can Washer Schematic

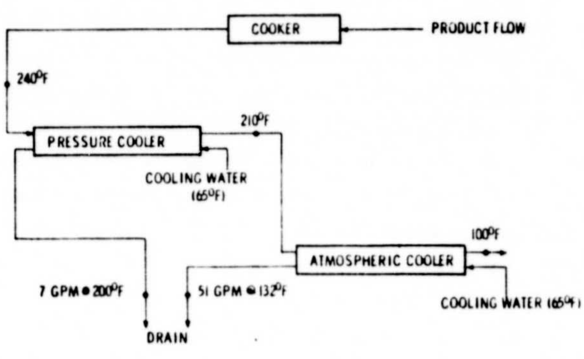

Figure 6. - Continuous Cooker/Cooler for Canned Food Products

Table 1 lists the results of the waste water survey for the Pittsburgh Factory. The available waste water sources can be separated into high temperature streams (above 140°F) and low temperature streams (below 140°F). Figure 8 is a schematic depicting the utilization proposed for these two streams. The low temperature stream can be used recuperatively through conventional heat exchange with the incoming process water. The high temperature stream can also be used in the same manner. However, when the process demands diminish while hot waste water is still available, the heated fresh water is diverted to storage. Using high temperature waste water to achieve the highest possible water storage temperature has been shown to minimize the storage cost/benefit ratio.

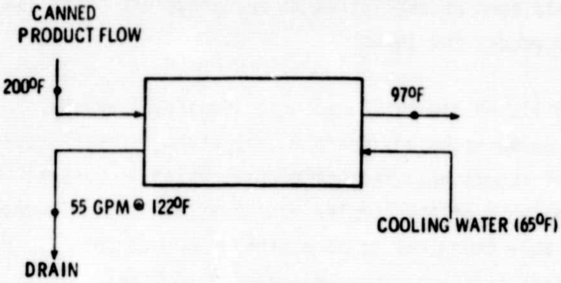

Figure 7. - Continuous Cooler Schematic

Table 1. - Waste Water Summary - Pittsburgh Factory

	Average Flow Rate & Temperature First Shift	Second Shift
Power Building		
Continuous Cooker/Coolers	120 gpm - 140°F	60 gpm - 140°F
Can Washers	37 gpm - 175°F	12 gpm - 175°F
Meat Products Building		
Horizontal Stationary Retorts (Glass Products)	316 gpm - 140°F	316 gpm - 140°F
Can Washers	25 gpm - 175°F	12 gpm - 175°F
Bottle Washers	7 gpm - 175°F	7 gpm - 175°F
Continuous Pasteurizer	80 gpm - 170°F	80 gpm - 170°F
Bean Building		
Can Washers	25 gpm - 175°F	12 gpm - 175°F
Continuous Coolers	110 gpm - 120°F	55 gpm - 120°F
Total Flow Rate & Average Temperature	720 gpm - 145°F	554 gpm - 145°F

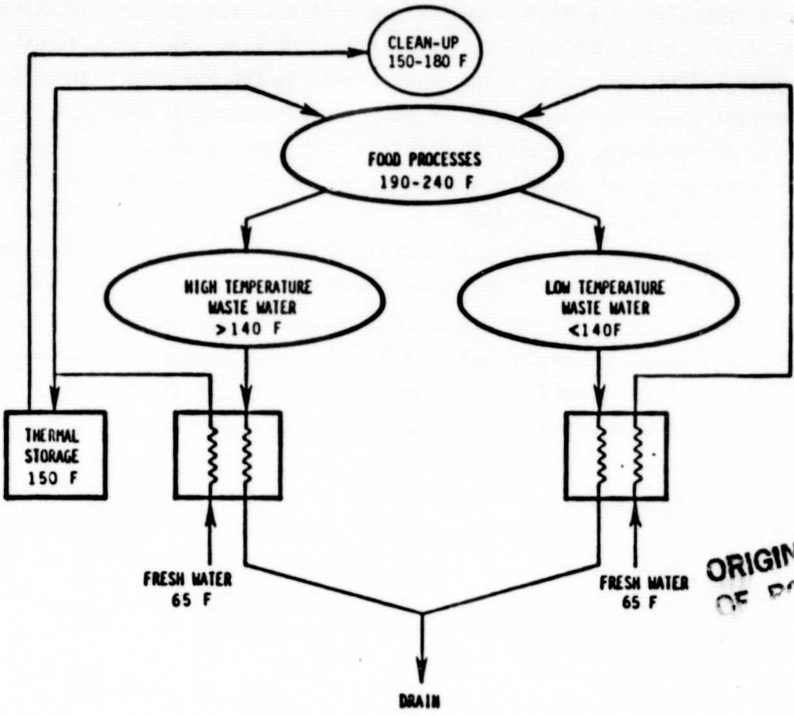

Figure 8. - Food Processing Plant Energy Recovery and Storage System

Water that accumulates in storage during the production period (first and second shifts) would then be used during the third shift for clean-up purposes. The plant's major clean-up effort is performed during the third shift when production hardware is disassembled and washed or cleaned in place. Recovery of approximately 7×10^{10} Btu annually is projected for the Pittsburgh Factory utilizing a system similar to that of Figure 8. This would result in reducing factory energy consumption by 5 to 6%. The projected dollar savings would return the estimated capital investment at the rate of 35% per year. Projected annual fuel savings for the food processing industry is approximately 0.8×10^6 bbl of oil.

It was concluded that for the Pittsburgh Factory waste heat recovery from selected food processes is feasible and can be performed economically using available, off-the-shelf hardware. Therefore, a decision was made to proceed with a technology demonstration at the Pittsburgh Factory based on the same factors as stated for the paper and pulp mill demonstration. This demonstration will be used to evaluate actual hardware performance, to optimize system design, and to determine actual costs and benefits resulting from the waste heat recovery and storage system. The results will then be publicized to encourage the installation of similar waste heat recovery systems within the food processing industry.

IRON AND STEEL

The primary iron and steel industry accounts for about 11% of the total national industrial energy usage. Rocket Research, with team members Bethlehem Steel Corporation and Seattle City Light, investigated the use of thermal energy storage with recovery and reuse of reject heat from steel processing in general and electric arc steel plants specifically (4). Thermal analysis of the complex heat availability patterns from steel plants indicates significant potentially recoverable energy at temperatures of 600 to 2800°F.

A detailed assessment for Bethlehem's Seattle scrap metal refining plant was made of the energy sources, energy end uses, thermal energy storage systems, and system flow arrangements. This plant is typical of electric arc furnace installations throughout the United States, allowing results of this site-specific study to be extrapolated to a national basis.

The hot gas in the primary fume evacuation system from a pair of electric arc steel remelting furnaces was selected as the best reject heat energy source. Presently, the dust laden fume stream is water quenched and then ducted to the dust collection system prior to discharge to the atmosphere as shown in Figure 9.

The new flow arrangement shown in Figure 10 would have the unquenched fume stream flowing through the energy storage media prior to discharge. The solid sensible heat storage media would have to be able to withstand the hot gas temperature which could be as high as 3000°F while averaging about 1750°F. Potential materials are refractory brick, slag or scrap steel.

Two energy storage beds are required. The operational storage bed serves to time average the widely fluctuating temperature of the energy source. The peaking storage bed serves to hold energy until the demand arises. During charging, all of the furnace-gas discharge flow goes through both storage beds and is exhausted through the baghouse, the dust collection system. During peak demand periods, the combined streams from the furnace (through the operational storage) and the peaking storage (in a reversed flow direction) would flow through the heat exchanger as shown in Figure 11.

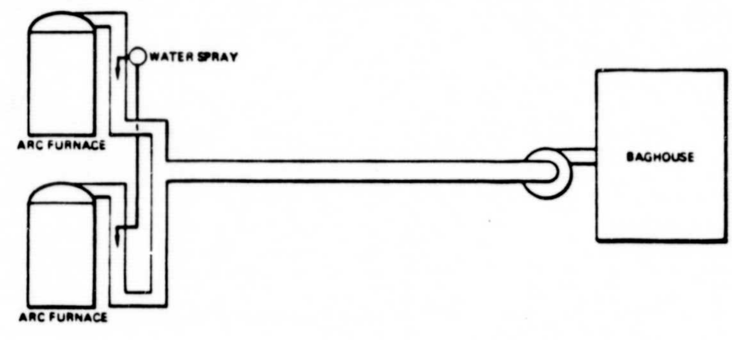

Figure 9. - Electric Arc Furnace Fume Evacuation System

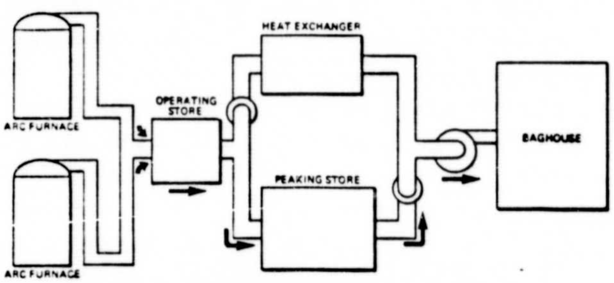

Figure 10. - Charging Arc Furnace Energy Storage System

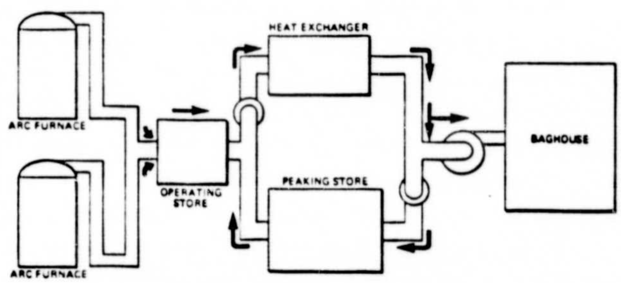

Figure 11. - Discharging Arc Furnace Energy Storage System

Figure 12 shows the entire energy recovery and storage system. The combined streams within the heat exchanger create steam to drive the turbogenerator. Upon initial discharge of the peaking store, ambient air is drawn in through the lower fan/valve arrangement. When the required flow rate through the peaking bed is established, the ambient air valve is closed. At the exit of the heat exchanger, gas flow is divided, with a portion going to the baghouse and the rest providing the peaking storage discharge gas stream.

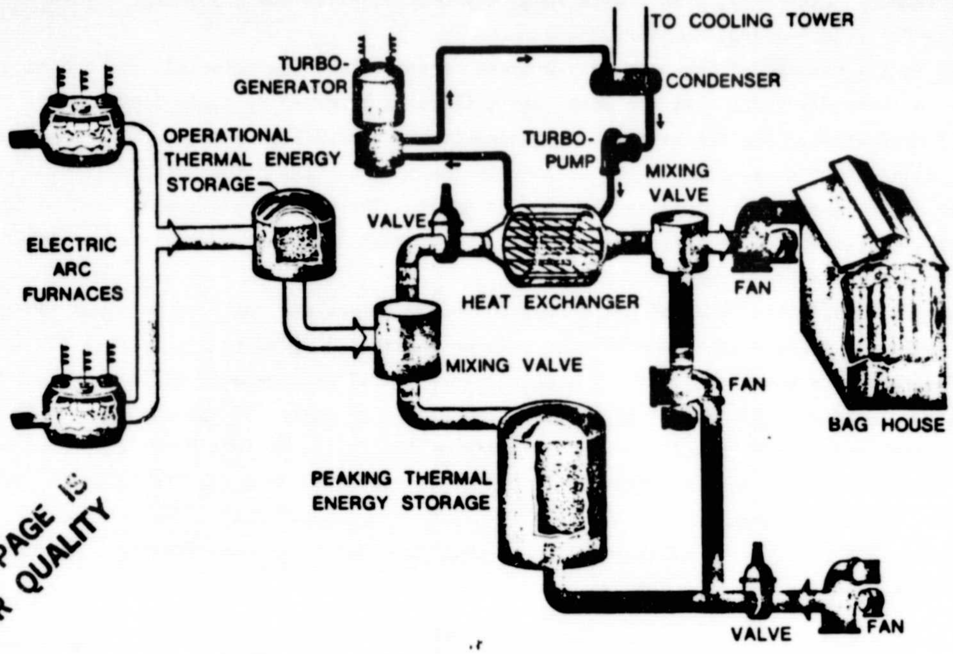

Figure 12. - Steel Arc Furnace Energy Recovery and Storage System

To complement the assessment, Seattle City Light provided data on electricity costs. The economic benefits to be derived from the use of energy storage to provide peak power generation is a direct function of either a demand charge, time of day pricing, or a combination of both. The conceptual system proposed for the Bethlehem plant would result in a payback period of about five years depending on the combination of electricity costs and size of the power generation equipment. For example, a system providing a four-hour peak storage capability and generating 7MW of peak demand electricity would result in a five-year payback period if it were displacing peak power at a cost of 10¢/kwh.

Assuming fossil fuel is required to produce peak power, annual oil savings attributed to TES at a plant with a daily production of 1200 tons for 300 days/yr would be about 16,000 bbl. The potential electric arc steel industry annual oil savings could approach 2×10^6 bbl based on a projected annual production of 50×10^6 tons by 1985.

The TES concept development in this study yielded favorable predictions of fossil fuel displacement and investment returns. However, the approach isn't ready to be applied directly to a full scale demonstration without an interim concept development period. Experimental scale studies of large, granular masses in the high temperature region (up to 1500°F) are required. Data from these studies would provide design criteria needed to verify analytical models for high temperature applications. The effect of the particulates in the furnace exhaust stream on the heat storage media must also be determined and resolved if detrimental. Successful completion of such a development phase could lead to a small scale demonstration followed by a full-scale system demonstration in an operating electric arc steel plant. Such a program would take about 8 years and cost between 5 and 10 million dollars.

CEMENT

The cement industry is the sixth largest user of energy in the United States. Eighty percent of the energy used is consumed as fuel for the kiln operation. Martin Marietta Aerospace, with team members Martin Marietta Cement and the Portland Cement Association, investigated the use of thermal energy storage in conjunction with reject heat usage in the cement industry (5). Thermal performance and economic analyses were performed on candidate storage systems for four typical cement plants representing various methods of manufacturing cement. Basically, plants with long, dry-process kilns and grate-type clinker coolers offer the best choice for reject energy recovery.

Figure 13 is a schematic of the long, dry-process cement kiln. Raw materials are ground, mixed and fed into the kiln in their dry state. At the other end a flame is produced by controlled burning of coal, oil or gas under forced draft. The raw material is heated to about 2700°F in a huge cylindrical steel, brick-lined, rotary kiln. As the raw material moves through the kiln counter current to the flow of hot combustion gas, some elements are driven off in the form of gases. The remaining elements combine to form the cement clinkers, grayish-black pellets about the size of marbles. The hot clinkers are discharged from the kiln and cooled to a manageable temperature.

An assessment of potential uses of the recovered energy determined that the best use for it would be in a waste heat boiler to produce steam for driving a turbogenerator to produce electricity for in-process use as shown in Figure 14. Approximately 75% of a plant's electrical requirements could be met with on-site power generation. However, this reject heat source for the steam boiler is not available when the kiln is down for maintenance of either the clinker cooler grate or the kiln. At this time, the power demand for other cement plant operations must be obtained from a utility. This would require demanding large amounts of utility power for short periods of time, e.g. 5 to 10 MW for 2 to 24 hours. The cost to the plant in peak power rates and to the utility in maintaining excess peaking capacity is significant. The other alternative is to curtail other plant operations such as raw or finish milling.

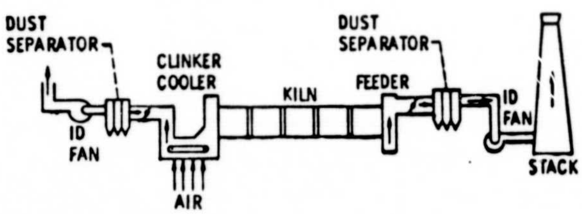

Figure 13. - Long, Dry-Process Cement Kiln

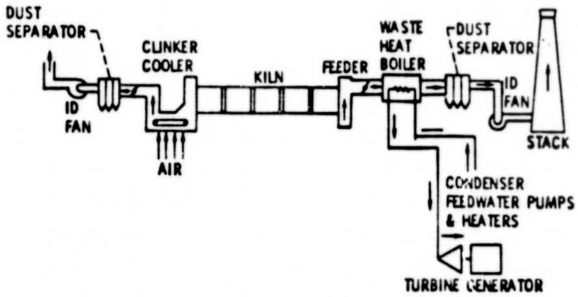

Figure 14. - Cement Kiln with Waste Heat Boiler

This problem could be alleviated by using thermal energy storage to reduce the utility load demand. By charging the storage unit while the kiln is operating, the stored thermal energy would be available when the kiln is down. The storage concept proposed in conjunction with dry-process kilns uses a solid sensible heat storage material such as magnesia brick, granite, limestone, or even cement clinker. The storage system would use two separate thermal stores as shown in Figure 15. One would store high temperature (1500°F) reject heat from the kiln exit gas. The other would store low temperature (450°F) heat from the clinker cooler excess air. These two separate storages would be charged independently but discharged in series.

As shown in Figure 16, ambient air would be passed through the low temperature TES units and heated to about 400°F. It would then be heated to about 1200°F while passing through the high temperature TES units. The heated air would then flow through the waste heat boiler and generate steam to produce electricity.

Storage system sizing for typical cement plants indicates that provision for 24 hours of power production at about 10 MW would be a beneficial size in relation to normal plant operation. During kiln operation 80-90% of the kiln exit gas would go directly to the waste heat boiler to produce electricity while the rest would pass through the high temperature storage unit. Therefore, it would take roughly one week to charge the system to its full 24 hour withdrawal capacity.

An economic evaluation of the system indicates that a 10 MW waste heat boiler/power plant/TES installation would cost about 10 million dollars. A 90% ROI was calculated for a 30-yr system life and an average energy cost of 2.8¢/kwh. About 15% of this ROI can be attributed to the TES system. Again, assuming fossil fuel is originally required to produce this waste-heat derived power, a potential energy savings of about 4×10^6 bbl of oil per year is projected. This is based on utilizing the cement industry's current installations of about 120 long dry kilns.

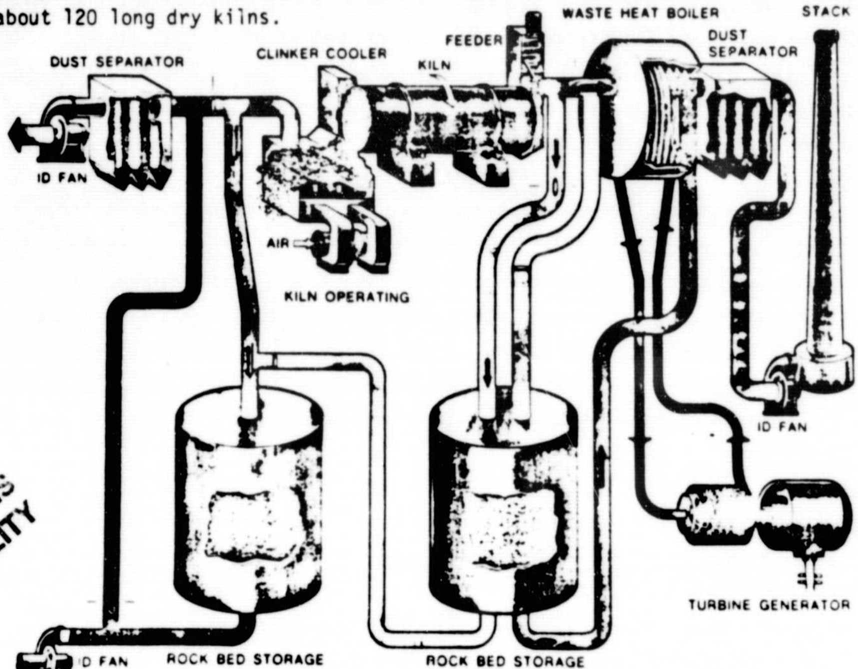

Figure 15. - Charging Cement Plant Energy Recovery and Storage System

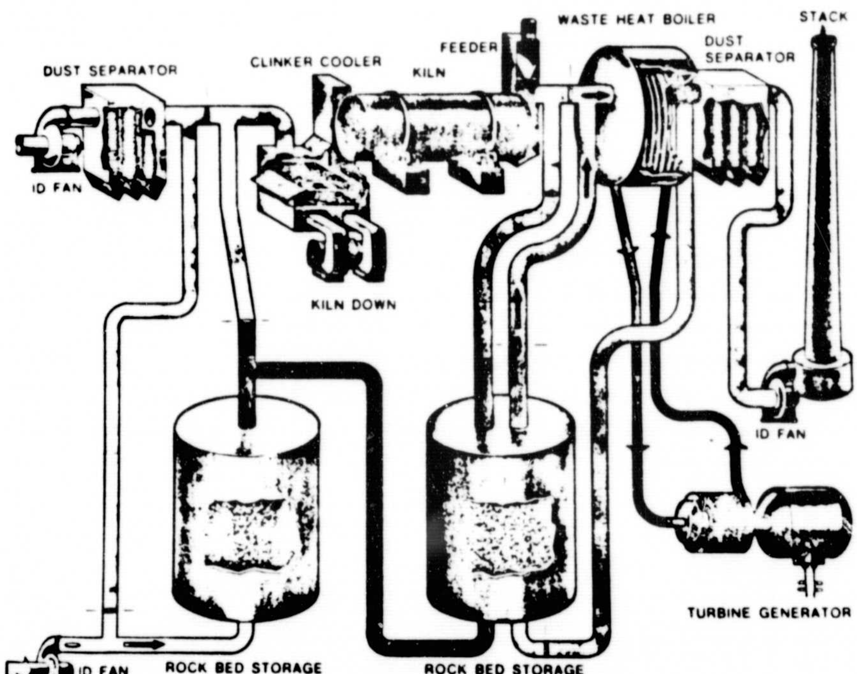

Figure 16. - Discharging Cement Plant Energy Recovery and Storage System

There is a similarity between the cement plant and steel plant systems. The necessity for a phased technology development and validation program through full scale demonstration also exists for the cement plant system. Estimates of 8 years and 5 to 10 million dollars appear to be valid for such a program.

SUMMARY

From the response to ERDA's FY 77 Industrial Applications PRDA, four attractive industries which could utilize thermal energy storage were selected for study. These industries are paper and pulp, food processing, iron and steel, and cement which together account for about 33% of the total national industrial energy usage. Potential annual fuel savings with large scale implementation of near-term thermal energy storage systems for these industries is over 9 x 10^6 bbl of oil. This savings is due to direct fuel substitution in the paper and pulp industry, recuperation and storage in the food processing industry, and reduction in electrical utility peak fuel use through in-plant production of electricity from utilization of reject heat in the steel and cement industries.

CONCLUDING REMARKS

The ultimate objective of the effort summarized in this paper is the demonstration of cost-effective thermal energy storage systems capable of contributing significantly to energy conservation. The results of these studies indicate that attractive opportunities for thermal energy storage applications exist within the paper and pulp, food processing, iron and steel, and cement industries. Within these industries thermal energy storage of process and reject heat for subsequent in-plant use appears to be economically and technically feasible with significant near-term conservation benefits. The system applications have a sufficiently attractive return-on-investment to encourage wide-spread implementation once the technologies are developed and demonstrated.

The applications identified by these studies fall into three categories: (1) existing operational thermal energy storage system applications for which detailed information has not been made public; (2) promising system applications that involve current technology, require no development, and are ready for immediate technology demonstration to stimulate commercial introduction; and (3) promising system applications that require development prior to a large scale industrial technology demonstration.

A program for the transfer of technology to the paper and pulp industry is in progress. A program for the demonstration of a thermal energy storage system in a food processing plant is also in progress. An additional program that consists of component development followed by technology demonstrations in selected industries is being formulated. All of these programs are funded by the DOE Division of Energy Storage Systems.

REFERENCES

1. Glenn, D. R.: Technical and Economic Feasibility of Thermal Energy Storage. General Electric Co., (COO-2258-1), 1976.
2. Carr, J. H.: Application of Thermal Energy Storage to Process Heat Storage and Recovery in the Paper and Pulp Industry. Boeing Engineering and Construction (CONS/5082-1), 1978.
3. Lundberg, W. L.; and Christenson, J. A.: Applications of Thermal Energy Storage to Waste Heat Recovery in the Food Processing Industry. Westinghouse Electric Corporation (CONS/5002-1), 1979.
4. Katter, L. B.; and Peterson, D. J.: Applications of Thermal Energy Storage to Process Heat and Waste Heat Recovery in the Iron and Steel Industry. Rocket Research Co. (CONS/5081-1), 1978.
5. Jaeger, F. M.; Beshore, D. G.; Miller, F. M.; and Gartner, E. M.: Applications of Thermal Energy Storage in the Cement Industry. Martin Marietta Aerospace (CONS/5084-1), 1978.