WASTE HEAT RECOVERY IN THE FOOD PROCESSING INDUSTRY

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ABSTRACT

A project is described which evaluated the potential for waste heat recovery in the food processing industry. The work was performed by Westinghouse Electric Corporation under a Department of Energy contract and with the cooperation of the H. J. Heinz Company. In particular, applications of thermal storage were sought. However, the project was not restricted to those applications, and attention was also given to satisfying immediate energy needs with recovered waste heat. The primary purpose of the work was the study of waste heat recovery systems and methods that could have a significant impact upon the nation's energy consumption if the food industry applied them on a large-scale basis. The paper discusses the technical aspects of potential waste heat recovery systems and the economics of installing them at selected survey factories.

INTRODUCTION

Westinghouse recently completed a nine month study project to assess the potential for economical waste heat recovery in the food industry and to evaluate prospective waste heat recovery systems. The project was funded by the U.S. Department of Energy (DOE) and was conducted by Westinghouse with the cooperation of the H. J. Heinz Company. Heinz arranged access to two of their manufacturing plants within the Heinz U.S.A. Division and permitted Westinghouse personnel to analyze factory and food system operations. At each factory, a waste heat availability study was performed and the resulting data were then applied as the basis for recovery system conceptual design. The system studies focused on thermal performance and economic evaluations and in this paper, the results of that effort and project conclusions regarding feasibility are presented.

SURVEY SITES AND SELECTION RATIONALE

The Heinz U.S.A. Division operates eleven factories engaged in a variety of thermal food processes. Two of those factories, located in Pittsburgh and Lake City, Pennsylvania, were selected as survey sites for our project. The Pittsburgh Factory is a large multi-building facility employing over 2,000 production people and specializing in foods processed with steam and hot water. The factory's main products are baby foods and juices, canned soups and canned bean products. At the Lake City Factory, approximately 150 employees are engaged in the preparation of dessert products that are quick-frozen as the last step in the process. Lake City operations are conducted in a modern, single-story building having a total floor area of approximately 70,000 ft^2.

The products manufactured by the Pittsburgh Factory place it in the Canned Specialties (SIC 2032) industry but the processes used are also common to Canned Fruits and Vegetables (SIC 2033) as well. Similarly, the Lake City products would place that factory, strictly speaking, within the Ice Cream and Frozen Desserts (SIC 2024) industry. However, similar food processes are also employed in the Frozen Specialties (SIC 2038) and Frozen Foods and Vegetables (SIC 2037) industries. Based upon food industry data, the annual energy consumption by these five industries (SIC 2032, 2033, 2024, 2038, and 2037), which are represented by our Pittsburgh and Lake City survey sites, totals to nearly 120 x 10^{12} Btu (Canned to Frozen Ratio ~60/40) and accounts for 13% of the total food industry (SIC 20) energy usage. If waste heat recovery systems were implemented to reduce energy consumption in those five industries by 10%, the annual savings, nation-wide, would amount to 0.012 quad or approximately 1.3% of the current SIC 20 usage. This potential industry impact is significant and therefore it appeared that survey and conceptual system design work at the Pittsburgh and Lake City Factories would be very worthwhile. This was the main reason for selecting those particular factories for use as survey sites.

WASTE HEAT AVAILABILITY

At each factory, operations were analyzed and waste heat production rates were estimated. At the Pittsburgh Factory, hot waste water is the main waste heat source and the estimates were based, in the case of several contributing systems, upon actual measurements of waste water flow rates and temperatures. Where only temperatures could be conveniently measured, the flow rates were estimated by applying the temperature data and known values of product temperatures and flow rates to a system energy balance. In several cases, neither waste water flow nor temperature could be determined conveniently and in those situations, the systems were modeled mathematically to produce estimates of the required parameters.

At the Lake City Factory, the refrigeration system condensers represent the waste heat source of most interest during this project. For conceptual system design purposes, average refrigerant flow rates and condenser heat dissipation rates were predicted based upon estimated compressor electrical loads and assumed refrigerant cycle state points. In this section, the food processing systems at the two survey sites are described and the results of the waste heat availability study at each site are summarized.

Pittsburgh Factory

The Pittsburgh Factory operates several food systems that produce hot waste water. To eliminate the possibility of product contamination, waste water from the processes is not recycled nor is waste heat recovery attempted. Instead, the waste water streams are collected by a drain system that transports them from the factory via clear water and sanitary sewer systems. The various waste water sources evaluated at the Pittsburgh Factory and waste water conditions for individual units are identified in Table 1. To assess the total waste heat availability, the unit data from Table 1 were combined with operational data (cycles per shift, cycle times. number of units in operation, etc.) supplied by Heinz U.S.A. The resulting information was compiled by shift and on a building-by-building basis and is summarized in Table 2. The table entries apply to those systems selected for waste heat recovery. Systems not represented in Table 2 were neglected due to low temperature and/or low volume reasons and to high fouling potential in the case of the blowdown heat source.

Lake City Factory

The Lake City Factory has two major refrigeration requirements - blast freezing and cold storage. Pie and cake products complete the preparation process on a conveyor line that transports them through a blast freezer maintained at -35 °F. When they exit the freezer in 20-40 minutes, the frozen products are placed in a storage freezer (-5 °F) to await shipment. The refrigeration effect for both freezers is provided by an ammonia system driven by ten rotary and reciprocating compressors. On the discharge side of the compressors, the refrigeration system is arranged in two separate parts. Eight compressors (five blast freezer, two storage and one ice bank unit)* discharge to six manifolded condensers while the two remaining compressors (Group 2) are staged units that serve a storage freezer and discharge to their own condenser. Since blast freezer operation only occurs during the one or two production shifts of each day, waste heat rejection at the first condenser group peaks during those shifts and declines to a minimum (imposed by the ice bank and storage load) during the night time hours. Heat rejection at the independent condenser, however, is more uniform over the entire day due to its storage function. The point of this discussion is that two independent sources of refrigeration waste heat exist at the factory that behave differently with time. Therefore, they could be linked with two independent waste heat applications whose energy demands also follow different time patterns.

At the compressor discharge, the assumed ammonia vapor conditions were 185 °F at 150 psia. An average refrigerant flow rate for each compressor was calculated based upon factory electrical data, compressor on-time estimates and nameplate horsepower, assumed state-points and a compressor mechanical efficiency of 0.85. The resulting refrigerant flow rate for the Group 1 compressors during production hours is 7,390 lb/hr and for Group 2, 1,860 lb/hr. On the basis of these flow rates and other system data, the annual heat dissipation at the condensers totals 4.0×10^{10} Btu. For comparison, this quantity is larger than the factory's annual total energy consumption (gas and electricity combined) by approximately 50%.

WASTE HEAT APPLICATIONS

Pittsburgh Factory

Three applications of waste heat were selected for study at the Pittsburgh Factory. They involve the heating of boiler make-up water, fresh water for food processes and factory clean-up water. The main method of heating process water at the factory is by the direct injection of cold water with steam. Since process water is not recycled, condensate losses are high and must be matched by make-up. By Heinz U.S.A. estimates, nearly two-thirds of the boiler feedwater flow is composed of make-up water and

*Referred to subsequently as the Group 1 compressors.

preheating that water would be an excellent use of waste heat. In this case, conventional heat exchange could be used and the timing is opportune since the highest demand for make-up occurs during production when waste heat availability also peaks. A similar application exists in the case of food processing water.

Production area clean-up is a daily operation that requires significant energy input. While spot clean-ups occur as needed during the production hours, the major clean-up effort is performed during third shift when production hardware is disassembled and washed or cleaned in place. Heinz U.S.A. estimates that the factory requires 200,000 gal. of heated clean-up water (150-180°F) per day and meeting that demand is responsible for 3-4% of the plant's total energy consumption. Waste heat could be used to satisfy a portion of the required energy. However, since this particular need and the waste heat supply are not in phase, thermal energy storage would be required.

Lake City Factory

The Lake City Factory also has a daily need for heated clean-up water (8,000 to 10,000 gal. at 150°F) and waste heat from the refrigeration system could satisfy it. Again, thermal storage would be needed since the waste heat supply and the demand for energy in this case are not in phase.

A second waste heat application involves the heating of air which is blown beneath the freezer floors. A potential problem with ground floor freezers is that the earth beneath the floor will freeze eventually and cause the floor to heave. To eliminate or minimize the problem, freezer plants usually install floor insulation and warm the earth beneath the floor electrically or by circulating a warm non-freezing liquid through a piping grid. A third method to prevent freezing is to blow warm air through ducts installed below the floor. This method is employed at Lake City. Outdoor air is drawn in through a roof-mounted system composed of a vaneaxial fan and an air temperature controlled gas-fired heater. The modulated heater is activated whenever the outdoor temperature falls below 70°F. The system is rated at 7000 scfm and the annual air heating load is 1.4×10^9 Btu or approximately 5% of the factory's total energy need.

WASTE HEAT RECOVERY SYSTEM DESIGN AND EVALUATION

Pittsburgh Factory

Several recovery system concepts to satisfy the waste heat applications discussed above are being considered for use at the Pittsburgh Factory. Features of the reference system, shown schematically in Figure 1, will be discussed herein. In that concept, waste water streams at various temperatures are collected from processes occurring in three production buildings. The high temperature streams (i.e., those above 140°F) are collected in the high temperature accumulator (HTA) while all low temperature streams are channeled to a low temperature accumulator (LTA). The LTA and HTA will be insulated and they serve as surge tanks between the waste water source and application points. All of the waste water sources identified in Figure 1 produce continuous waste water streams except the retorts. Retort operation occurs on a batch basis and the temperature of the waste stream emitted by a retort varies with time. It is intended, therefore, that the retort drain system will be equipped with temperature-sensing, three-way valves. The valves will direct waste water to the HTA during the high temperature part of the cooldown and to the LTA when the waste water temperature falls below a set-point value. In studies performed to date, the set-point has been 140°F. The purpose in separating the waste water streams by temperature as opposed to mixing them pertains to the storage part of the system. Using high temperature waste water to prepare the highest temperature stored water decreases the cost/benefit ratio for storage and causes it to approach that for the entire system.

From the HTA, waste water flows on demand to the high temperature heat exchanger (HTHX) located in the Power Building. At the HTHX, heat is transferred to incoming fresh water as it flows to various food processes. When those demands diminish while hot waste water is still available at the HTA, the system will automatically divert the flow of heated fresh water to storage. Water that accumulates in storage during the production period would then be used during third shift for clean-up purposes.

Waste water collected in the LTA will flow to two low temperature heat exchangers (LTHX) also located in the Power Building and mounted in parallel. Waste heat will be applied at that location to preheat fresh water for food processing and for boiler make-up. The parallel heat exchanger arrangement is necessary since the food processing and make-up applications require water from two different sources — on-site wells and the city water main, respectively.

Estimated materials and installation costs for the reference waste heat recovery system are identified in Table 3. Allowing an additional 15% for engineering brings the total system cost to $413,300. At current fuel prices, Heinz U.S.A. estimates the delivered value of energy at $3.05 per million Btu's and in one year's time (220 production days, 2 shifts per day, 7 hours per shift), it is further estimated that the reference system described above will recover approximately 7.0 x 10^{10} Btu thereby reducing factory energy consumption by 5 - 6%. Thus, the projected dollar savings produced annually by the system are $214,000 which would return the capital investment at the rate of 35% per year. The return on investment (ROI) calculation is based upon the Heinz ten-year, discounted cash flow method and assumes a 10% investment tax credit, a 12% depreciation rate and a 50% income tax. The calculation made no allowance for fuel price escalation.

<u>Lake City Factory</u>

For the Lake City Factory, two independent systems have been evaluated. The first system, shown schematically in Figure 2, will apply refrigeration waste heat from the Group 1 compressors to heat fresh water for later use during third shift clean-up operations. The system will be located in an existing water distribution system at a point between the softener exit and the first clean-up stat on take-off. The thermal storage tank and its circulation loop will be solid at water main pressure with a storage capacity of approximately 6,000 gallons which would be sufficient to supply the factory's daily clean-up water needs. System control will center on the storage tank temperature and the refrigerant temperature at the heat exchanger exit. For tank temperatures less than a set point value (say 150°F), the centrifugal circulation pump will energize provided the refrigerant temperature is greater than a set point value representing its saturation temperature. With those conditions satisfied, the temperature sensing flow control control valve will open and water will circulate from storage to the heat exchanger and back to storage. The water will enter the thermal storage tank via a low velocity distribution ring near the tank top and horizontal baffling arranged along the height of the tank will promote stratification. The circulating pump will take its suction from the low temperature zone at the bottom of the tank and water to be delivered to the clean-up stations would be withdrawn at the top.

The system heat exchanger will operate as a desuperheater and under normal conditions, vapor will exit the unit with 5-10 °F of superheat still remaining. The vapor will then flow to the existing condensers to complete the heat rejection process.

Table 4 presents materials and installation cost estimates for the water heating system. The total system cost, including engineering, would be $36,900 and the system would displace natural gas at the rate of nearly 1900 MCF annually. This reduction in fuel consumption is valued, at current fuel prices, at $3,870 per year and it would reduce the factory's total energy input (gas and electricity) by 7% and its natural gas consumption by 13%. Again based upon the Heinz project evaluation method and assumptions, the annual ROI for the water heating system will be 8%.

A second waste heat recovery system for the Lake City Factory is shown schematically in Figure 3 and would apply refrigeration waste heat to warm freezer floor air. As the figure indicates, outdoor air is presently warmed by an existing gas-fired heater and distributed to floor ducts by a fan. The fan operates continuously and air temperature control is achieved by regulating the flow of natural gas to the heater. Waste heat from the Group 2 compressors could be utilized to preheat or completely heat floor air by installing an air-cooled condenser at the heater inlet. Refrigerant vapor from the storage freezer system would be routed through the condenser on its way to the existing evaporative condenser. The system control would cause the incoming air to bypass the new condenser in any proportion to maintain the gas heater inlet temperature at a set-point value. Thus, the fraction of the refrigerant condensing load handled by the new condenser would also be a variable ranging from zero during warm weather operation to nearly one-fourth under design, cold-weather conditions. It is noted that the function of the recovery system would be to supplement the existing gas-fired system. Thus, any portion of the air heating load not satisfied by waste heat will be supplied automatically by the gas heater which will continue to operate with its own control system and independent of the waste heat recovery system.

Costs to procure and install an air heating system are identified in Table 4 and the total estimated cost, with engineering, is $17,700. The system would displace natural gas at the yearly rate of 1390 MCF (valued at $2,880) and reduce the factory's natural gas and total energy consumption by 10% and 5%, respectively. The air heating system ROI is estimated at 14%.

CONCLUSIONS

Based upon our study, it is concluded that waste heat recovery from certain food processes is feasible and can be performed economically using available, off-the-shelf hardware. This conclusion is certainly valid for the large Pittsburgh Factory where both the anticipated ROI and the predicted fuel and energy savings are especially attractive. In fact, the predicted performance of the Pittsburgh Factory system is sufficiently attractive that plans are being developed to design and install an instrumented demonstration system at the factory. The purpose of the DOE supported project will be to evaluate actual hardware performance, to optimize system design and to determine actual costs and benefits resulting from the waste heat recovery system. The results of the project will then be publicized to encourage the application of similar waste heat recovery concepts within the food industry.

While the predicted economic performance of the Lake City systems is less than desired, it is believed that the project results do warrant additional system studies. This is especially true in the system scaling area and the results of the study should be extrapolated to refrigeration plants of other sizes. In fact, a similar effort should also be undertaken for the hot water systems of the Pittsburgh Factory type. Through such efforts, it will likely become evident that retrofit projects within a certain heat recovery range are more feasible than others and plant sizes and conditions most appropriate for such projects could therefore be identified.

TABLE 1. INDIVIDUAL UNIT WASTE WATER CONDITIONS — PITTSBURGH FACTORY

Source	Flow Rate (gpm)	Temperature (°F)
Continuous Can Washer	12	175
Continuous Bottle Washer	7	175
Continuous Cooker/Cooler	60	140
Horizontal Stationary Retorts		
Canned Products	100	100
Glass Products	100	140
Continuous Pasteurizer	80	170
Continuous Cooler	55	120
Horizontal Rotary Retorts		
Type 1	10	135
Type 2	30	125
Continuous Boiler Blowdown	12	212

TABLE 2. 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

TABLE 3. ESTIMATED COSTS — PITTSBURGH FACTORY SYSTEM

Item	Materials ($)	Installation ($)
Tanks	90,000	—
Heat Exchangers	44,400	6,700
Pumps	13,400	6,000
Strainers	10,000	4,000
Valves	15,500	12,800
Piping	27,300	92,200
Instrumentation/Controls	17,800	19,300
	218,400	141,000

Total Materials & Installation — $359,400

TABLE 4. ESTIMATED COSTS — LAKE CITY WATER HEATING SYSTEM

Item	Materials ($)	Installation ($)
Thermal Storage Tank (6000 gal)	8,300	3,000
Heat Exchanger	3,500	1,200
Pump	500	500
Water Flow Control Valve	1,100	200
Temperature Sensor & Transmitter	3,500	400
Piping	2,300	5,000
	19,200	10,300

Total Materials & Installation — $29,500

TABLE 5. ESTIMATED COSTS — LAKE CITY AIR HEATING SYSTEM

Item	Materials ($)	Installation ($)
Condenser	2,800	1,800
Piping	600	1,100
Air Ducting	} 3,000	1,200
Controls		800
Fan Motor	500	—
	6,900	4,900

Total Materials & Installation — $11,800

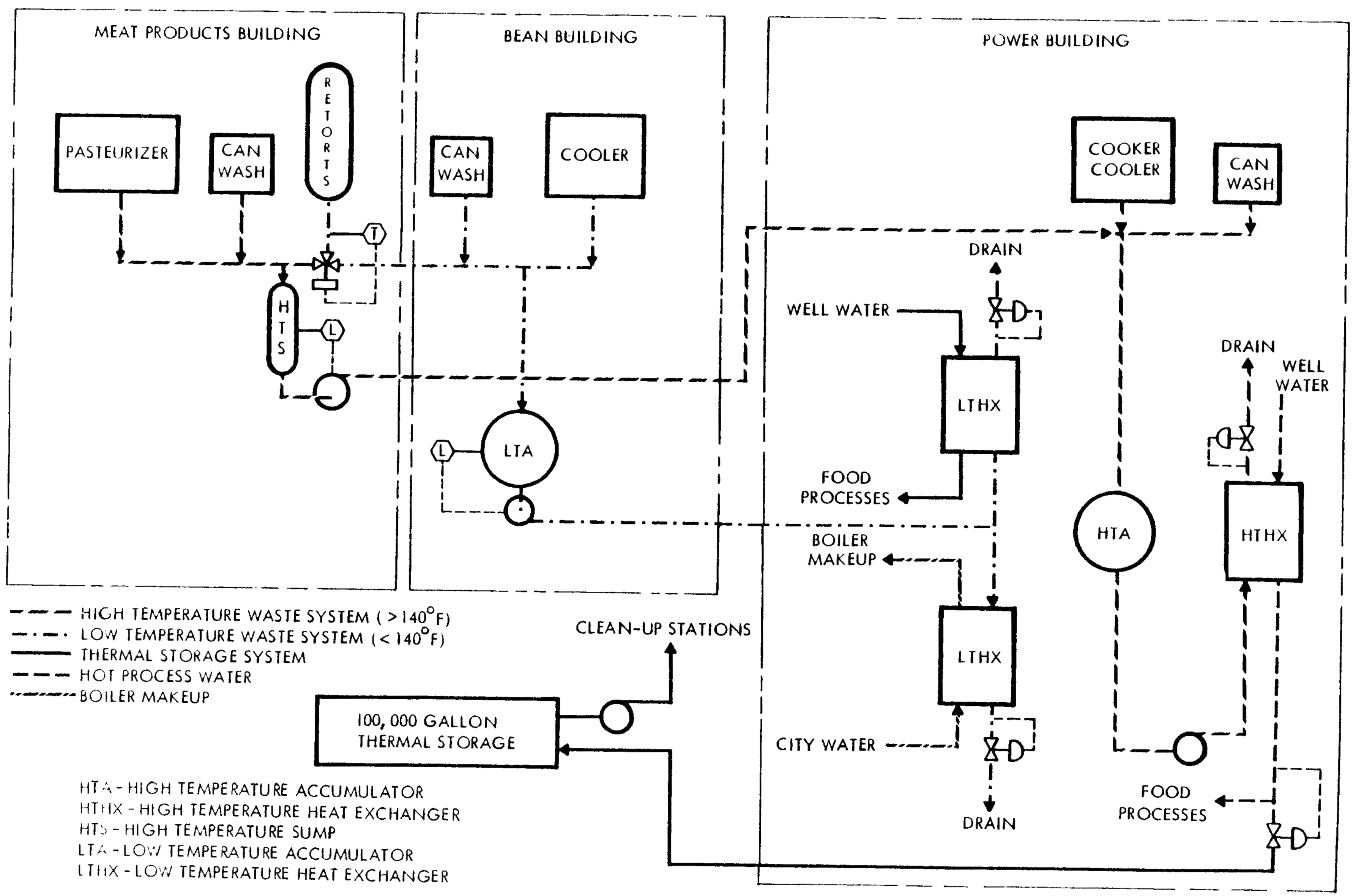

Fig. 1. Waste Heat Recovery System - Pittsburgh Factory

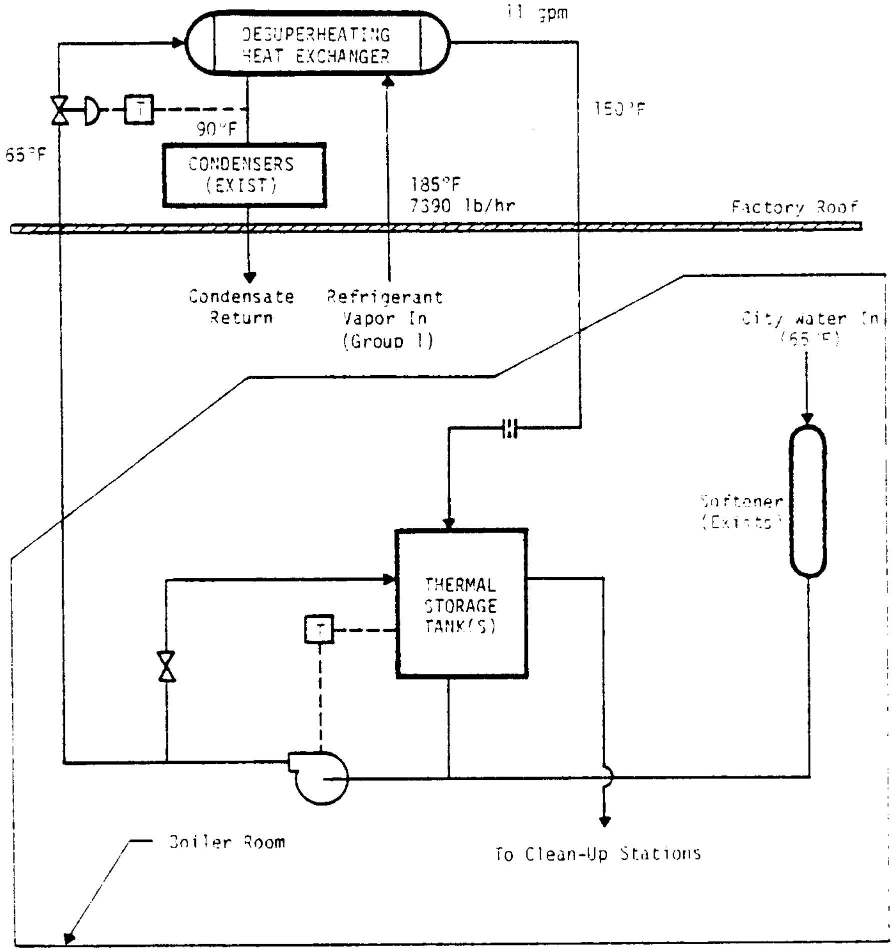

Fig. 2. Waste Heat Recovery System for Water Heating - Lake City Factory

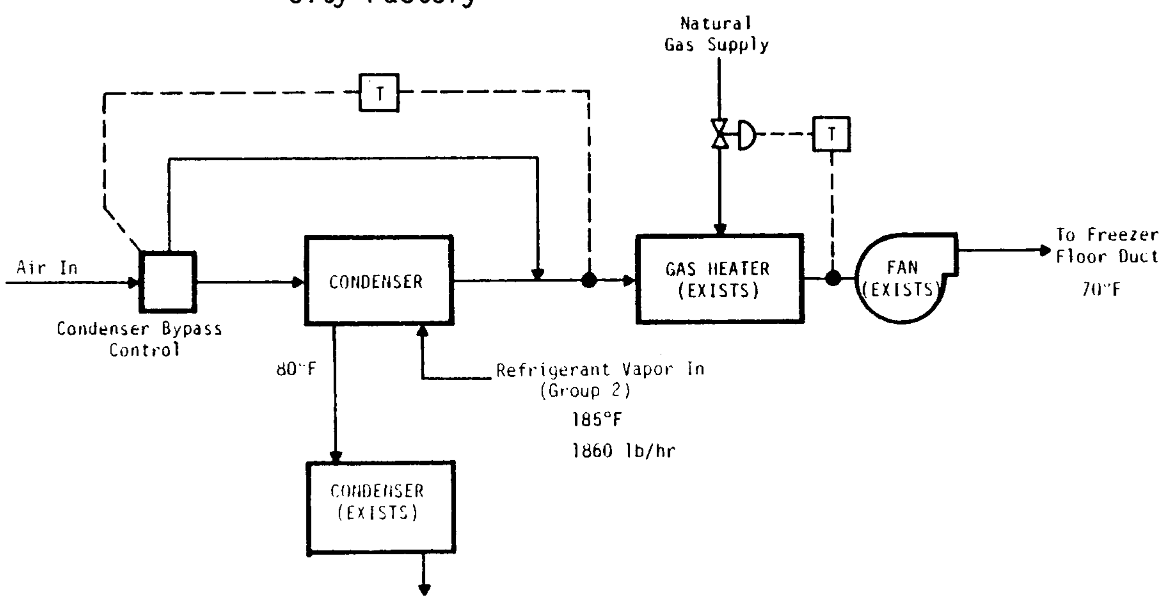

Fig. 3. Waste Heat Recovery System for Air Heating - Lake City Factory