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FEASIBILITY STUDY AND DEVELOPMENT OF MODULAR APPLIANCE TECHNOLOGIES, CENTRALIZED HEATING (MATCH) FIELD KITCHEN

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Modular Appliance Technologies, Centralized Heating (MATCH) explores field kitchen design from a heat transfer perspective. This effort included a feasibility study and preliminary design effort intended to replace the small individual gasoline burner units currently used in field kitchens with one large, more reliable and efficient multifuel burner unit. Phase I preliminarily considered three approaches: (1) Pumped Liquid System (a pumped liquid transfers the heat energy from the heater to the temperature controlled appliance). (2) Vapor Transport System (heat is transferred to the appliance by vapor as in a heat pipe or steam radiator). (3) Multiple Transport Media System (each appliance is heated by its own suitable fluid from a central heating plant). The pumped liquid system was selected at the conclusion of Phase I because of simplicity, cost, and the availability of food grade thermal fluids. In Phase II a MATCH prototype was designed and fabricated that featured a central burner and thermal fluid heater that heats a food grade mineral oil to 425°F which is then pumped to four appliances (griddle, fryer, kettle, and oven). This report includes design details, a manufacturing cost analysis, system safety analyses, standard efficiency tests, and cooking performance tests.

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PREFACE

The Feasibility Study and Development of a Modular Applicance Technologies, Centralized Heating (MATCH) Field Kitchen was undertaken by the TECOGEN Division, Thermo Power Corporation, Waltham, MA between May 1991 and January 1994. The study was performed under Contract DAAK60-91-C-0053.

The following are comments from Natick Project Officer Don Pickard:

Objective In addition to inefficiency, poor heat control, and arduous working conditions, current field kitchens pose potential safety and health hazards from fire and fumes. To improve efficiency, heat control, and working conditions, and reduce fire and fume hazards, a novel approach of employing a single burner as a central heat source for a compliment of kitchen appliances was considered. The objective of phase I was to conduct a feasibility study which considered three approaches: (1) Pumped Liquid System (thermal fluid is heated and pumped to appliance heat exchangers). (2) Vapor Transport System (thermal fluid is vaporized at the heater and condenses on the appliance heat exchanger as in a heat pipe or steam radiator). (3) Multiple Transport Media System (each appliance is heated by best method from a central heating plant that provides liquid, vapor and combustion gas heat). The objective of phase II was to design and fabricate a unit that would demonstrate the concept.

Technical Perspective The pumped liquid system was selected for phase II because of simplicity, cost, and the availability of food grade thermal fluids. A kitchen featuring a thermal fluid system integrated with cooking appliances offers many advantages over more conventional approaches such as fuel fired appliances equipped with small individual burner units or electric appliances powered by a large generator. For example, an inexpensive (e.g. $250) 2 to 3 gallon/hour oil burner provides the heat energy equivalent to that provided by a 75 kilowatt generator at a small fraction of the cost, size, weight, and fuel consumption. Based on the inherent reliability of large oil burners, it is expected that a MATCH system would be much more reliable and maintainable than either generators or small individual burner units. Although reliability will be an important advantage, the principle disadvantage is that in the unlikely event of an unrepairable failure in the burner, pump, or distribution system the MATCH will be completely inoperable and unable to perform its mission. In addition, the thermal fluid is hot (operating temperature 425F) and hazardous (flash point 340F). Therefore, the principle challenge of the next phase will be to develop a thermal fluid heating and distribution system that has the design reliability and structural integrity to survive a mobile application.

Results A prototype MATCH was designed, fabricated, tested, and delivered to the U.S. Army Natick RD&E Center. The prototype, mounted on a frame, consists of a residential oil burner, combustion chamber, fluid heater, expansion tank, pump, and steel pipe through which the thermal fluid is pumped to each appliance. The appliances include a fabricated griddle, and a commercial fryer, jacketed kettle, and oven. Each appliance had been retrofitted to accommodate the thermal fluid including a solenoid valve coupled to the appliance thermostat. The thermal fluid or heat transfer fluid is a non-toxic pharmaceutical grade, FDA and USDA approved mineral oil. A push button starts the unit; the burner heats the thermal fluid to 425F; the appliance temperatures are set; the thermostat signals the solenoid to open; and hot fluid enters the appliance heat exchanger. When the appliance reaches the set temperature, the thermostat signals the solenoid valve to close. The burner cycles on/off to maintain fluid temperature. The solenoid valves cycle open/close to maintain appliance temperatures. A natural gas fired MATCH was designed and tested to determine energy utilization and cooking performance. The unit was then retrofitted with an oil burner and combustion chamber, and delivered to the U.S. Army Natick Research, Development and Engineering Center for further test and evaluation. Both heat transfer and food preparation studies, as well as a manufacturing cost analysis are included in this report

Natick Installation The MATCH was delivered and installed at Natick. Several problems were encountered, including vapor leakage during operation, fluid leakage after operation, sooting and clogging of fins on heat exchanger, combustion chamber leakage, premature shut down of burner, and excessive heat transfer to the expansion tank. One by one the problems were solved with the help of the prime contractor. Most of the problems were caused by the retrofit of the small gas fired thermal fluid heater with an oil burner and combustion chamber. The gas fired unit was selected because it was compact. However, after adding the combustion chamber and burner, the unit was as large as other commercially available systems that were already equipped with oil burners and had properly sized integral combustion chambers. In addition to the recommendations listed at the end of this report, the following improvements need to be made: add a time delay switch on the pump to ensure that soak-back from the combustion chamber does not overheat the static fluid, add a high-temperature limit switch for over-temperature protection, add a fluid level indicator, reduce the size of the expansion tank and add a flow restriction to prevent the hot fluid from convectively rising into the tank, add a mechanical air vent on the tank, and develop better fluid filling and draining methods.

Acceptance Tests

Preliminary testing of the MATCH prototype has shown that the performance is not significantly different from what has been reported in this report. After correcting the noted problems, the thermal fluid heater and burner have operated flawlessly. The griddle performs exceptionally well with respect to heat up time, temperature uniformity, and ability to hold temperature irrespective of the load. The fryer although reported to be undercapacity has worked well. The kettle which is heated directly with the thermal fluid could experience sauce scorching at the air interface although the addition of a small water heat exchanger could solve this problem. The oven performance is limited by the fluid temperature. At a fluid temperature setting of 425F the oven had no trouble holding a temperature of 350F. If a higher oven temperature is desired i.e. 450F, it is possible that the fluid thermostat could be temporarily set at a higher temperature i.e., 500F.

Conclusions

All of the original objectives were accomplished. The MATCH prototype installed at Natick is adequate for demonstrating the capability and advantages of a central heat unit concept for field kitchen applications. This study has determined that from a performance, manufacturing cost, and operating and support cost perspective, the MATCH concept would provide an excellent alternative to either a generator or individual burner based kitchen.

Follow-on Effort

The program has subsequently been transitioned to the Technical Demonstration phase of Advanced Development. During this phase the MATCH will be redesigned and assembled with other components to provide a fully functioning kitchen and field food service capability for a company sized group (150 soldiers). For mobility, the kitchen will be installed on a 1 1/4 ton trailer that is towable by the standard High Mobility Multi-purpose Wheeled Vehicle (HMMWV). Packaged on a trailer and towed into the field, this Central Heat Unit Concept for Kitchens represents the State-of-the-Art in Chuck Wagons.

Natick Project Officer
Don Pickard
Advanced Technology Branch
Equipment and Systems Division
Sustainability Directorate

FEASIBILITY STUDY AND DEVELOPMENT OF A MODULAR APPLIANCE TECHNOLOGIES, CENTRALIZED HEATING (MATCH) FIELD KITCHEN

EXECUTIVE SUMMARY

Tecogen, under contract to the U.S. Army Natick RD&E Center (No. DAAK60-91-C-0053), (Natick) has successfully completed the feasibility and development of an advanced field kitchen prototype. The objective of this program was to analyze, develop and test an advanced kitchen based on the modular appliance technology centralized heating (MATCH) concept.

A pumped liquid transport approach was selected over two other candidate approaches to be incorporated into the MATCH field kitchen system. In the pumped liquid approach, a low volatility, non toxic thermal fluid is continuously pumped through a thermal fluid heater and in parallel to each appliance (griddle, fryer, kettle and oven) in the kitchen. The fluid is returned to the heater at a lower temperature, depending on the appliance load. A diesel-fueled burner supplying energy to the fluid heater is modulated "off-on," heating the fluid to a constant supply temperature of 450°F. An "off-on" control valve at each appliance controls the appliance temperature in response to varying loads by regulating the fluid flow through the appliance.

The pumped liquid system and cooking equipment were designed. The cooking equipment was designed by modifying commercial gas and electric cooking equipment. The system was designed using conventional components which are available. Safety, reliability and cost were major considerations in the design of the system and the cooking appliances.

A bread-board system, using a natural gas-fired burner, was assembled and tested to prove the feasibility of the MATCH concept. Operation and testing of the system did prove the feasibility of the concept and the ability of the system to perform as a food service unit.

A prototype pumped liquid system was later assembled. The prototype system used many of the components developed for the bread-board system; however, a diesel-fueled burner and combustion chamber were added. The prototype system was mounted on a frame and included all of the cabinet enclosures. All piping, wiring and controls were included on the prototype pumped liquid system.

The prototype system was operated and tested at the Tecogen laboratory prior to shipping it to the U.S. Army RD&E Center in Natick, Massachusetts. Testing of the prototype system produced results similar to the bread-board system and proving again the feasibility of the MATCH field kitchen concept. The prototype testing also showed the system to be reliable, safe and easy to operate.

During the prototype system assembly and testing, it became evident that certain modifications to future pumped liquid field kitchen systems would further enhance the operation cooking performance, reliability and safety of the system. The recommended modifications include:

- a redesigned liquid heater
- the use of only welded and flanged piping fittings
- a thicker griddle cooking surface
- increased heat transfer surface on the fryer
- a lower cost liquid pump
- higher temperature solenoid valves
- an enclosure on all exposed piping, valves and fittings
- the addition of a spring loaded safety valve on the fuel supply line
- the addition of a flame detection and foam spray system under the appliance cabinets

In general, it has been shown that the MATCH field kitchen using a pumped liquid system is a reliable, safe and cost effective system capable of efficiently producing large quantities of cooked food.

1. INTRODUCTION

The operation of a military field kitchen is hard work and dangerous. The food service specialist, in addition to preparing food, must also operate and maintain the current gasoline-fired field burner units. Operation of these burner units include cleaning, fueling, preheating outside the kitchen, and transporting to the kitchen. These burners are vented directly into the kitchen, thus providing an unhealthy environment. The present procedure of operating a gasoline burner in the confines of the tent kitchen is very dangerous. The procedure has caused numerous injuries to operating personnel and has caused the costly destruction of materials.

It is, therefore, in the best interest of the U.S. Army to find a safer and more practical method of operating a field kitchen system. A Modular Appliance Technology Central Heating (MATCH) System was proposed to fulfill the needs of a modern field kitchen system. The general requirements of this MATCH system are as follows:

The system will consist of a remote, single, multi-fuel burner which provides the energy to operate several modular cooking appliances by circulating a heat transfer medium. The burner will be capable of venting the products of combustion outside the cooking area. The cooking appliances will be similar, in operation, to those used in conventional kitchens. The cooking appliances will be modular and interchangeable and will include a griddle, a deep-fat fryer, a kettle and an oven. The system will feature a single push-button start for the burner and the heat transfer medium circulation. The system will be modularized, self-contained and transportable for installation in a vehicle, trailer or container based kitchen.

A program to establish the feasibility of the MATCH System concept was undertaken by Tecogen. The specific objective of this program was to prove the technical and economic feasibility of an integrated field kitchen which uses a central heater for all appliances.

The program to develop the field kitchen concept of a multi-appliance, centralized heating and heat transfer system was divided into two phases. During the first phase, a feasibility study was conducted and the following three potential approaches for an integrated kitchen were evaluated:

- Pumped Liquid System
- Vapor Transport System
- Multiple Transport Media System

The evaluation led to the selection of a Pumped Liquid System. Additionally, during Phase 1, a gas-fired bread-board system of this selected concept was fabricated and tested. This bread-board system used many of the final components such as the liquid heater, griddle, fryer, kettle and oven. It was, however, a gas-fired system and the components were not in their final configuration. During Phase 2, a diesel-fueled prototype system of the pumped liquid concept was developed, tested and delivered to Natick for further testing and evaluation. In this prototype system, all components were properly mounted on frames which contained removable stainless steel panels. The prototype system also contained a diesel-fueled combustion system and all appropriate controls.

The following report describes the work performed during the two phases of the program, including the system selection, component and system design, system fabrication and system testing. The system testing includes the results from general performance tests and cooking tests. These test results are discussed together with recommended modifications to the system to improve the performance.

2. SYSTEM EVALUATION AND SELECTION

2.1 INTRODUCTION

A study was conducted to examine the technical, economic and operating feasibility of integrating cooking appliances in a system using a central heat source. In the integrated field kitchen, a remote diesel-fueled heater is connected to the appliances with an appropriate conduit. Three approaches were evaluated for transporting the heat from the central heater to the appliances. These approaches are as follows:

- Pumped Liquid System
- Vapor Transport System
- Multiple Transport Media System

In each of these systems, several appliances of the same or different type may be integrated. The systems studied all included the same appliances listed below:

- Griddle
- Deep-Fat Fryer
- Kettle
- Convection Oven

In the pumped liquid approach, high temperature liquid at 450°F to 550°F is pumped in parallel to the different appliances. A low volatility liquid heat transfer medium, a mineral oil, is used so that the operating pressure of the liquid in the system is atmospheric at the pump suction.

In the vapor transport system, heat is transported by vapor which is condensed in the appliances and the condensed liquid is returned to the central heater either by gravity or by a pump. The system's pressure is determined by the fluid vapor pressure at the central heater operating temperature. Perfluorinated organic fluids of varying volatilities and the family of biphenyls and diphenyls are available for this approach.

In the multiple heat transport media approach, different media are used for different appliances. Each medium is heated by a single burner with individual heat exchangers for each medium. For example, fryer oil, oven air, griddle transfer liquid and steam can be heated in four separate heat exchangers integrated with a single burner, with each medium circulated through separated appliances.

The pumped liquid system was selected as the best overall approach. The study also indicated that the integrated field kitchen using the pumped liquid approach has many advantages over an independent and manually operated burner for each appliance. The advantages are:

- Reduced operating cost
    - Higher energy efficiency (lower fuel consumption by a factor of 2)
    - Easier cleaning and reduced maintenance
- Improved cooking performance
    - Accurately controlled temperature
    - Uniform temperature over cooking surface
    - Fast recovery
    - Instantaneously available from hot standby condition
- Efficient space utilization
    - Compact appliances (small footprints, heights)
    - Countertop and under-counter installation
- More comfortable environment for cooks
    - Exhaust gases not exhausted to kitchen space
    - Reduced kitchen temperatures
- Improved Safety
    - Automatic startup and operation controls
    - Automatic safety controls
    - Exhaust gases vented out of kitchen space
    - Fuel storage isolated from kitchen space

2.2 PUMPED LIQUID APPROACH

A schematic of the pumped liquid approach is given in Figure 2.1. A thermal fluid is continuously circulated by a centrifugal pump through a thermal fluid heater and in parallel through each appliance in the kitchen. The heater supplies hot oil to the supply line at a controlled temperature of 450°F to 550°F. The fluid is returned by a return line to the heater at lower temperatures, depending on the appliance load. The burner in the fluid heater is modulated in response to the load to heat the fluid to a constant supply temperature. Pumped liquid systems similar to this are used in a wide variety of industrial applications ranging from food to laundries.

Each appliance is connected in parallel across the fluid supply and return lines. The fluid passes through a heat exchanger in the appliance with heat transfer to the cooking load and leaves at a lower temperature to the return line.

A control valve on each appliance is used to control the appliance temperature in response to varying loads by regulating the liquid flow rate through the appliance.

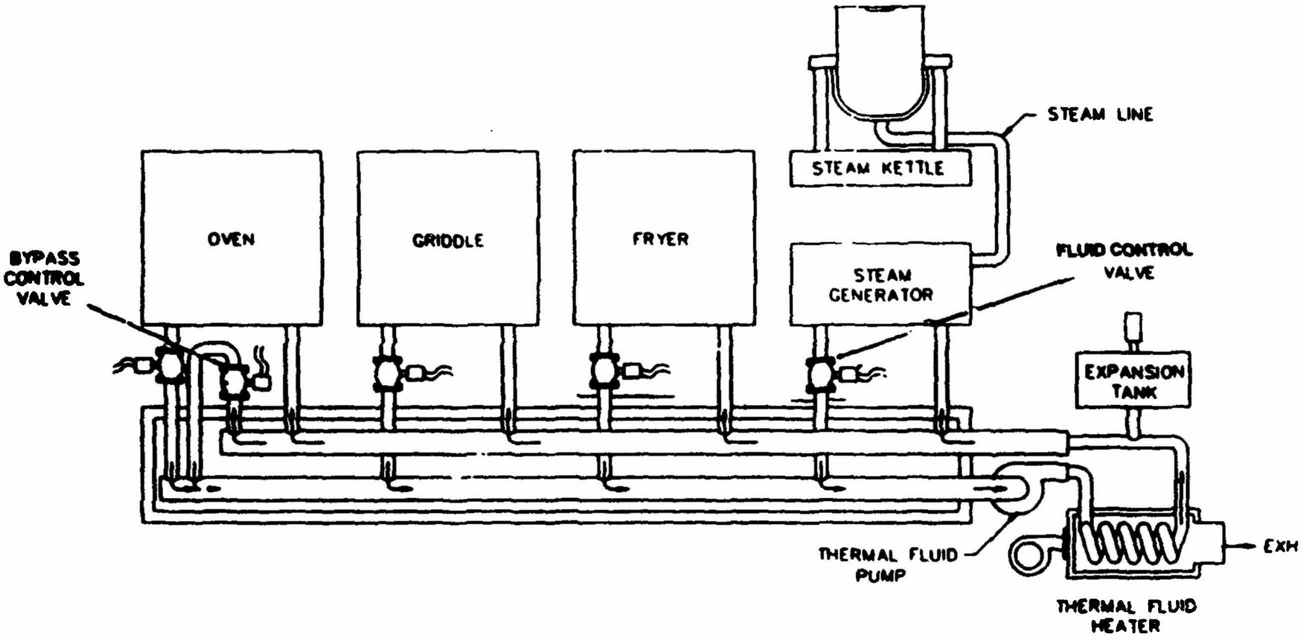


Figure 2.1 Pumped Thermal Fluid Concept

An expansion tank is required to allow for thermal expansion of the fluid when it is heated from ambient temperature to operating temperature. This tank also allows for the escape of any gases dissolved in the fluid, or gases formed by decomposition of the liquid. This expansion tank is generally vented to the atmosphere so that the system operates close to atmosphere pressure.

Since heat transfer media temperatures up to ~600°F can be used, the pumped liquid approach can be used for all of the appliances in the MATCH kitchen.

Heat transfer fluids with the required thermal stability and low toxicity are summarized in Table 2.1. Two are highly purified mineral oils (Multitherms PG-1 and IG-2), and the Dow Corning fluid is a synthetic silicone-based fluid. Multitherm PG-1 is an excellent fluid for this application and has been rated by the FDA as nontoxic and acceptable for food contact. It is used as a thermal heat transfer medium for industrial food processing Paratherm NF is a similar mineral oil supplied by another company. The fluid is pumpable down to -13°F. It is available in quantity at an FOB cost of ~$6/gallon.

Burning diesel fuel, with 20-percent excess air and a final exhaust temperature of 932°F, requires a fuel LHV input of 261,000 Btu/hr (2.09 gal/hr) to supply 200,000 Btu/hr total to the cooking appliances. The LHV efficiency is thus 76.6 percent. This efficiency can be greatly improved by using a heat recovery water heater on the flue gas from the heater. Assuming the exhaust is cooled to 300°F in the heat recovery water heater, 53.2 gal/hr of hot water is produced (100°F temperature rise), and the LHV efficiency is raised to 93.6 percent. The energy efficiency of the pumped liquid integrated kitchen will be excellent.

Commercial appliances can be modified for use with thermal fluid heating by replacing the gas-fired combustor or electric heaters with a heat exchanger through which the hot oil flows. Because of the lower heat source temperature, a larger heat transfer area is required for the pumped thermal fluid system. Commercially available plate-coil heat exchangers are a low-cost option for modifying the appliances for thermal fluid heating. Plate-coil heaters have a serpentine coil formed as part of the plate through which the thermal fluid flows. The plate-coil can either comprise part of the appliance structure or can be used as an immersion heater. Tube bundles are another heat exchanger option which integrates well with some appliances.

TABLE 2.1. Heat Transfer Fluid

Heat Transfer Fluid	Maximum Recommended Temperatures (°F)		Flammability Data (°F)			Toxicity	Cost (dollars/gal)
	Bulk	Film	Flash Point	Fire Point	Auto Ignition		
Multitherm PG-1 (or Paratherm NF)	600	640	340	385	980	Nontoxic	8.54
Multitherm IG-2	600	650	440	500	700	Slightly Toxic	7.00
Dow Corning Slytherm 800	750	800	320	350	725	Nontoxic	23.00

2.3 VAPOR TRANSPORT APPROACH

Vapor transport of heat is used extensively in industry for providing process heat to locations remote from a central boiler. Examples are 150-psig steam for low-temperature heating (to 350°F) and Dowtherm A vapor for high temperature heating (to 700°F).

In Figure 2.2, a schematic is given of an integrated kitchen approach using vapor transport of heat from a single burner to the four appliances. Since the appliances operate at different temperatures, the vapor generator is split into four independent vapor generators so that a different working fluid and temperature can be used for each appliance. The vapor generator is illustrated as a fire-tube approach with the combustion gases flowing through vertical tubes fabricated into each vapor generator section. In each vapor generator section, an exhaust damper is used to automatically regulate the combustion gas flow rate through that vapor generator section in response to the desired set-point temperature for that appliance.

Two approaches are illustrated for vapor transport heating. For the griddle, a sealed system is illustrated which is filled only with the working fluid liquid and vapor (no noncondensable gases), forming a gravity-assisted heat-pipe. A leak-tight vapor space is formed under the entire bottom of the griddle by a shallow flat pan welded to the 1/2" thick griddle plate at all edges. Internal support pins are used on the pan so that it does not collapse under high vacuum. The vapor space is connected to the griddle vapor generator by a single tube, with vapor flowing up through the tube and condensed liquid draining by gravity back to the vapor-generator. No pump is required.

Tecogen has fabricated and tested a gas-fired heat-pipe griddle that gives excellent performance and temperature uniformity. Dowtherm A was used as the working fluid. A photograph of the unit and performance comparison with a conventional griddle are shown in Figure 2.3 and Table 2.2, respectively. A key consideration in using this approach for the field kitchen is that the system must be absolutely leak-tight (hermetic) in order to function. Even a pinhole leak will permit air leakage into the system since the internal pressure is less than atmospheric in the shutdown mode. This air will prevent vapor transport of heat to the cold griddle surface. Further, repair of such a leak is very difficult. However, hermetic systems of greater complexity than the griddle are used extensively, the best example being residential refrigeration systems.

In the second approach, an air-breathing system is used for the oven, fryer, and steam generator. While the heat-pipe approach can be used for these appliances, the air-breathing approach eliminates the requirement for an absolutely leak-tight system. In this approach, an air-breathing valve is used which is open at low temperatures. In the shutdown mode, the working fluid has drained into the vapor generator and the appliance heat exchanger filled with air. When fired up, the working fluid is heated to its boiling point at the ambient atmospheric pressure. As additional heating occurs, the vapor pushes

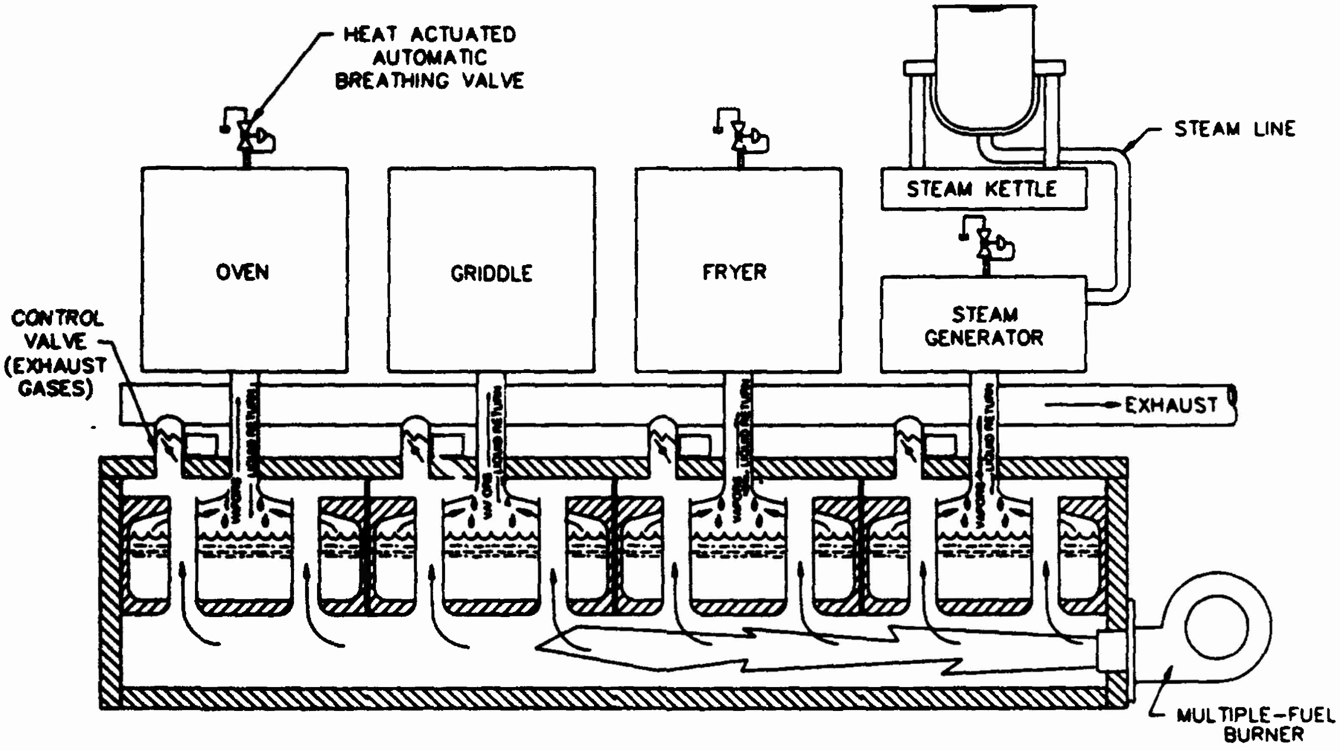


Figure 2.2 Organic Vapor-Heated Integrated Kitchen Approach – Concept No. 2

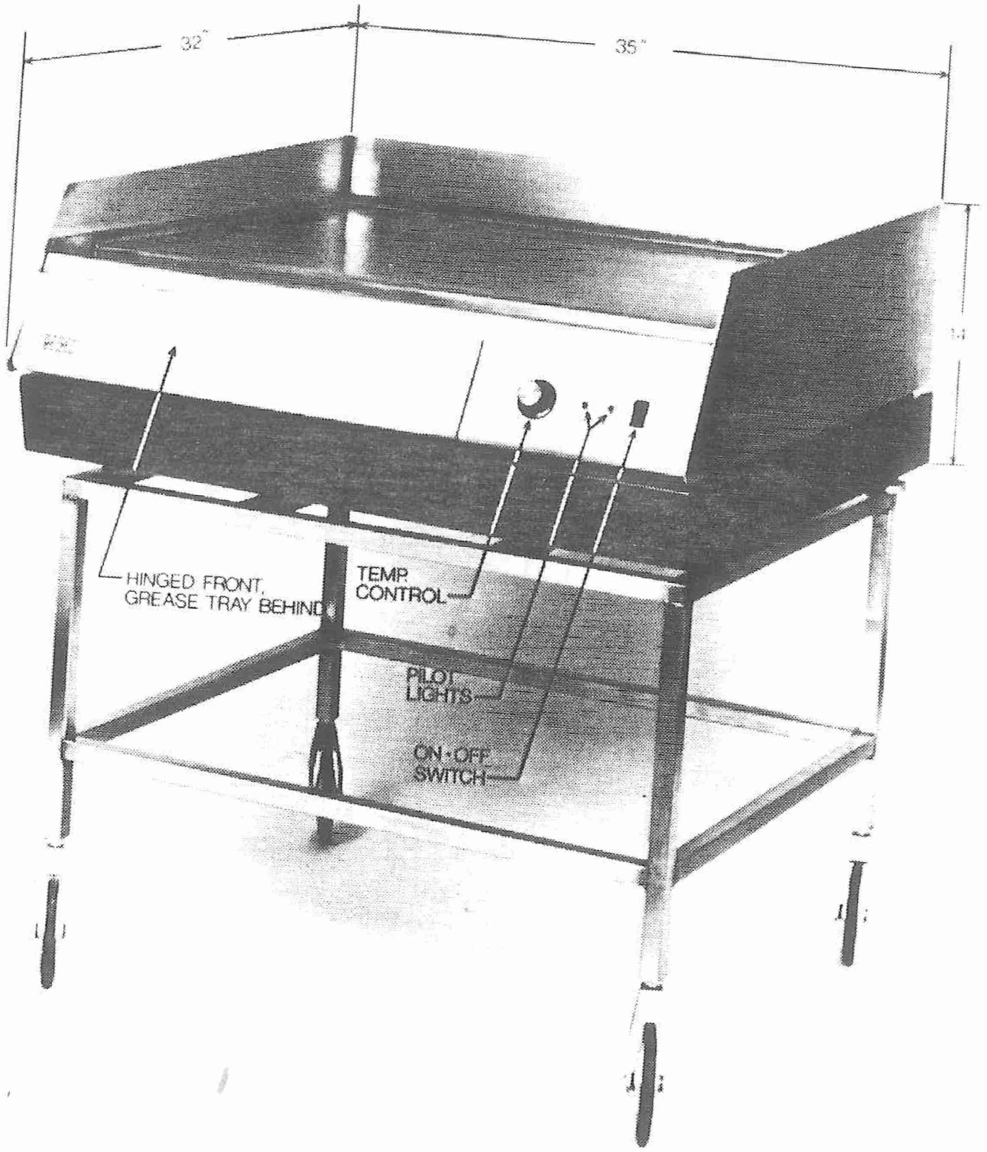


Figure 2.3 Gas-Fired Heat Pipe Griddle

TABLE 2.2. Performance Comparison of Heat Pipe Griddle Versus Conventional Griddle

	Heat Pipe Griddle	Conventional Griddle
Initial Gas Input, Btu/hr	83,000	85,000
Control Gas Input, Btu/hr	35,000	32,000
Time to Reach 400°F, minutes	7	26
System Efficiency, %	81	40
Steady-State Gas Consumption, Btu/hr	12,000	32,000
Control Type	high-low/OFF-ON	high-low/continuous
Control Accuracy, °F	±10	±30
Control Temperature Variation, °F	±5	±25
Surface Temperature Variation, °F	±2.5	±25
Cabinet Temperature, °F	240	350
Exhaust Temperature, °F	430	580
Excess O_2, %	5.5	17.3
Exhaust CO, %	0.001	0.002
Exhaust CO_2, %	8.7	2.0

the air from the heat exchanger and heats the part of the heat exchanger exposed to the vapor. A sharp air-to-vapor interface occurs as the vapor motion sweeps any residual air to the interface. As heating continues, the vapor is pushed into the tube leading to the air-breathing valve. A fluid-filled bulb is heated when the vapor reaches the bulb location and closes the valve. The system then functions as a heat-pipe, and additional heat input will raise the vapor pressure (and temperature) above ambient pressure. This approach is analogous to a residential steam-heating system.

For these appliances, this approach should provide excellent temperature control over a wide-load range. For the convection oven and deep-fat fryer, plate-coil heat exchanges could be used as for the thermal fluid heaters, but with a revised one-pass embossed tube pattern to permit gravity draining of condensed liquid to the vapor generator. For the steam generator, a tube in-shell unit would be used. This unit would be similar in size to that used for the thermal fluid system, but with the shell positioned vertically and a vertical one-pass tube bundle used. The appliance sizes will be almost identical to those for the pumped thermal fluid approach.

Application of the air-breathing approach to the griddle is difficult, since the heat transfer surface is of necessity horizontal. It would thus be difficult to sweep the air completely from the vapor plenum beneath the griddle. The sealed heat pipe approach as described earlier is preferable for the griddle.

It is essential that the working fluids used in these systems have a low toxicity, low flammability, high thermal stability in the presence of air (O_2), and the proper vapor-pressure for the appliance operating temperature. A family of perfluorinated fluids produced by the 3M Company, and marketed under the trademark "Fluorinert", fulfills these requirements. In Table 2.3, selected properties of the fluids are given. A note of caution: while the fluids have low toxicity, high temperature decomposition of the fluid may result in toxic degradation products. At the temperatures of interest here, this degradation should not occur. As an example of one current use of these fluids, FC-70 is used for vapor phase soldering systems of electronic boards at a temperature of 215°C (419°F), the boiling point of this fluid at 1 atm pressure.

In terms of heat transfer, the condensation coefficient of heat transfer is generally in the range of 100 to 150 Btu/hr-ft^2-°F. While this coefficient is less than that obtained with the pumped thermal fluid (~350 Btu/hr-ft^2-°F), the controlling heat transfer resistance is on the hot air side or hot oil side for the convection oven and deep-fat fryer, respectively. Previous testing of a heat pipe griddle had indicated excellent performance with another vapor heat transfer fluid, Dowtherm-A, which has a condensing coefficient comparable to that of the Fluorinerts.

TABLE 2.3. Selected Properties of Fluorinert Fluids

Property Fluid	FC-72	FC-77	FC-104	FC-75	FC-40	FC-43	FC-70
Boiling Point, °F	133	207	214	216	311	345	419
Density, 25°C gm/cm^3	1.68	1.78	1.76	1.76	1.85	1.86	1.94
Pour Point, °F	-130	-166	-85	-126	-70	-58	-13
Heat of Vaporation at Boiling Point, Btu/lb	38	36	40	38	31	30	29
Heat Capacity, 25°C, Btu/lb°F	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Vapor Pressure, 25°C, psia	4.49	0.812	0.50	0.600	0.058	0.025	<0.002

For the steam generator, in which the water boiling coefficient is very high, the required tube area in the steam generator is increased by a factor of 3 to 4 relative to the thermal fluid-heated steam generator. It should be noted that some modifications can be made to increase the condensing coefficient, such as a spiral rib on the condensing side of the vertical tube to collect the condensate and minimize the condensate film thickness.

2.4 MULTIPLE HEAT TRANSPORT MEDIA

In this concept, each application is heated by the fluid most suitable for that particular appliance. Fluid heating is done in separate heat exchangers, but in a centralized heating plant. This is illustrated in Figure 2.4. A single burner is used, and the combustion gases are distributed through an independent heater for each appliance. Dampers in each appliance heater's exhaust duct are used to control the temperature of that appliance by regulating the flow rate of combustion gases through the heater. Temperature regulation can be either be manual or automatic.

For the oven, the air is circulated to the central heater, either by a blower or by natural convection, where the oven air passes through a plate steel heat exchanger similar to that of a clam-shell furnace. The heated air circulates back to oven. The oven construction is simple, being nothing more than an insulated box with a door. The clam-shell heater construction is also simple and inexpensive, consisting of two pressed steel plates welded together.

For the fryer, the frying oil is circulated by a pump through a tube bundle, where it is heated by the combustion products flowing through the tube bundle, and then returned to the fryer. A filter would also be included in the flow circuit to keep the frying oil clean. Tecogen previously developed and demonstrated a pumped-oil commercial fryer, using a gas-fired heater. The primary purpose of this development was continuous filtering of the frying oil with improved product quality and oil life. The fryer tank construction is also simplified relative to a direct-fired fryer tank, but a fluid pump, heat exchanger, nd filter are required. Temperature control and recovery are also excellent.

For the griddle, a pumped thermal fluid approach using Multitherm PG-1 is used exactly as described previously, except the pumped thermal fluid is dedicated solely to the griddle. The griddle temperature control is greatly simplified when the thermal fluid is dedicated solely to the griddle. The thermal fluid temperature can be modulated up and down in response to the desired griddle temperature. The thermal fluid maximum temperature can also be lower, reducing the cost of the circulating pump.

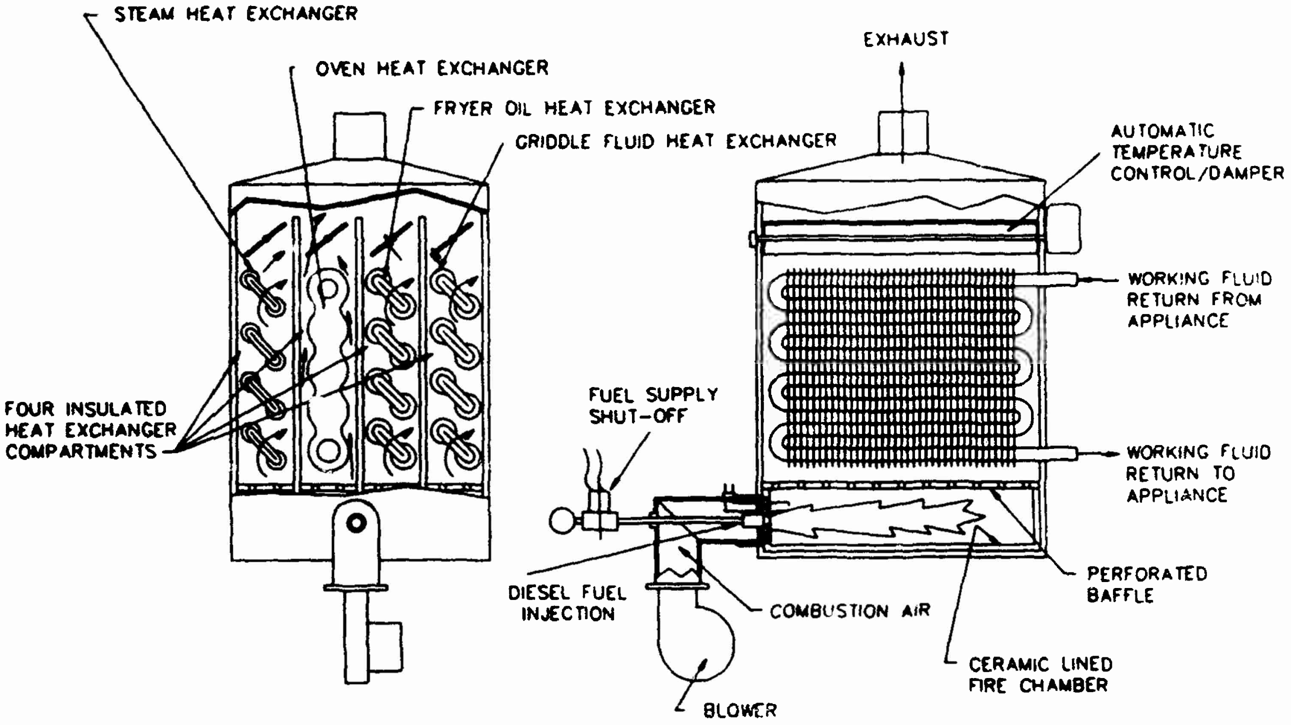


Figure 2.4 External Heat Exchanger Component for Integrated Kitchen with Multiple Transport Fluids

For the steam generator, water is pumped through a vapor generator tube bundle where the water is partially evaporated. The steam is separated from the water for delivery to the steam-heated kettle. The separated water and returning condensate from the kettle are recirculated through the vapor generator.

In the approach just described, the combustion gas from a single burner is split and passed through separate heat exchangers for each appliance. The heat exchangers are integrated with the burner, and separate heat transport media, optimized for each appliance, are used for transferring the combustion heat to the appliance.

2.5 SYSTEM SELECTION

The three approaches investigated all indicated an ability to perform as an integrated cooking system. The investigation did, however, show that each approach possessed both positive and negative features which made them either more or less attractive for use as a mobile integrated kitchen. An assessment of the features of each system was made to decide on the best approach. The assessment was based on the following criteria:

- Ability to Cook
- Ease of Operation/Control
- Multi-fuel Capability
- Efficiency
- Cost
- Reliability
- Electrical Power Requirements
- Ease of Maintenance
- Safety

2.5.1 Ability to Cook

All approaches indicated the ability to deliver the proper amount of energy at the appropriate temperatures to all appliances. These are the two factors required by any cooking appliance.

2.5.2 Reliability

In general, all three approaches are considered to be very reliable. This is an important aspect of any food service system. The pumped liquid system and the multiple media system can continue to operate even if they develop a small leak in the heat transfer fluid system. A small leak in the vapor transport system, however, would render it inoperative. All systems would be incapable of operating if the circulating pump, central burner, or electrical system failed to operate.

2.5.3 Ease of Operation/Control

All systems would use simple off-on controls to control the burner and each appliance. The multiple media system, with its individual circuits controlled at the appliance temperature, would provide closer but not easier temperature control.

2.5.4 Electrical Power Requirements

All systems will require the same electrical power for the combustion system. The vapor transport system uses a small condensate return pump which would require the least pumping power. The pumped liquid system, with a high volume flow rate and moderate pressure requirement, will have the second highest electrical power requirement. The multi media system, with separate fluid pumps for each circuit, will require the highest electrical power.

2.5.5 Multi Fuel Capability

All systems would be designed to use a single gun-type oil burner which would be capable of burning diesel fuel, kerosene and gasoline.

2.5.6 Ease of Maintenance

In all systems, the appliances would be designed for ease of cleaning and maintenance. All other maintenance items such as burner servicing and cleaning, pump lubrication and fuel filter changing will be the same in all three approaches.

2.5.7 Efficiency

All three approaches will be much more efficient than the current method used for field cooking. The multi media system has the ability to vary the temperature in each circuit to accommodate the appliance requirements. If an appliance is maintained at a low temperature or turned off, the heat loss from that circuit is reduced from a low value to zero. In the pumped liquid system and the vapor transport system, the entire transport fluid circuit is maintained at a single high temperature of 450°F to 550°F even if only one appliance is operating. This will result in higher heat losses than for the multiple media system.

2.5.8 Safety

Safety is one of the most important criteria of a food service system and careful consideration has been given to it in the final design of the selected system. It must, however, be realized that any cooking appliance which is heated by a combusting fuel and operates at temperatures as high as 450°F possesses certain risks. In the three approaches evaluated, the single combustion system, located remote from the appliances and vented outside the cooking compartment reduces the safety risks. There are, however, special safety considerations which must be addressed in all three approaches concerning the potential for leakage of the hot transport fluid. In the pumped liquid system and the multiple media system, the transport fluid is FDA approved and is safe if it comes in contact with the food. In the vapor transport system, available transport fluids have a certain level, even if low, of toxicity which can render it unsafe to use in certain cooking applications.

2.5.9 System Cost

Many of the itemized costs in the three approaches are the same or similar. The combustion system, fuel supply system, electrical system, appliance support structures and system frame will be the same in all three approaches. There are, however, major differences in the systems which will greatly effect the cost. The appliances used in the pumped liquid and multiple media systems will be similar and will be based on modifications of existing cooking equipment. Similarly, the piping systems in both cases will be relatively conventional requiring conventional welded or flanged fittings. The appliances and the piping system in the vapor transport approach will require all fittings to be welded or brazed to vacuum integrity. Additionally, the vapor transport appliances must be designed to have a low pressure drop in the fluid transport side. This will probably eliminate the use of modified conventional appliances.

The heat exchangers of the pumped liquid and vapor transport systems are for single fluid heating and much less expensive than the multi-channel heat exchanger used in the multiple media approach.

2.5.10 System Selected

Although the three approaches can all fulfill the cooking requirements, a careful examination of the evaluating criteria and discussions with Natick personnel led to the conclusion that the pumped liquid approach would be the best candidate for a Modular Appliance Technology Centralized Heating Field Kitchen. This approach was used as the basis for the development and construction of a demonstration prototype for an army field kitchen as described in the next chapter.

3. SYSTEM DESCRIPTION

3.1 GENERAL DESCRIPTION

The flow schematic of the MATCH thermal fluid system prototype, constructed for demonstration of this approach for an army field kitchen, is presented in Figure 3.1. A low-volatility, non-toxic thermal heat transfer fluid, such as mineral oil, is continuously circulated by a centrifugal pump through a central thermal fluid heater, and in parallel through each appliance in the kitchen. The heater supplies hot oil to the supply line at a controlled temperature of 450°F ±12°F. The fluid is returned by a return line to the heater at a lower temperature, depending on the total appliance cooking load. The burner in the fluid heater is modulated in response to the load to heat the fluid to a constant supply temperature.

Each appliance is connected in parallel across the fluid supply and return lines. The fluid passes through a heat exchanger in the appliance, with heat transfer to the cooking load, and leaves at a lower temperature to the return line. A control valve on each appliance is used to control the appliance temperature in response to varying loads by regulating the liquid flow through the appliance.

An expansion tank is required to allow for thermal expansion of the fluid when it is heated from ambient temperature to operating temperature. This tank also allows for the escape of any gases dissolved in the fluid, or gases formed by decomposition of the liquid. This expansion tank is generally vented to the atmosphere so that the system operates close to atmosphere pressure. If the expansion tank is connected to the suction side of the pump as on the demonstration prototype, the return line will be at atmospheric pressure and the return line at subatmospheric pressure. A subatmospheric system could have slight safety benefits. In the event of a pipe rupture, the tendency would be for air to leak into the system rather than for hot liquid to leak out.

Multitherm PG-1 is used as the heat transfer fluid, with selected properties given in Table 3.1. This fluid is a highly-purified mineral oil developed specifically for heating of food products, and has been rated by the FDA as non-toxic and acceptable for food contact. It is used as a thermal heat transfer medium for industrial food processing. Important characteristics of the fluid for the field kitchen are its pour point of -40°F, permitting cold startup at this ambient temperature, its high thermal stability limit of 640°F, and its high boiling point of 600°F permitting unpressurized operation.

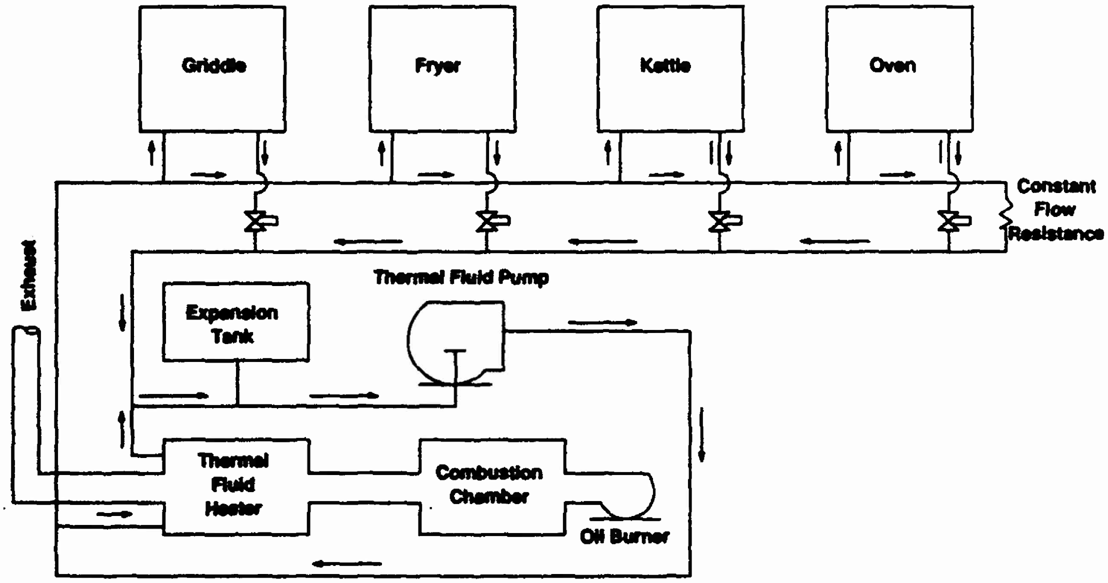


Figure 3.1 MATCH Thermal Fluid System

TABLE 3.1. Selected Properties of Multitherm PG-1

Composition	NF/USP Pharmaceutical Grade White Mineral Oil
Appearance	Bright Clear Colorless Fluid
Odor	None
Taste	None
Pour Point, ASTM D97	-40°F
Density, Pounds per gallon (75°F)(24°C)	7.25
Flash Point, coc, ASTM D92	340°F
Fire Point, coc, ASTM D92	385°F
Auto Ignition Temperature, ASTM D2155	980°F
Atmospheric Boiling Point, Initial, ASTM D86-87	600°F
Average Molecule Weight	350
Maximum Recommended Film Temperature	640°F
Optimum Use Range	150 to 600°F
Pumpable, Centrifugal, 2,000 centipoise	-13°F

Temperature (°F)	200	400	600
Heat Capacity (Btu/lb-°F)	0.51	0.61	0.70
Viscosity (centipoise)	3.5	0.9	0.37
Thermal Conductivity (Btu/hr-ft^2-°F/ft)	3.5	0.9	0.37
Density (lb/gallon)	7.00	6.65	6.25
Prices (FOB)	1-2 55-Gallon Drums >60 55-Gallon Drums Bulk (5800 gallons)		$8.55/gallon $6.09/gallon $5.77/gallon

In Figure 3.2, the nominal design point energy and fluid flow rate balances are presented for the prototype demonstration system. The oven, griddle and deep-fat fryer are each rated at 40,000 Btu/hr heat transfer rate at an operating temperature of 350°F. Three gal/min of Multitherm PG-1 passes through each appliance, with the fluid temperature decreasing from 450°F to 395°F in each of these appliances. The kettle is rated at 80,000 Btu/hr at an operating temperature of 212°F, with 3 gal/min thermal fluid flow rate and temperature change from 450°F to 340°F. To provide hot oil flow when no appliances are cooking, a bypass flow of 36 gal/min is provided across a constant flow resistance.

The total nominal heat load is thus 200,000 Btu/hr with all appliances operating at full capacity, not including standby losses. The required input fuel rate is 261,000 Btu/hr (LHV) or 277,700 Btu/hr (HHV). The Becker burner used in the system is rated at 2 GPH diesel fuel burning rate, corresponding to 280,000 Btu/hr (HHV) input.

The flue gases leave the fluid heater at a nominal temperature of 932°F, corresponding to an overall heater efficiency of 76.6% (LHV). This flue gas is hot enough to be used for other heating purposes if desired, such as heating of water as included in the energy balance of Figure 3.2. The LHV overall system thermal efficiency could then be increased to over 90%. The water heating option is not included on the demonstration prototype.

The system is designed to provide a high flow rate of 33 gal/min minimum through the fluid heater. This high flow rate is achieved by providing bypass flow through the fluid heater so that a high flow rate is maintained through the heater tube bundle regardless of the flow rate to the appliances (maximum of 15 gal/min, minimum of 3 gal/min). The high flow rate in the fluid heater is required to provide a low fluid film temperature (high heat transfer coefficient) and eliminate, by high turbulence, stagnant flow regions where hot spots would form, thereby eliminating or minimizing thermal degradation of the thermal fluid by high temperatures.

The particular flow arrangement of Figure 3.1 and 3.2 was based on maintaining a very-simple and reliable system with a minimum of controls. Each appliance is controlled at the desired set-point temperature by means of an on-off solenoid valve operated by a thermostat. As indicated in Figure 3.1, these control valves are located on the return line from the appliance to minimize the temperature rating of the valve (395°F fluid temperature instead of 450°F). During the preliminary cooking test, this on-off control of the fluid flow to each appliance was adequate for temperature control.

The fluid heater is also operated on-off with a relatively wide temperature band of 25°F to prevent rapid on-off cycling of the burner. The preliminary testing also indicated adequate behavior, with adequate temperature control and on-off cycling periods of several minutes.

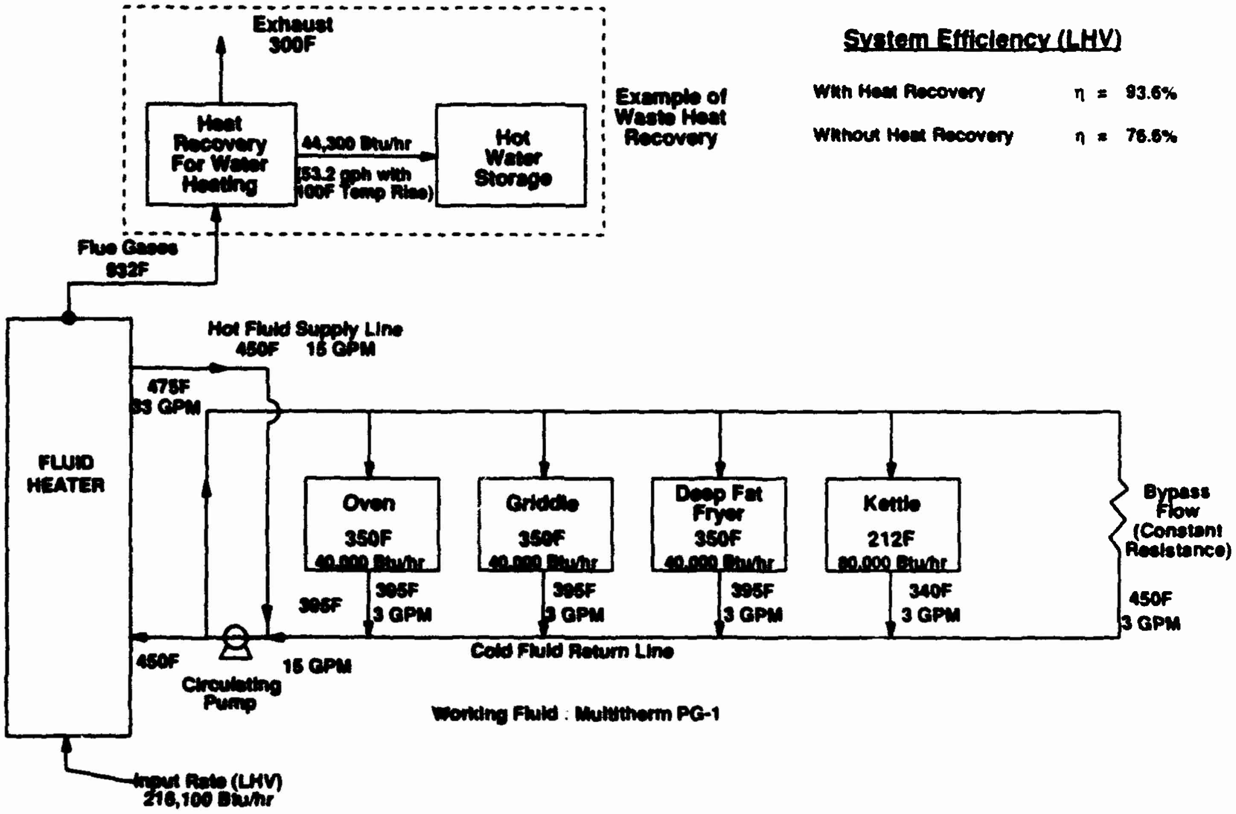


Figure 3.2 Nominal Energy Balance and Operating Temperatures of an Integrated Kitchen with a Pumped Liquid System

On-off cycling of the burner is thus representative of home furnace use of the burner, for which it was designed. Residential furnaces cycle on-off frequently throughout a heating day, with reliable operation and clean combustion.

The high by-pass flow system does not include active pressure control across the supply and return lines in the interest of simplicity and reliability. Depending on the flow rate to the appliances, some variation from the nominal value of 13 psid will occur as appliances are turned on and off, or control valves are turned on and off. Variation above and below the 3 gal/min nominal flow rate through the appliances will occur. However, this variation is small enough to not seriously degrade the cooking performance, based on the preliminary cooking tests.

Other flow loop arrangements are possible for more precise control. Industrial heating system, as illustrated in Figure 3.3, generally include modulating valves and control for very precise temperature control in response to variations in heating loads. This type of control was not included in the demonstration system for cost and reliability reasons. Some relatively simple changes can be incorporated for improved control, if deemed necessary from additional cooking tests. In Figure 3.4, an alternative flow arrangement is illustrated in which a bypass control valve rather than a constant flow resistance is used across the supply/return lines. The control valve provides a constant pressure differential between the supply and return lines, regardless of the cooking load. The appliance will therefore operate near the nominal design point flow rate at all times, with improved cooking performance. Modulating valves on each appliance, coupled with the pressure differential regulation, would provide the ultimate in cooking performance, but with higher cost and lower reliability.

An alternative option for kettle heating is also illustrated in Figure 3.4. A fluid-heater steam generator is used to supply steam to the kettle, providing better cooking performance than when directly heated by the 450°F thermal fluid which can result in some overheating and sticking for thick products such as sauces. The steam generator can also provide steam for other appliances, such as steam tables and compartment steamers.

From Figure 3.1, the modularity of the MATCH field kitchen is evident. Field kitchens to meet varying field needs can be supplied simply by substituting appliances. For example, a portable field kitchen with four ovens can be supplied simply by substituting three ovens for griddle, fryer and kettle. Tubing connectors for the supply/return lines for each appliance facilitate substitution of appliances in any combination desired.

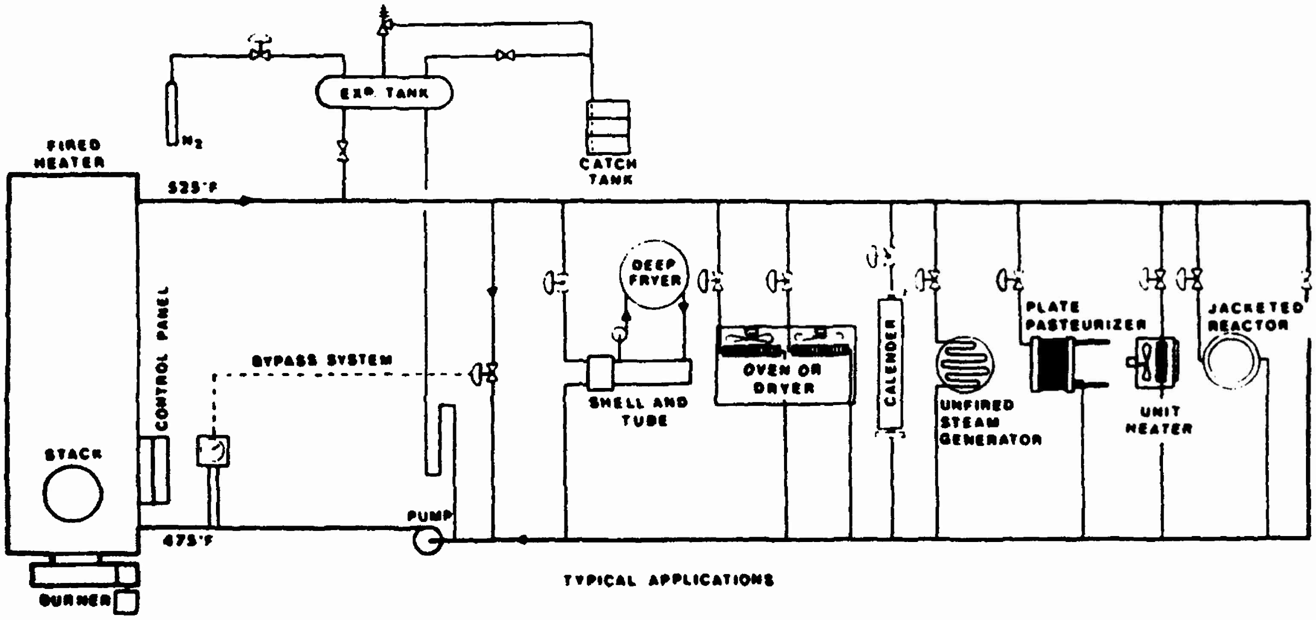


Figure 3.3 Hot Oil Heating System for Various Industrial-Scale Cooking and Process Heating Applications

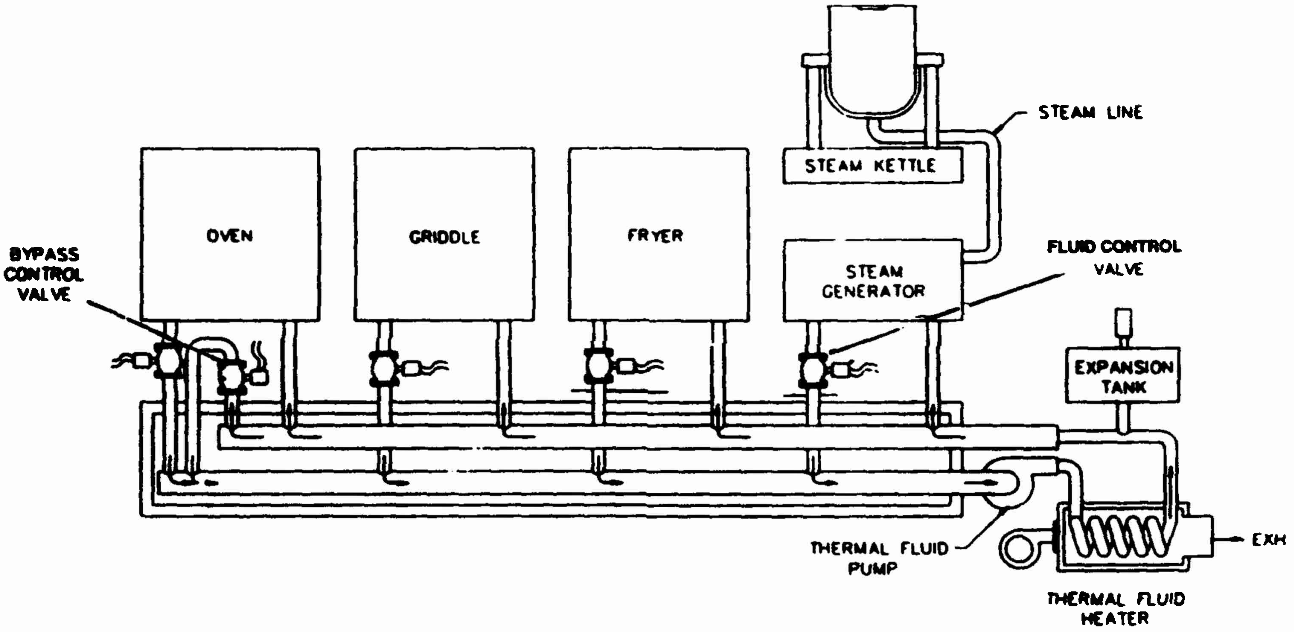


Figure 3.4 Pumped Thermal Fluid

3.2 HARDWARE DESCRIPTION

3.2.1 Overall Demonstration System

The complete MATCH demonstration kitchen is illustrated in the photograph of Figure 3.5. The system incorporates a griddle, two-basket deep-fat fryer, kettle and convection oven as illustrated. The hot-oil heater subsystem is located under the griddle and deep-fat fryer as illustrated in Figure 3.6, which shows the system installed on the frame prior to incorporation of the sheet metal skirts. Figure 3.7 is an end view of the installed hot-oil system. The rear-view of Figure 3.8 illustrates the insulated hot-oil supply and return lines. The return line has the four solenoid on-off valves used for on-off control of the hot-oil flow through each appliance, the two connecting lines to each appliance are also illustrated in this photograph. Figure 3.9 illustrates the one-piece heavy-duty frame used for the system.

The overall foot-print for the four appliance demonstration system is 12'10 " Length by 3'2" Depth. The appliances are placed at a height typical of use in commercial kitchens.

Operation of the system by the cook is simple. To start the system, the cook only has to press the "Start" button. The hot-oil system is automatically started and brought to the nominal operating temperature of 450°F oil supply temperature (about 8 minutes for the hot oil system only and 23 minutes with all four appliances set at 350°F). The hot oil system automatically maintains the nominal 450°F oil supply temperature by on-off operation of the burner, regardless of cooking load. Each appliance includes a thermostat for temperature control, which operates the on-off solenoid valve for that appliance to maintain the set-point temperature. The thermostat also acts as the on-off switch for the appliance. To shut down the system, the cook presses the "Stop" button.

3.2.2 Appliance Descriptions

The appliance used in the demonstration system are based on off-the-shelf components, either modified for use with hot oil or used as-is (no modifications). In Table 3.2, a listing of the appliances/components used for the demonstration system is summarized. Also listed are recommended improvements, based on the preliminary testing. Descriptions of each appliance follow:

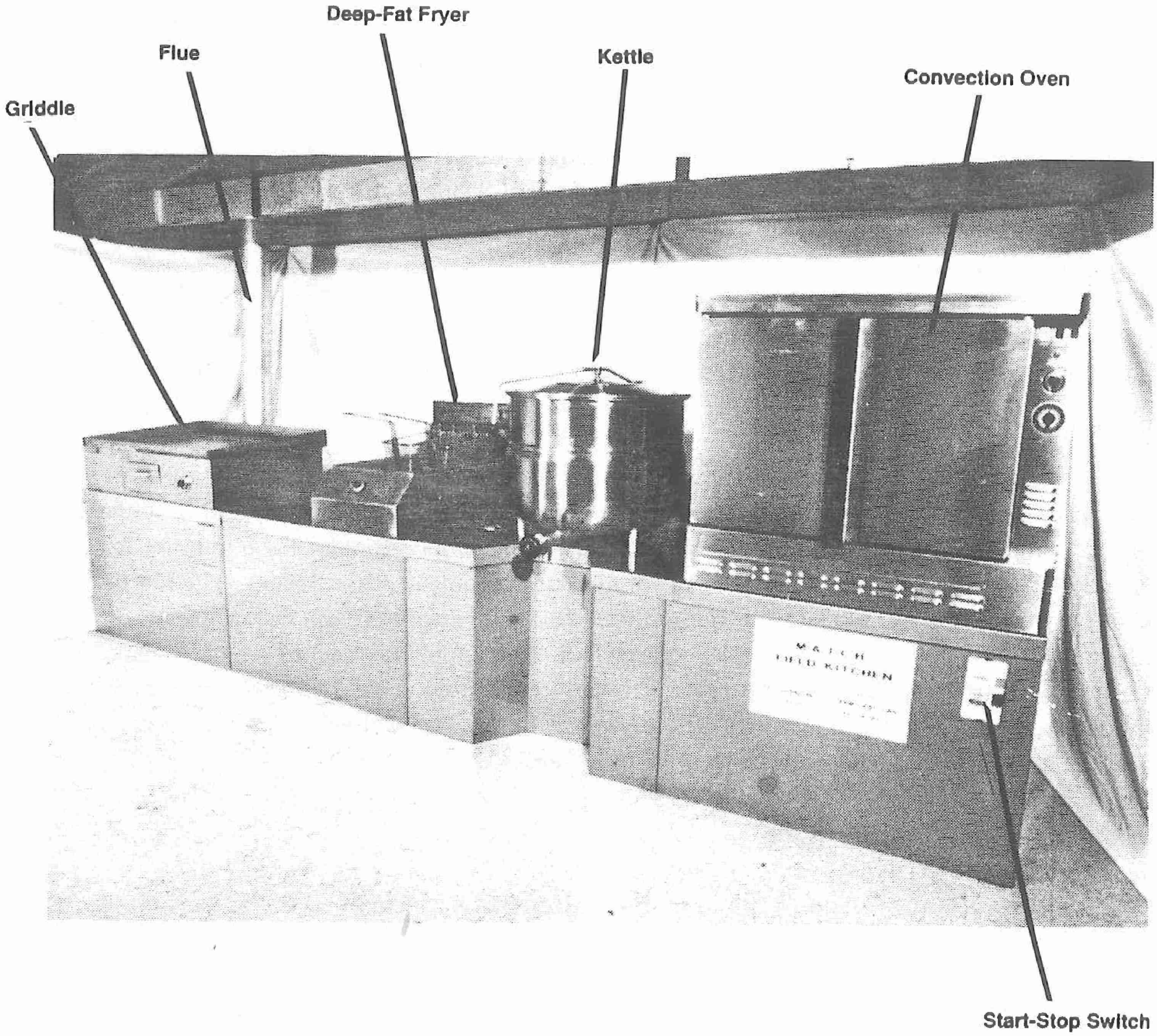


Figure 3.5 Photographs of Complete MATCH Demonstration

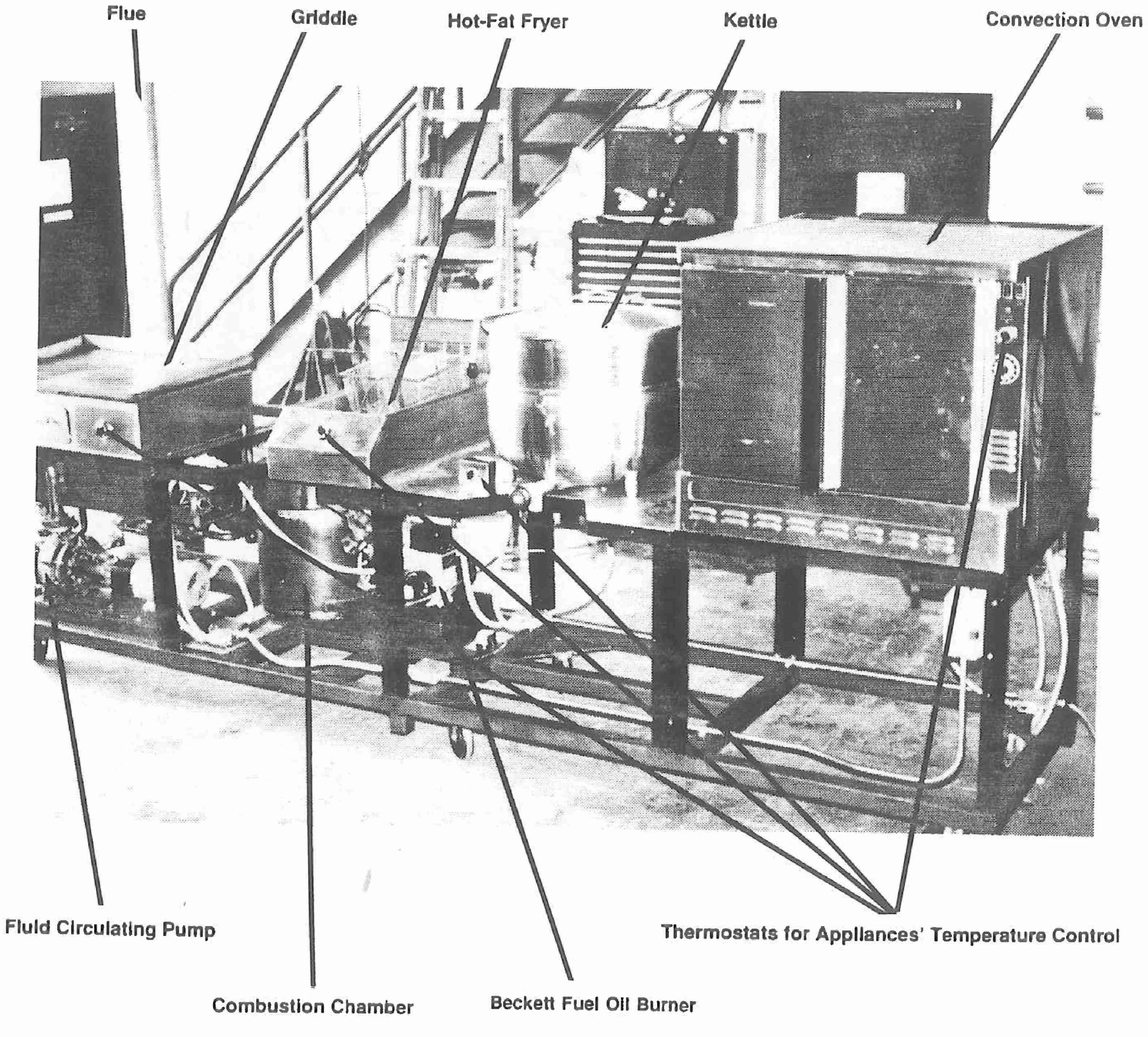


Figure 3.6 Photograph of MATCH Demonstration System Assembled on Frame

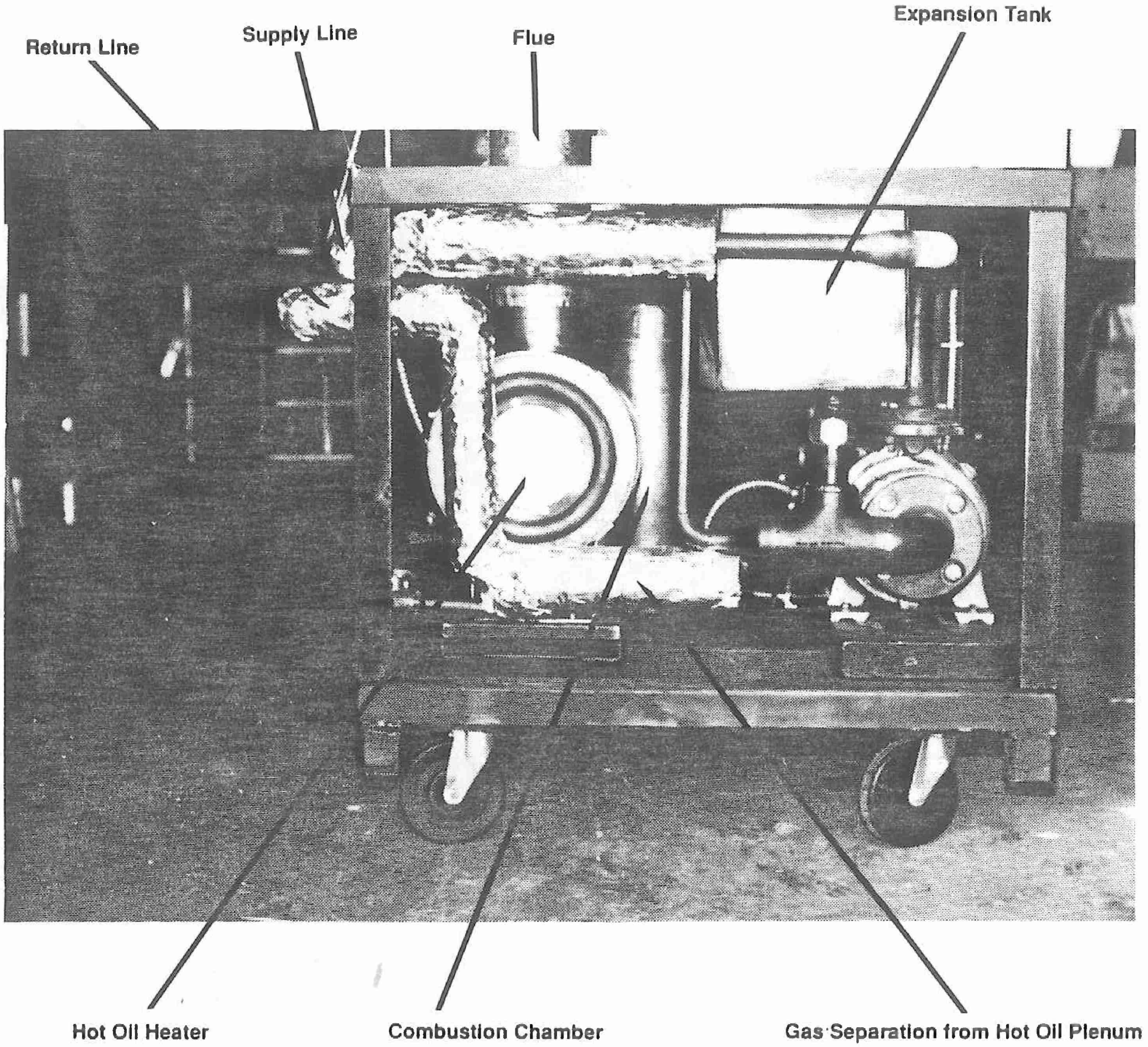


Figure 3.7 End View Photograph of Hot Oil System

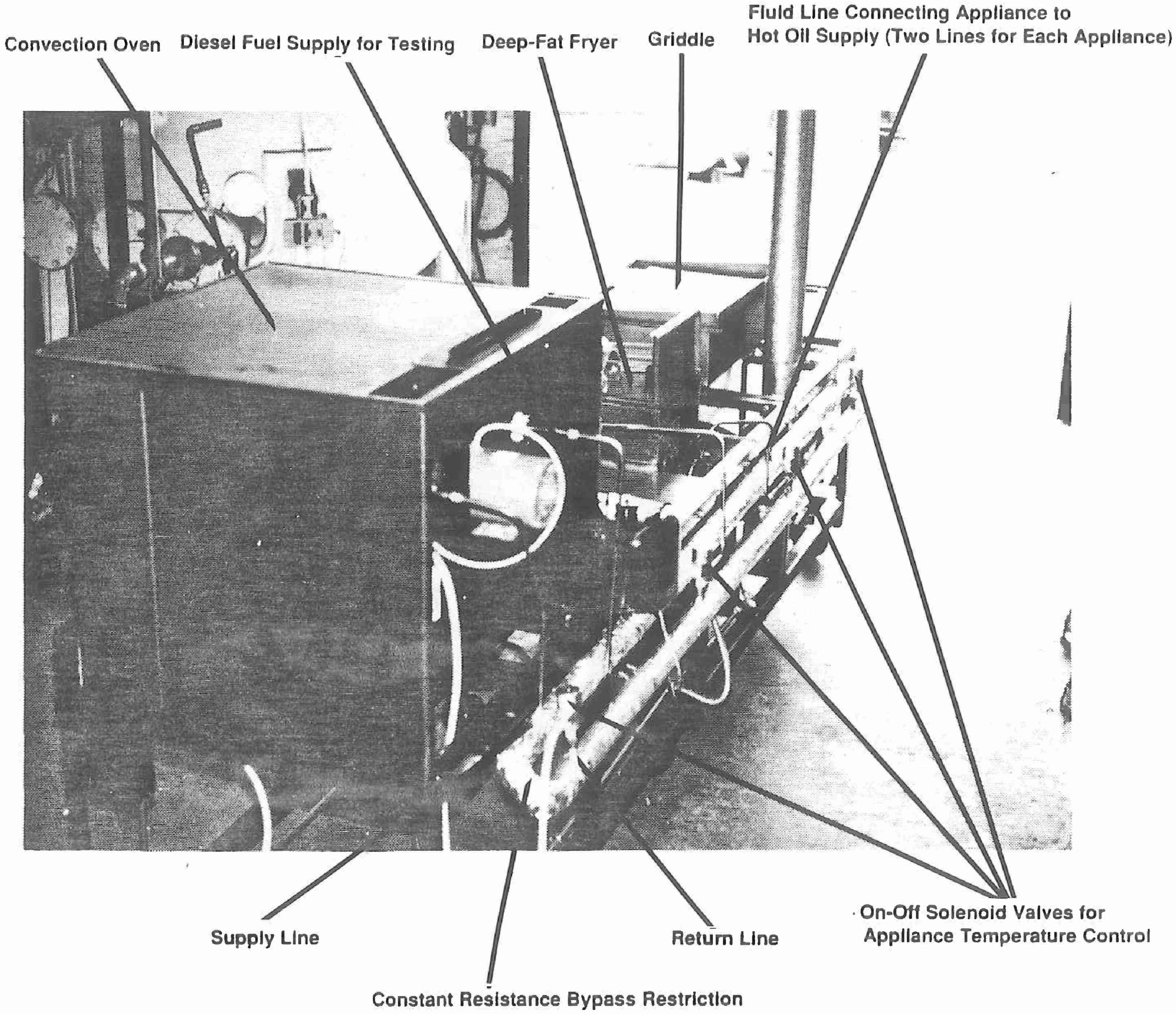


Figure 3.8 Rear View of Assembled MATCH Demonstration System

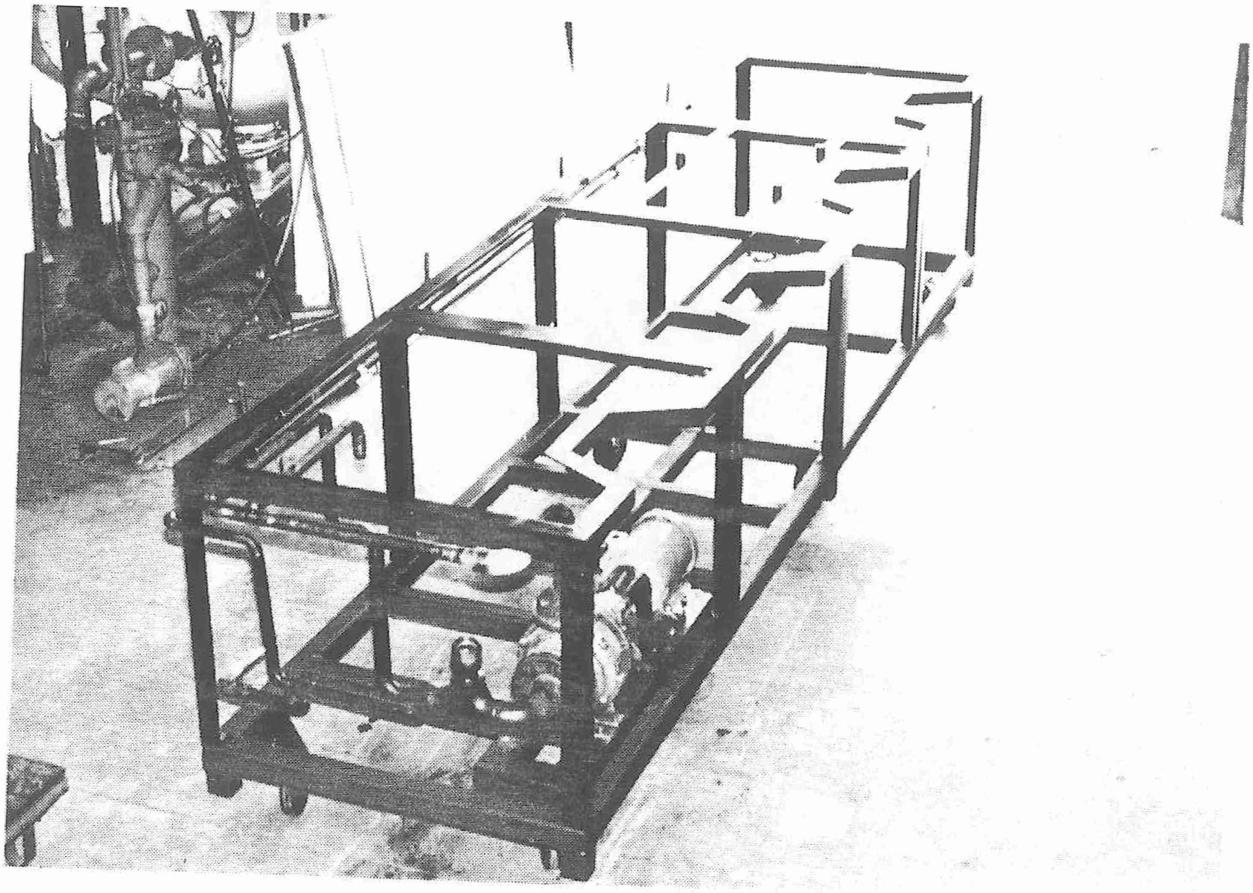


Figure 3.9 Complete Frame for MATCH Demonstration System

TABLE 3.2. Appliances Procured and Modified or Used As-Is for Use with Hot Oil

Appliance	Description as Procured	Vendor	Price	Modifications Made	Recommended Improvements From Testing
Oven	Commercial full size convection oven, gas-fired	The Blodgett Oven Co., Burlington, VT	~$2,500*	Gas burner removed and replaced by four 15 ft long spiral wound SS tubes, 1/2" OD x 0.035" wall, total surface area of 8 ft^2	None
Kettle	Commercial 40 gallon, stationary steam jacketed kettle with cover and pouring spigot	Market Forge Corp., Boston Showcase, Newton Highlands, MA	$2,750	None, except for tube connections to match hot oil tubing	Operation satisfactory for low viscosity foods, i.e., water boil, soups. Use with sauces of thick consistency was not satisfactory. Either heat sauces in covered pots immersed in water heated kettle or use oil-heated steam generator with steam supplied to kettle.
Fryer	Commercial two basket deep fat fryer, gas-fired fire tube type	Pitco Corp., Concord, NH	~$2,500*	Gas burner removed: Insert placed in each of four fire tubes to restrict oil flow, providing high velocity at tube wall. Headers added to fire tubes for series flow of hot oil through fire tubes.	Recovery time was slow, resulting in low production capacity. Increase heat transfer area by 100% by use of larger fire tubes in place of 2" x 4" fire tubes and improve hot oil flow baffling for higher hot oil heat transfer coefficient. Also consider use of plate coil heat exchangers to replace fire tubes.
Griddle	(A) Standard plate coil, style 50 RS serpentine, single side embossed, SA415 steel, 14 Ga on embossed side, 12 Ga on companion side smooth side used to cook-on, 22" depth, 35" width.	Transfer, Inc., Wichita Falls, TX	$ 262	Integration of plate coil with griddle base.	Heavier Ga steel on companion side to add thermal mass for lower temperature droop during food drop. Use of non-standard embossed tube flow pattern for improved cooking uniformity over entire surface should be evaluated, but is not essential.
	(B) Prototype base taken from 36" x 24" second hand electric griddle	Vlakos Restaurant and Supply, Canton, MA	$ 150		

*Estimated Price – All others reflect actual purchase price.

Oven. A commercial, gas-fired, forced convection oven manufactured by the Blodgett Oven Co. of Burlington, Vermont, is ideal for modification to a hot-oil heated oven. In these ovens, both gas-fired and electric, a blower wheel at the rear of the oven cavity is enclosed by a rear baffle plate. This wheel draws the air from the oven at a high rate. This air flows radially outward from the blower wheel behind the rear baffle and is reinjected into the oven around the top, bottom and sides of the baffle plate, resulting in rapid flow and uniform convective heating of food being processed in the oven.

The modification made is illustrated in Figure 3.10 and 3.11. In Figure 3.10, the spiral-wound tube bundle surrounding the blower wheel is illustrated. The tube bundle has four spiral-wound tubes operating in parallel from a common supply header and return header. Characteristics of the tube bundle are:

Tube Type	Stainless Steel
OD	1/2"
Wall Thickness	0.035"
Total Outside Surface Area	8 ft^2
Total Tube Length	60 ft
Number of Parallel Passes	4
Tube Bundle - Outside Diameter	19 1/2"
Inside Diameter	12"

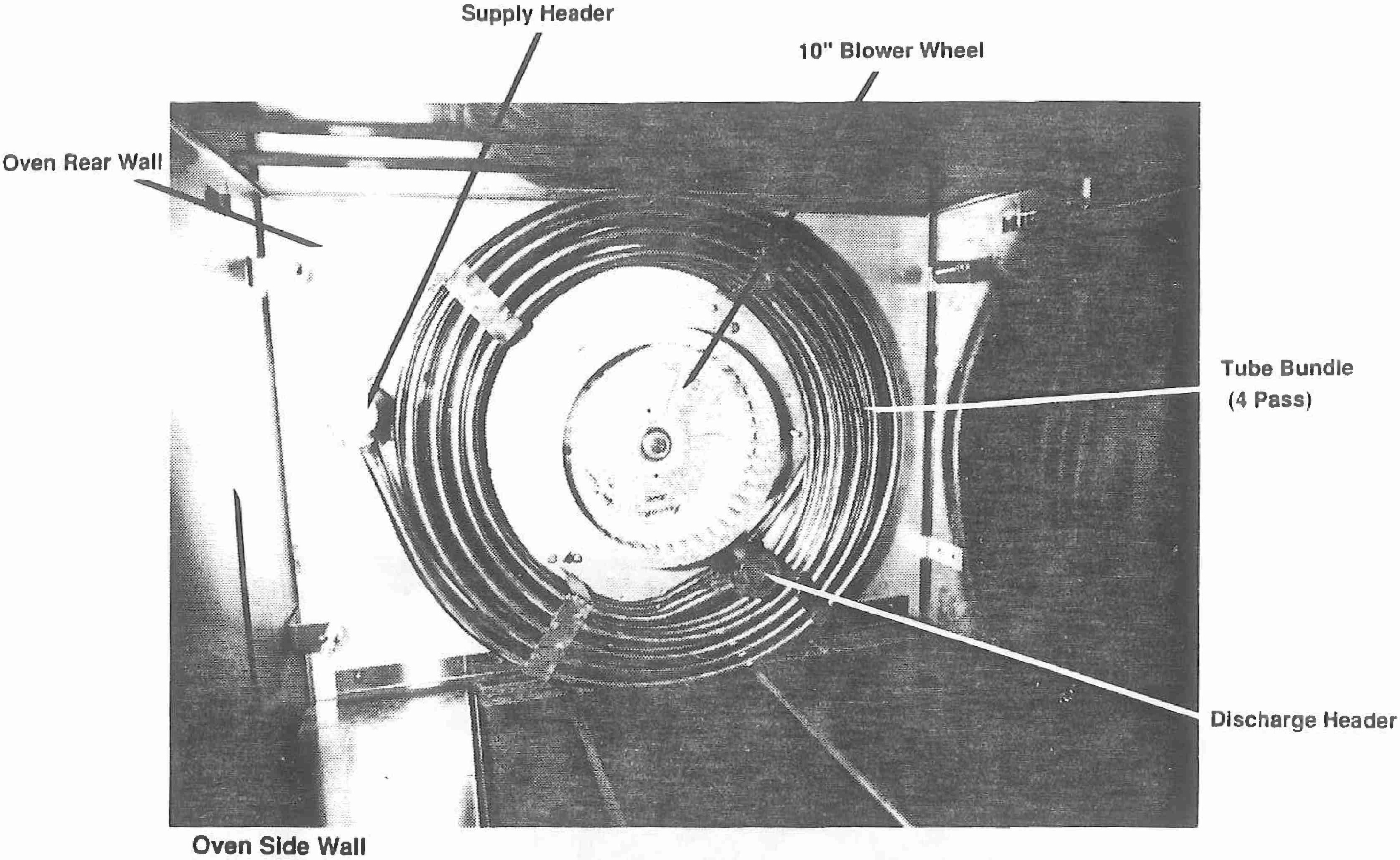
Figure 3.11 illustrates the oven interior with the rear baffle and support wire-grid shelves in place. Testing on the oven with baked potatoes and sheet cakes indicated excellent cooking performance.

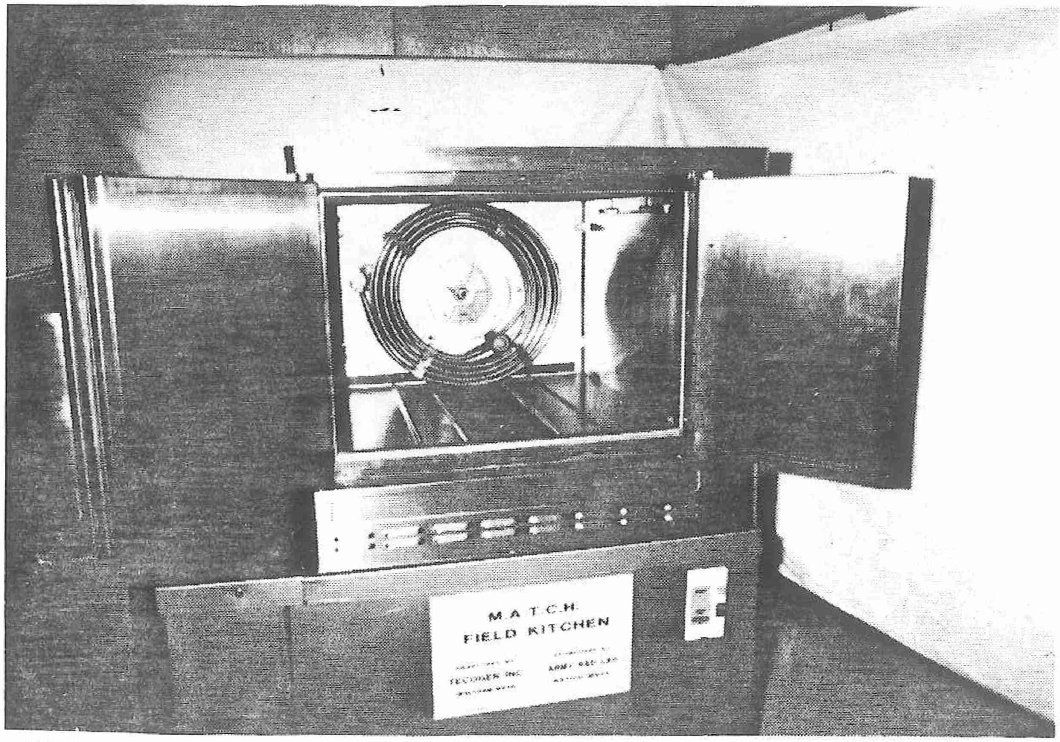
The similarity of the approach with the commercial Blodgett electric oven is evident by comparison for the hot-oil oven to the Blodgett electric oven in Figure 3.12. Electric calrod heaters surround the convection blower behind a rear panel as in the MATCH oven.

Kettle. The kettle is standard commercial steam-jacketed stationary kettle manufactured by the Market Force Co. (40 gallon, Model DL-40). The only modification was converting the tube fittings to the size for hot-oil heating. The kettle installed on the MATCH demonstration system is illustrated in Figures 3.5 and 3.6.

The cooking performance with products, such as boiling water or soups, was satisfactory. Thick sauces, such as oatmeal, gravy and spaghetti sauce, can be properly heated and simmered if the thermostat is set and maintained at a temperature of under 220°F. Higher temperature settings will cause the sauce to crust or scorch. Very delicate sauces or multiple sauces can be heated in the kettle by treating the hot oil-heated kettle like a double boiler. In this application illustrated schematically in Figure 3.13, separate pots holding the sauces can be set in boiling water inside the kettle.

(A) Close-Up View





(B) Overall View

Figure 3.10 Tube Bundle for Oven Heated by Hot Oil

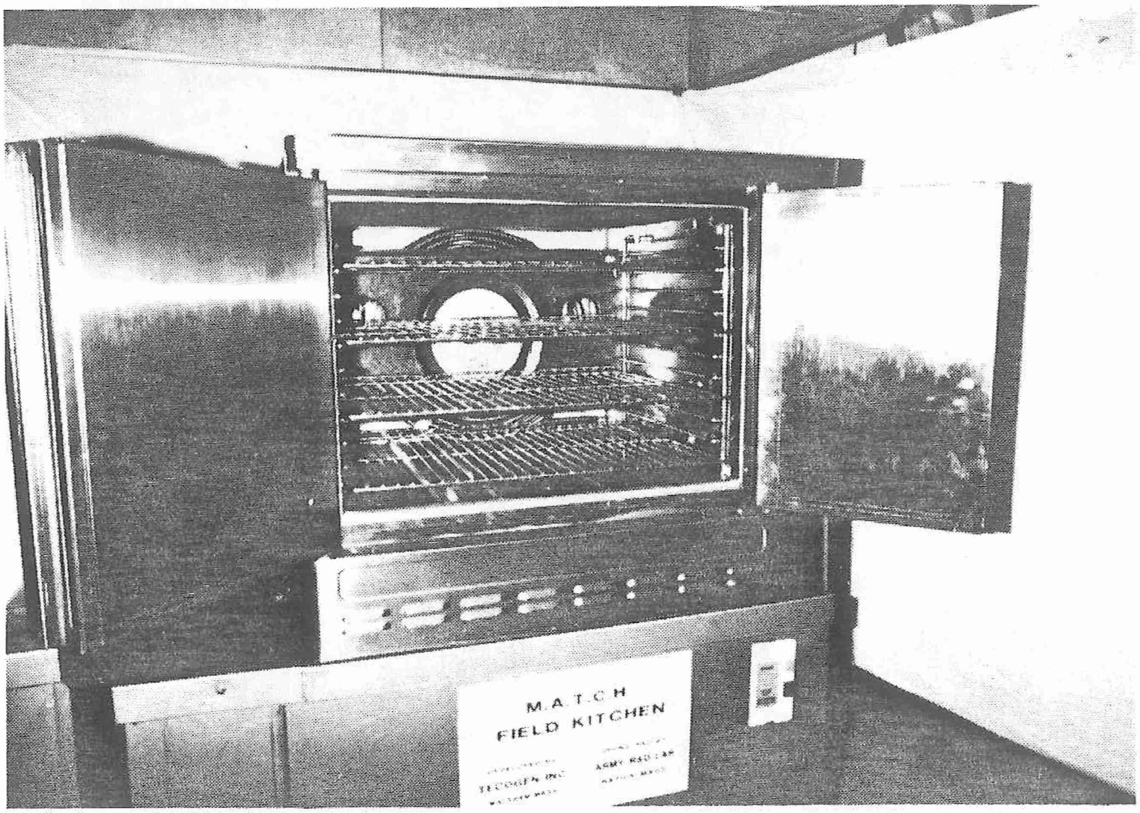
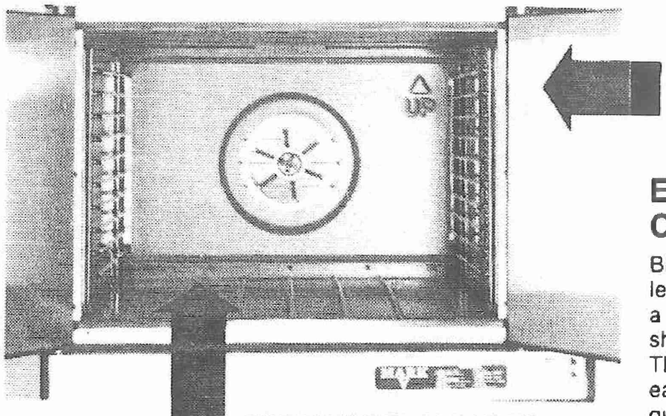


Figure 3.11 Complete Oven Interior With Rear Panel in Place and Tube Bundle Visible Above and Below Rear Panel

THE FAST, EASY ELECTRIC CONVECTION OVENS



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UNCLUTTERED, 3" DEEPER BAKING CAVITY

Easy to Operate and Clean . . .

Blodgett's new heavy-duty stainless steel doors are fully insulated; a cooler exterior and a clean, sharp appearance are the result. The smooth porcelain interior is easy to clean; racks and rack guides remove without tools.

Easy to Use.

Our new 3″ deeper cavity and blower coiled heating elements provide exceptional heat distribution in the baking compartment. With the addition of the two-speed motor and steam injectors, the MARK V's versatility is virtually unmatched. For limited heavy volume applications, the MARK V can be furnished with solid state temperature controls that offer superior temperature accuracy.

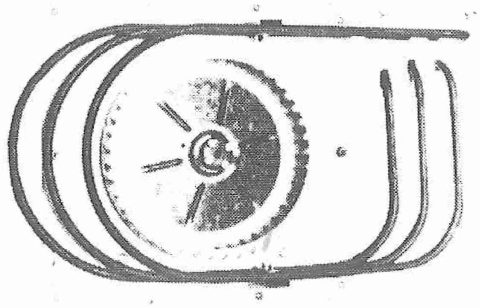


Figure 3.12 Interior and Electric Heater Arrangement for Blodgett Electric Convection Oven

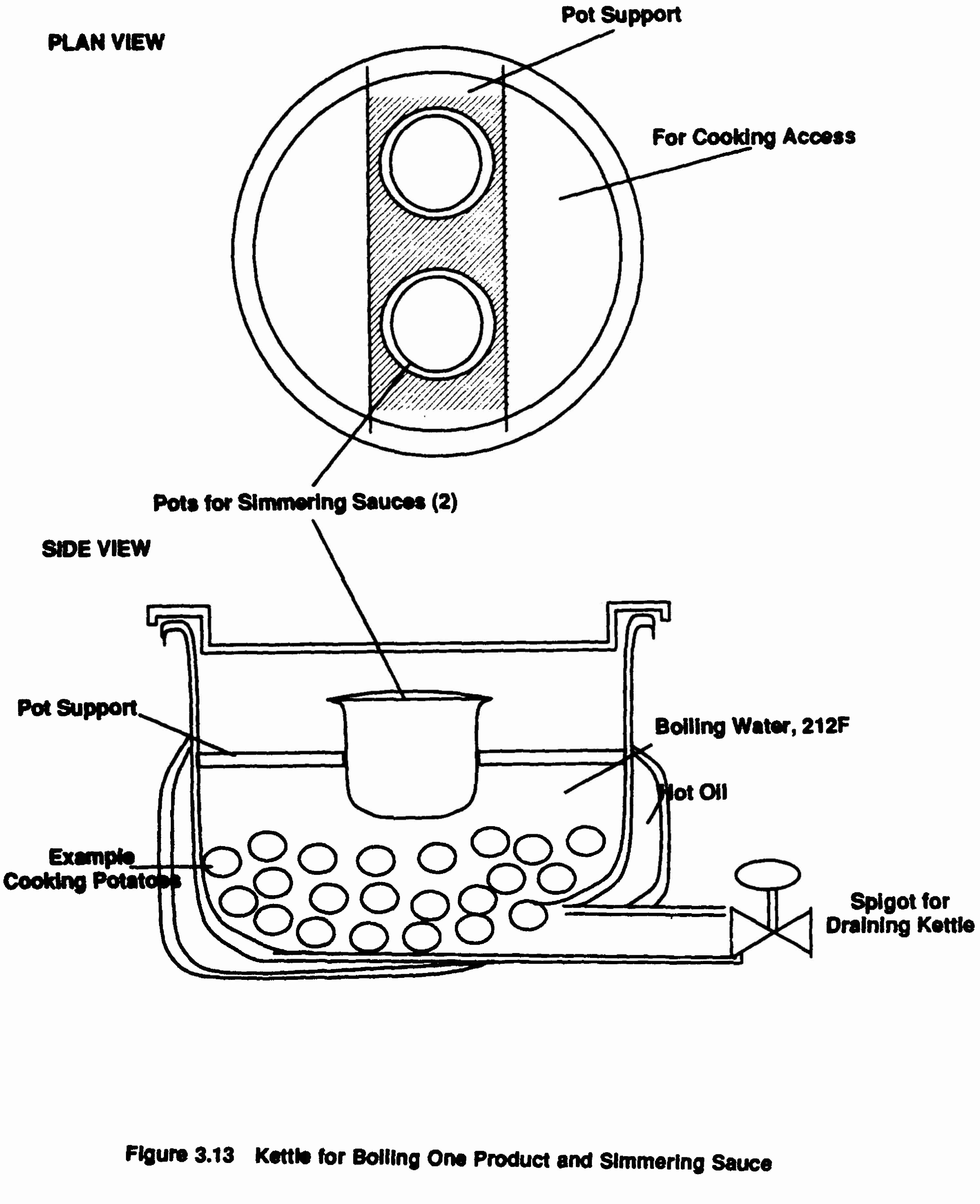


Figure 3.13 Kettle for Boiling One Product and Simmering Sauce

Fryer. A commercial gas-fired two-basket fryer was modified for hot-oil heating. The fryer modified was the Pitco Frialator Model 14 gas tube-fired type fryer, manufactured by Pitco Frialator, Inc., Concord, NH. The fryer, pictured in Figure 3.14, has the following characteristics:

Number of Baskets	2
Minimum Fat Capacity	40 lbs
Frying Area	14" x 14"
Frying Depth	4"
No. of Fire Tubes	4
Size of Fire Tubes (Outside)	4" H x 2" W x 14" L, Circular Ends
Inside Surface Area	
Per Tube	0.99 ft^2
Total	3.95 ft^2
Gas Firing Rate	110,000 Btu/hr
Heat Rate to Cooking Oil at 350°F	40,000 Btu/hr

In modifying the unit for hot-oil heating, it was necessary to provide a high flow velocity of hot-oil by the tube surface. For this purpose, metal box inserts or fillers where placed inside each of the tubes, as indicated in the cross-section drawing of Figure 3.15 and the photographs of Figure 3.16. These inserts forced the oil to flow in 1/4" wide channels along the tube surface, and increased the inside heat transfer coefficients by a factor of about 6 and the overall heat transfer coefficients from the hot-oil to cooking oil by a factor about 3, relative to the low velocity, hot-oil flow without the insert. The insert box was open on one-side and filled with stagnant hot-oil. To position the insert as well as provide a higher heat transfer coefficient, baffles were also welded to the outside of the insert as illustrated schematically in Figure 3.15. These baffles diverted the oil flow path as illustrated.

The second modification was to provide for connections to the supply/return lines and provide oil flow through the four fire tube. The flow path is illustrated in Figure 3.17 and the central connections for the fryer in Figure 3.18. Two parallel passes are used, with the hot-oil flowing down one fire tube, through a plenum at the front to the second fire tube, and back to the rear of the fryer through the second fire tube. The end caps welded to the rear of each fire tube are illustrated in Figure 3.16. Tube fitting were welded to these end caps for connection to the supply/return line, with the connections illustrated in the top view of the fryer installed on the MATCH demonstration system (Figure 3.18). The solenoid valve used for temperature control is also illustrated in Figure 3.18.

Pitco Frialator

Model 14 Tube-Fired Gas

There's Always Something Cooking.

MINIMUM FAT CAPACITY: 40 lbs. (19.7L)

The Model 14 Pitco Frialator is guaranteed to fry at least 75 lbs. (34 kg.) of potatoes raw to finish in 1 hour! Its many exclusive-with-Pitco features make frying easier, faster and more profitable. Unique Astro-Therm tubes provide instant recovery and eliminate waits between loads. This makes the Model 14 the perfect fryer for heavy-duty all-purpose frying in every type of kitchen.

FRIALATOR FEATURES

New Astro-Therm tubes. Astro-Therm tubes, an exclusive Pitco design, permit over 50% more heat to be transferred to fat instantly, reducing waits between loads. Recovery time is instant and food can be fried at lower temperatures. Astro-Therm tubes are exclusive with Pitco.

Simple to clean. Wide spacing between tubes at center of fryer permits easy access by hand to all areas below and between tubes for simplest possible cleaning.

Cool zone for better frying. Positive Pitco cool zone traps burnt particles, crumbs and black specks; prevents the major cause of fat breakdown and eliminates taste transfer.

Drain in a jiffy. Handy out-front quick open drain valve for quick draining and filtering of fat.

Eliminate spill-overs. Large foaming and surging area at the top of the fat container prevents messy spill-overs while cooking the larger loads possible with this fryer.

Accurate controls. Thermostat application gives chefs more exact control of frying temperatures. Extremely sensitive to any temperature change.

Combination control. Prevents gas flow to burners before pilot is lit. Automatically turns off all gas if pilot flame goes out. Acts as manual main gas valve, gas filter, diaphragm valve and pressure regulator.

Lift-off basket hanger. Exclusive "lift-off" design greatly simplifies back splash cleaning. It snaps on and off without tools and provides a rigid basket support.

Smart modern cabinet. Polished stainless steel front and door with sturdy one-piece welded steel body. 6" (15 cm.) adjustable sanitary legs, designed to meet public health requirements throughout the country.

Typical hourly production. *
Potatoes, raw to finish, 75 lbs. (34 kg.); Chicken, raw to finish, 50 lbs. (22.6 kg.); Cutlets, Fritters, 80 lbs. (36.6 kg.).

*Based on tests by Pitco Frialator, Inc.

Pitco Frialator, Inc.
P.O. Box 501, Concord, NH 03302-0501
Tel. (603) 225-6684; 1-800-258-3708; FAX (603) 225-8472; A BLODGETT Company

Figure 3.14 Commercial Fryer Modified for MATCH Demonstration System

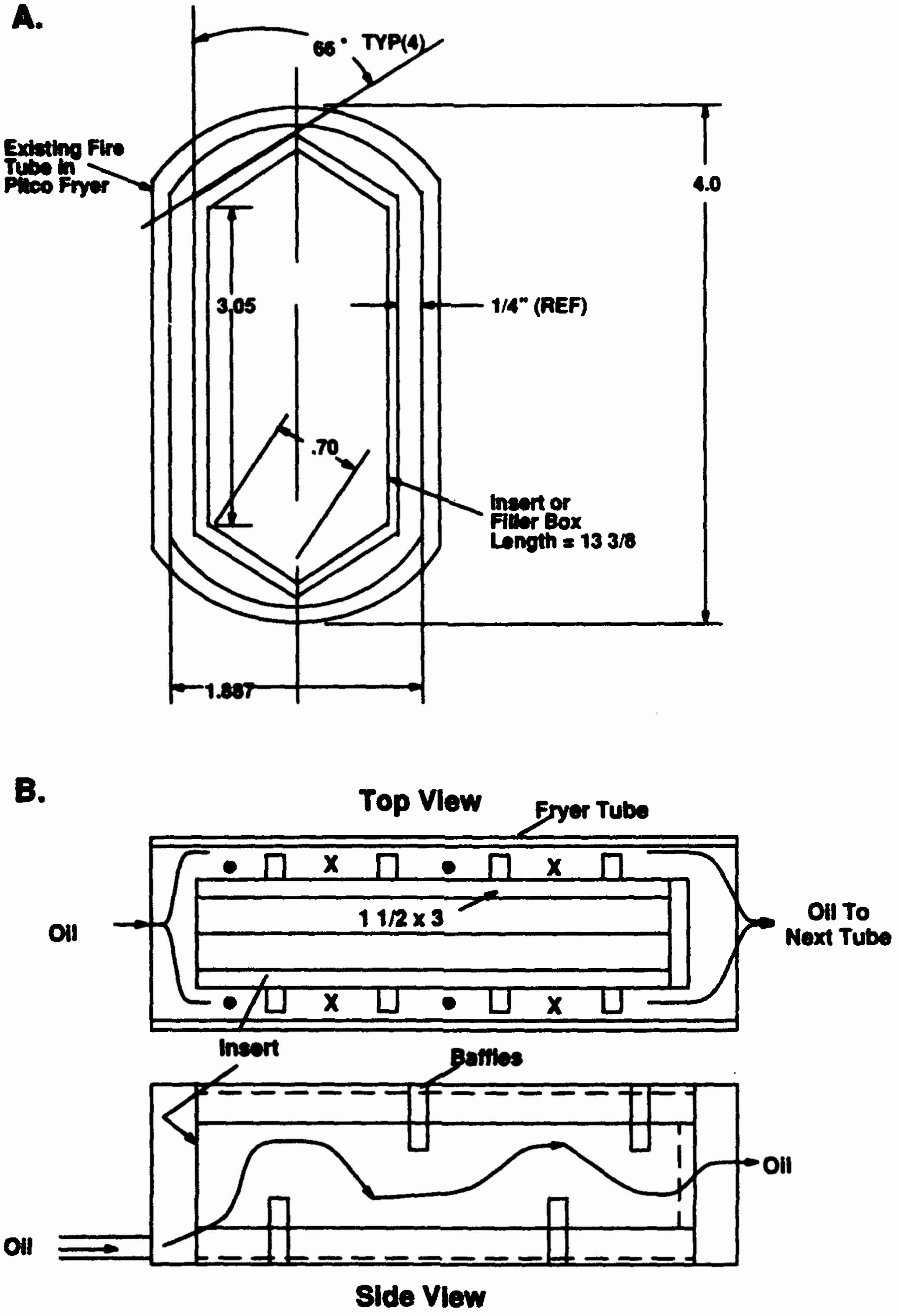
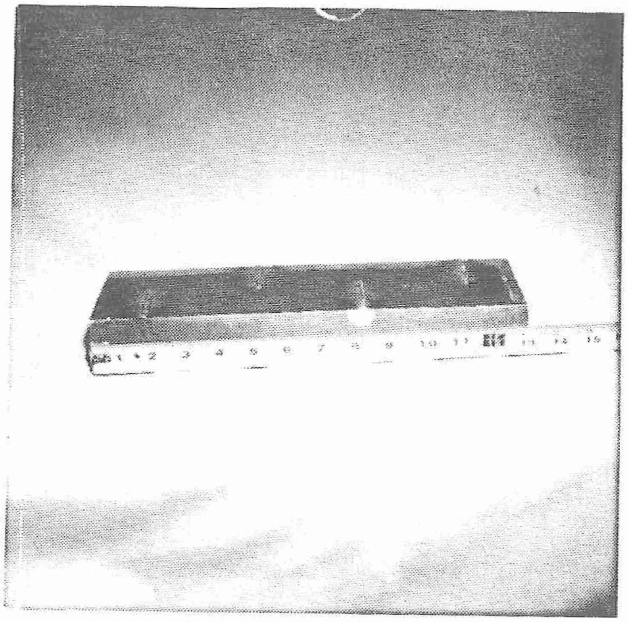
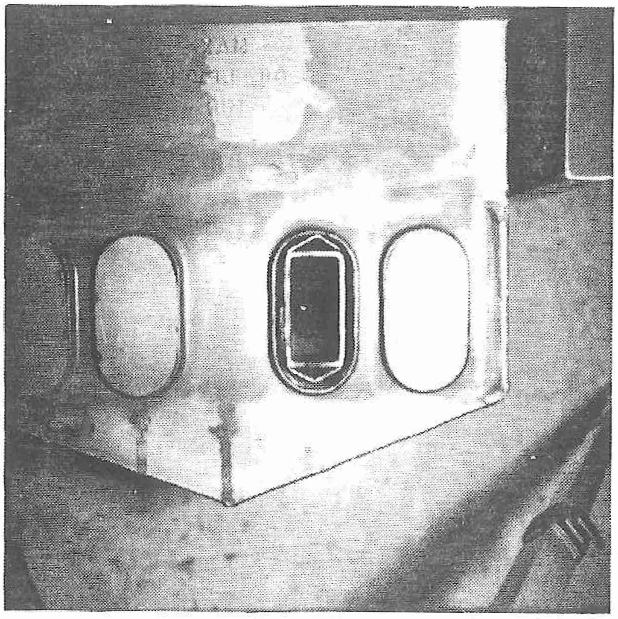


Figure 3.15 Tube Inserts for High Hot-Oil Velocity Past Tube Surface



(A) Core = 13" Long



(B) Fryer Tank (15" Long) With One Core Showing and End Caps

Figure 3.16 Photograph of Tube Modifications for Hot-Oil Flow

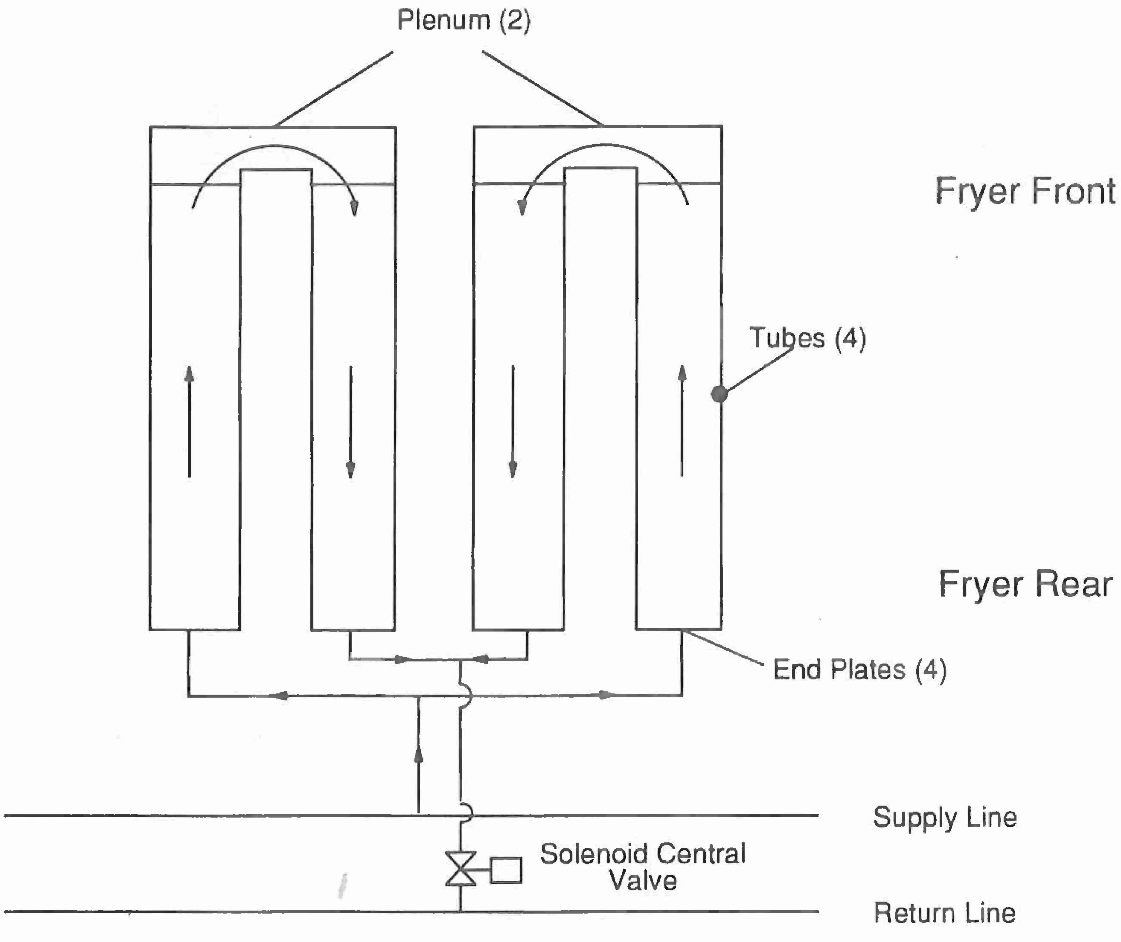


Figure 3.17 Flow Path Schematic of Hot Oil Through Four Immersed Tubes

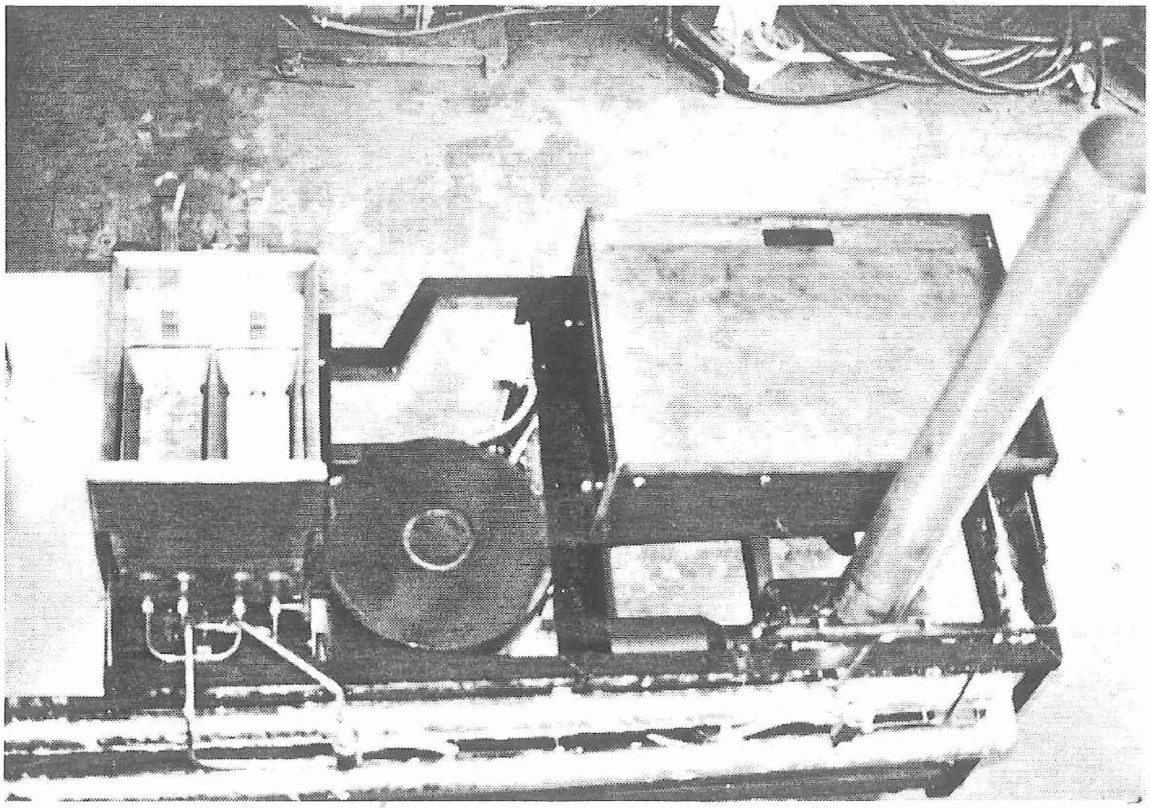


Figure 3.18 Photograph of Fryer and Griddle With Supply/Return Connections Illustrations

In the preliminary testing, the recovery rate was slow resulting in a low production rate. It is thus recommended that the heat transfer area in the immersed tubes be doubled from 4 ft^2 to 8 ft^2. This increase can be accomplished by increasing the height of the tubes, by use of special plate coil inserts, by adding one additional tube (total of five) or by a combination of these methods. These modifications to the standard fryer can be readily incorporated in manufacturing providing cooking performance equivalent to current gas-fired commercial fryers at reasonable cost.

Griddle. The griddle was made from a standard Tranter, Inc., plate coil with the following characteristics:

Plate Coil Style 50 RS
Serpentine
Single Side Embossed
Carbon Steel (1020)
14 Ga on Embossed Side
12 Ga on Companion Side
Depth = 22"
Length = 35"
FOB Cost = $262

A photograph of the embossed side of the plate coil is presented in Figure 3.19 showing the inlet-outlet tubing welded to the coil. The other surface (companion side) is flat and provides the cooking surface, with top view shown in Figure 3.18, as installed on the MATCH demonstration system. With the plate coil, the flowing hot oil is in direct contact with the cooking surface providing excellent thermal response. The on-off solenoid valve used for thermostatic temperature control is also evident in Figure 3.18.

The plate-coil was integrated into the base of a commercial electric fryer, complete with a grease tray and grease drawer. Splash shields around the griddle edge were also incorporated.

In preliminary cooking tests, cooking performance on pancakes and frozen hamburger patties was excellent. It is recommended that a thicker companion plate than the 12 Ga (0.1094" thick) be used to provide more-stored thermal energy to reduce the temperature drops when a frozen patty is dropped on the surface. Non-standard embossing patterns could also be used to improve temperature uniformity, but this modification is not believed necessary based on the preliminary testing.

3.2.3 Ancillary Equipment

The primary ancillary equipment is the hot oil delivery system. In Table 3.3, a listing of the components used for the demonstration system is summarized. Also listed are the modifications made and recommended improvements.

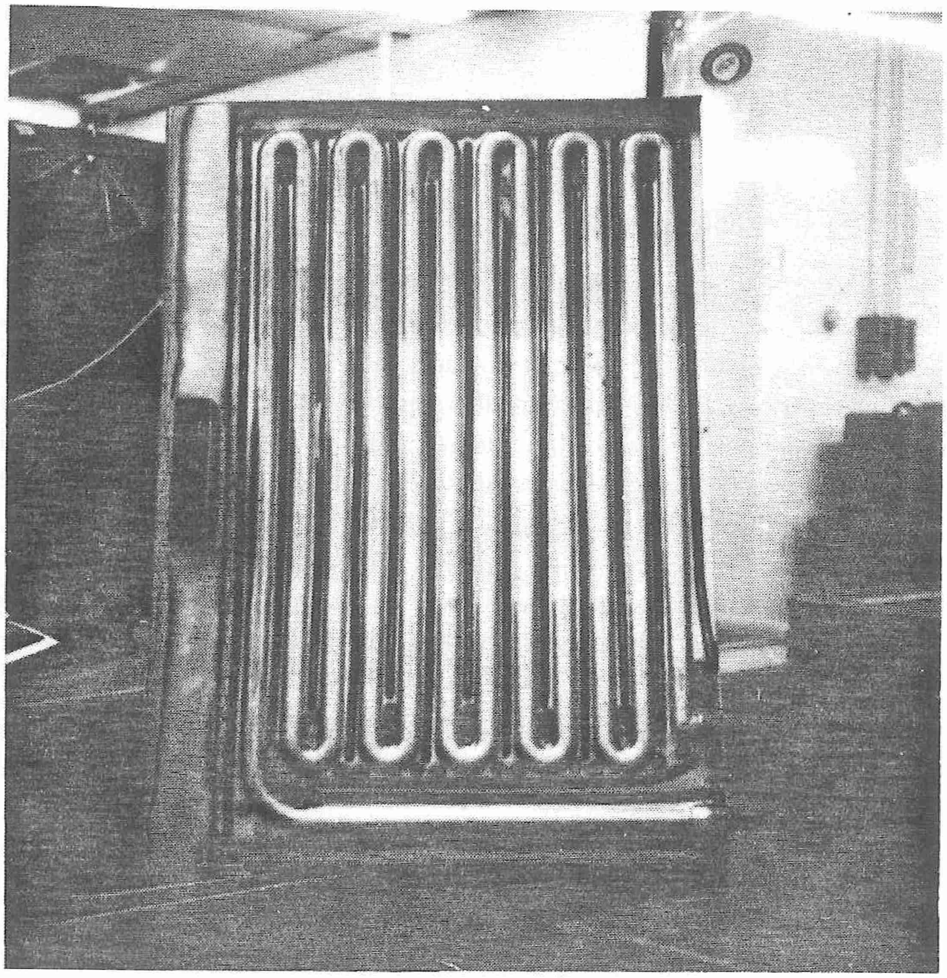


Figure 3.19 Photograph of Embossed Side of Griddle Plate Coil

TABLE 3.3. Ancillary Equipment Procured and Modified or Used As-Is

Component	Description as Procured	Vendor	Price	Modifications Made	Recommended Improvements From Testing
Oil Burner	Turbo-type residential oil burner, flange mount, 2 gal/min 60 degree hollow cone nozzle, 7 inch long air tube, cadnium sulfide controller	R.W. Beckett Corp. Elynie, OH	$326	None	None
Heat Transfer Fluid Heater	QNP 1650 Thermal Fluid Heater (Heat Exchanger), natural gas, 250,000 Btu/hr firing rate, 225,000 Btu/hr heat to liquid	Indust. Micro. Grp. Amana Refrig. Inc. Amana, IA	$5,500	Gaskets replaced with Gore-Tex to prevent leaks. Gas burner removed and replaced with duct from oil burner/combustion chamber.	Use welded construction rather than gaskets Open combustion side flow passages to reduce soot plugging potential in off-spec burner operation through redesign of heat exchanger.
Hot Oil Pump	SIHI Series ZTNA non-self priming centrifugal pump, suited for fluid temperature up to 610°F without active cooling, 145 psig max. pressure at 610°F, 156 mm (6.14") impeller	Fulton Thermal Corp. Pulaski, NY	~$2,000*	Pump rating much higher than needed, 10 hp 3300 RPM motor replaced with 1 1/2 hp 1730 RPM motor, E16 providing 48 gal/min at 11 psi head.	Use smaller pump; pump performance was excellent in testing.
Hot Oil Solenoid Valves for On-Off Controls	Solenoid valve hot oil service, 400°F rating, Gould Type G-1, 303; SS body and pilot valve assembly, normally closed, 3/8" FNPT 1/4" orifice, Class H or better, 12V AC, leakproof seat screw	J.D. Gould, Inc. Indianapolis, IN	$57 (OEM)	None	Increase temperature rating of valve to 500-550°F for increased life (limited now to 400°F by plastic insulation in coil)

*Estimated Price -- All others reflect actual purchase price.

Oil Burner and Combustion Chamber. A commercial residential oil burner (R.W. Beckett Corp.) was used without modification. The burner was coupled to a combustion chamber designed according to Beckett recommendations and fabricated at Tecogen. The design is given in the sketch of Figure 3.20. The photograph in Figure 3.21 illustrates the burner and combustion chamber. The combustion gas discharge to fluid heater from the combustion chamber is visible at the left of the photograph. The combustion chamber assists in achieving very clean combustion by use of thermal radiation from the chamber walls to vaporize the burning fuel oil droplets.

Fluid Heater. The fluid heater is manufactured by the Raytheon Company and marketed through its Amana Division. As indicated in the specification sheet of Figure 3.22, it is capable of directly heating temperature sensitive fluids, such as cooking shortening. For the MATCH demonstration system, the gas heater was replaced by the Beckett oil burner and combustion chamber. It was also found necessary to replace the gaskets supplied with the heater with 100% PTFE Gore-Tex GR™ sheet gasketing (W.L. Gore & Associated, Inc., Elktony, MD) because of oil leaks with the original gasketing. Gore-Tex GR gaskets have an operating range of -450°F to +600°F and are in a form that will not creep or cold flow. In Figure 3.23, the heat exchanger assembly is illustrated. The combustion gas enters the heater central column from one end and flows radially out through one row of heavily-finned tubes surrounding the central column. The gases then leave through the top stack connection. In Figure 3.24, a photograph into the stack opening shows the finned tubes indicating the tight fin spacing.

The liquid flow is directed by the gasketed manifolds on each end. The entering flow is split with half flowing through one tube-half circle and the other half flowing through the other tube circle. In each of the two parallel flow paths, the liquid flows in series back and forth through the tubes in a serpentine fashion. The split flows are re-combined at the hot-oil discharge line. The tight-finning provides a heat transfer area and high efficiency for the single tube row heater in a very-compact configuration.

In Figure 3.25, a photograph is presented of the fluid heater heat exchanger installed in the MATCH demonstration system, with the combustion gas inlet pipe and inlet/outlet hot-oil lines on the left side of the heater.

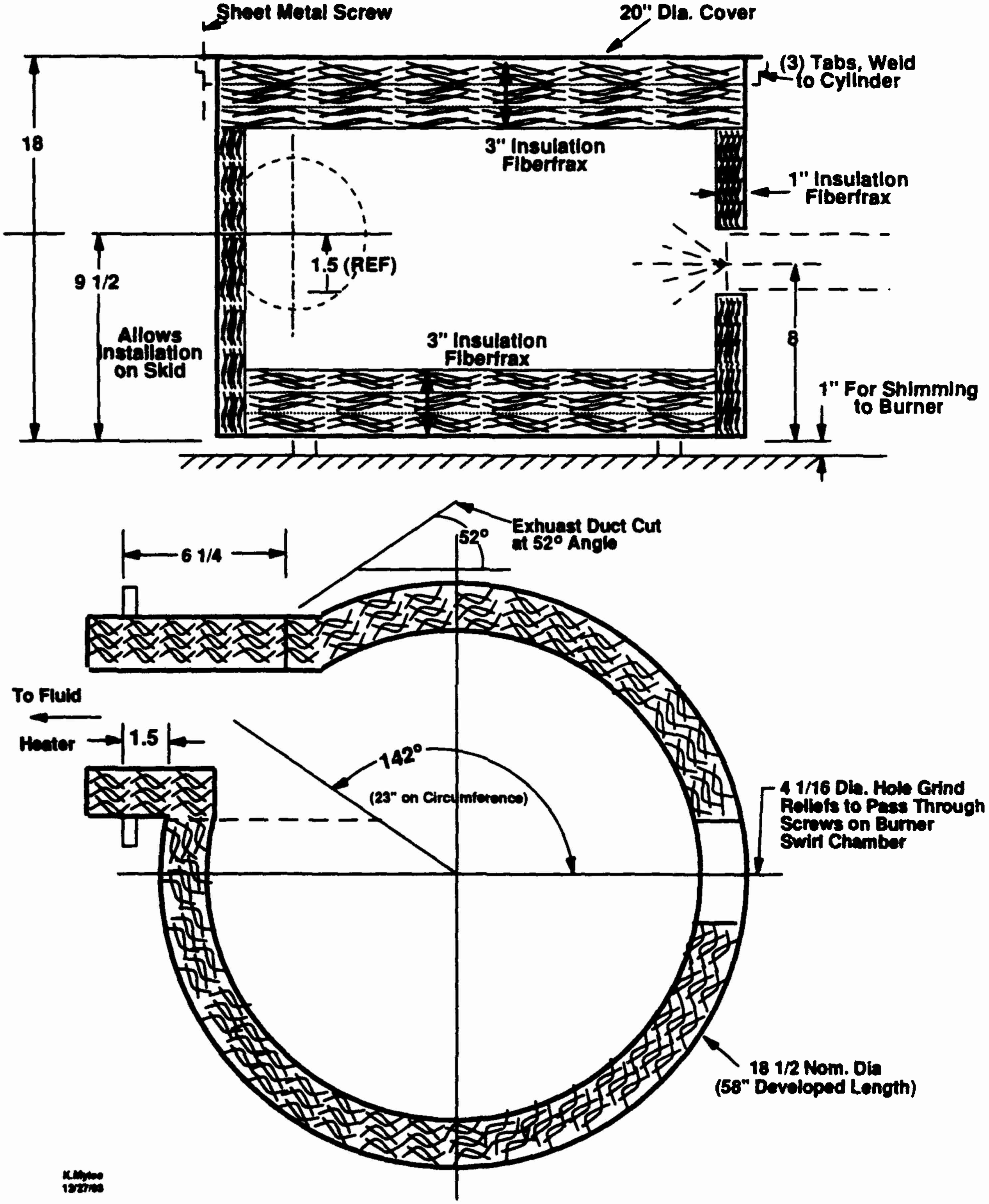


Figure 3.20 Combustion Chamber

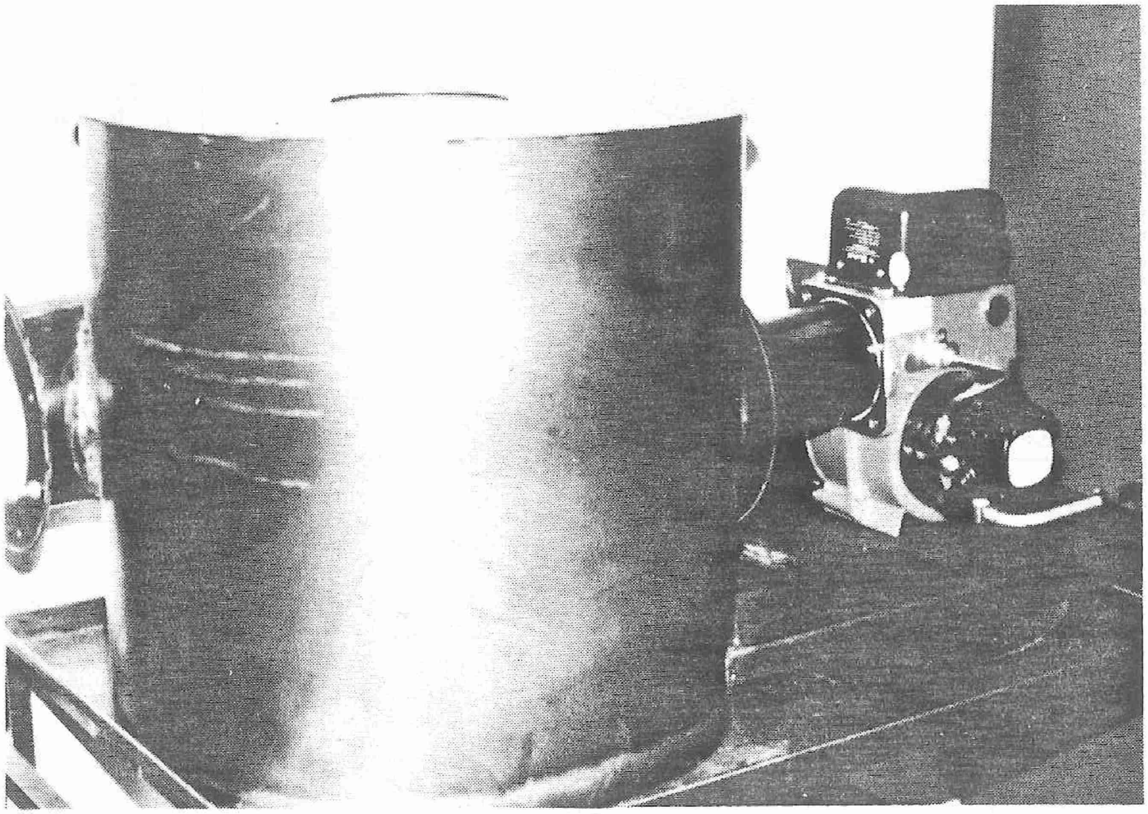


Figure 3.21 Photograph of Beckett Fuel Oil Burner and Combustion Chamber

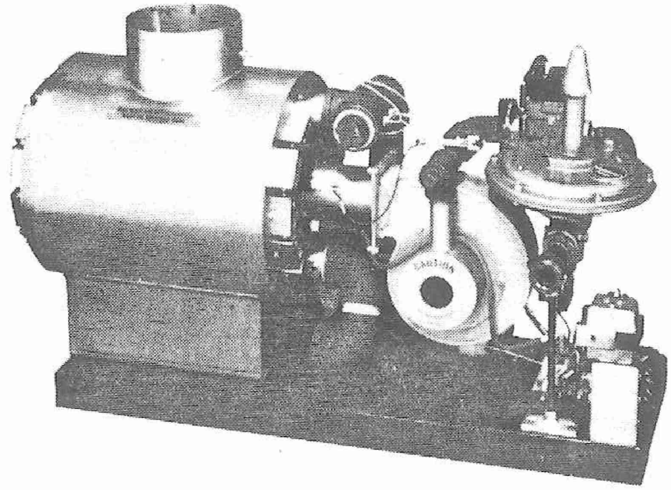
Raytheon
Company

Food
Processing
Equipment

190 Willow Street
Waltham, MA 02254
Tel 617 642-3361 or 2843

QNP 1650

Thermal Fluid Heater



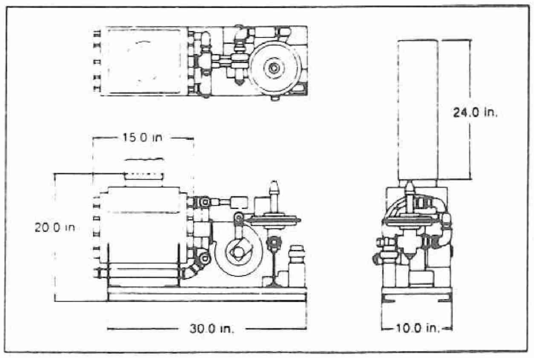
The RadarLine® QNP 1650 is a basic "building block" fluid heater that provides 210,000 BTUH into high temperature liquid for process applications. It is also capable of directly heating temperature sensitive fluids, such as cooking shortening.

SPECIFICATIONS

Input	Natural Gas 250,000 BTUH
Heat to Liquid	225,000 BTUH
Weight	Approx. 185 lbs.
Overall Dimensions	30" long × 20" high × 10" wide
Liquid Input/Output Pipe	1 1/2" Iron
Flow Rate	35 GPM
Gas Input Pipe	3/4" Iron
Ignition Control	Direct Spark/Flame Rectification
Electrical Input	115 VAC, 1.2 Amps

FEATURES

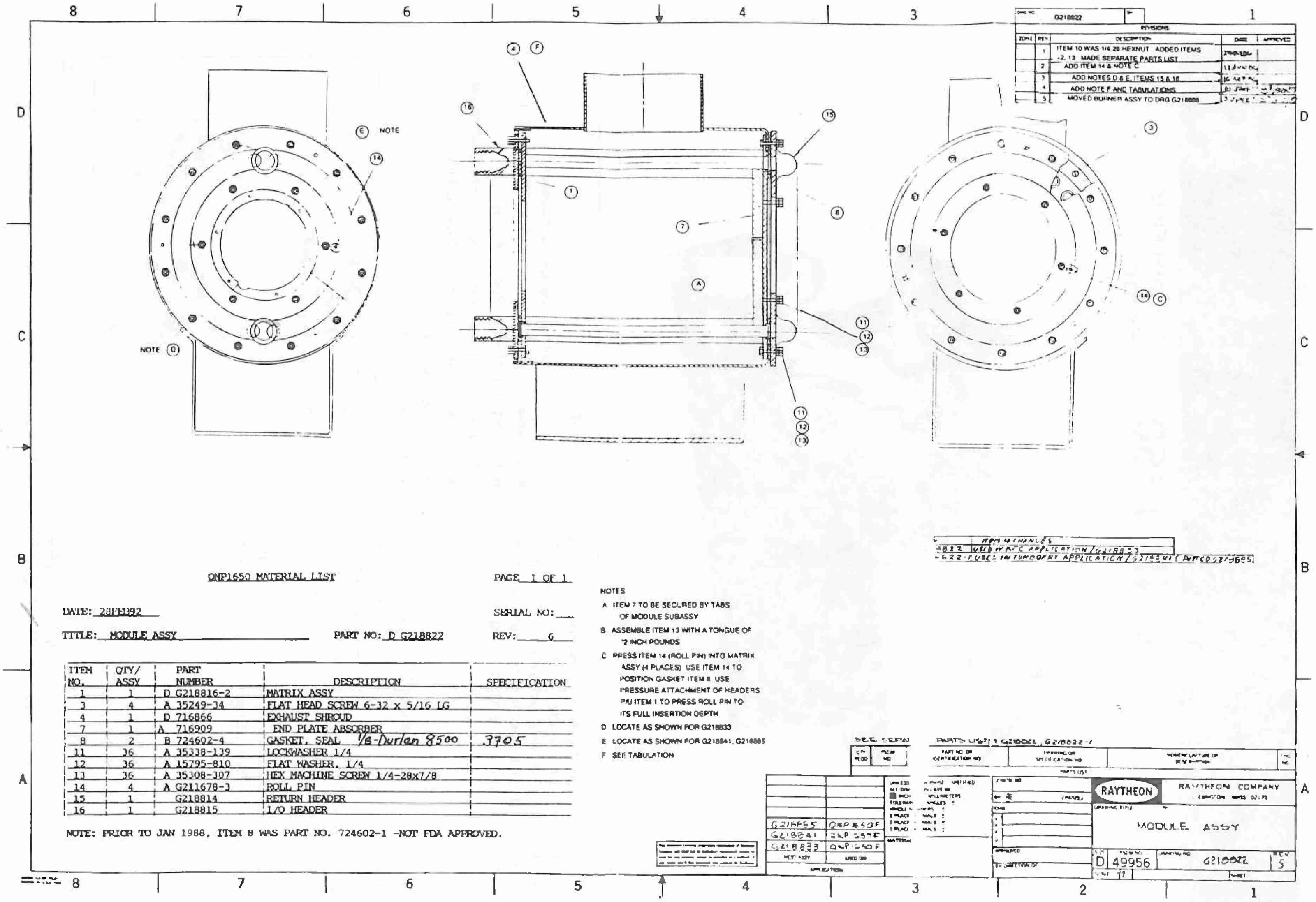
- Complete, Compact Heater Subsystem
- Variable Heat Input – 125,000 to 250,000 BTUH
- Proportional Mixing, Power Burner
- Raytheon Heat Transfer Module, Heat Exchanger
- Low Temperature Gradient, Bulk to Film
- Fast Thermal Response
- One Year Warranty



Raytheon

989

Figure 3.22 Manufacturer Specification Sheet for Thermal Fluid Heater



QNP1650 MATERIAL LIST

PAGE 1 OF 1

DATE: 28FEB92

SERIAL NO: ___

TITLE: MODULE ASSY

PART NO: D G218822

REV: 6

ITEM NO.	QTY/ ASSY	PART NUMBER	DESCRIPTION	SPECIFICATION
1	1	D G218816-2	MATRIX ASSY	
3	4	A 35249-34	FLAT HEAD SCREW 6-32 x 5/16 LG	
4	1	D 716866	EXHAUST SHROUD	
7	1	A 716909	END PLATE ABSORBER	
8	2	B 724602-4	GASKET, SEAL 1/8-Durlan 8500	3705
11	36	A 35338-139	LOCKWASHER 1/4	
12	36	A 15795-810	FLAT WASHER, 1/4	
13	36	A 35308-307	HEX MACHINE SCREW 1/4-28x7/8	
14	4	A G211678-3	ROLL PIN	
15	1	G218814	RETURN HEADER	
16	1	G218815	I/O HEADER	

NOTE: PRIOR TO JAN 1988, ITEM 8 WAS PART NO. 724602-1 -NOT FDA APPROVED.

NOTES

A ITEM 7 TO BE SECURED BY TABS OF MODULE SUBASSY

B ASSEMBLE ITEM 13 WITH A TONGUE OF 72 INCH POUNDS

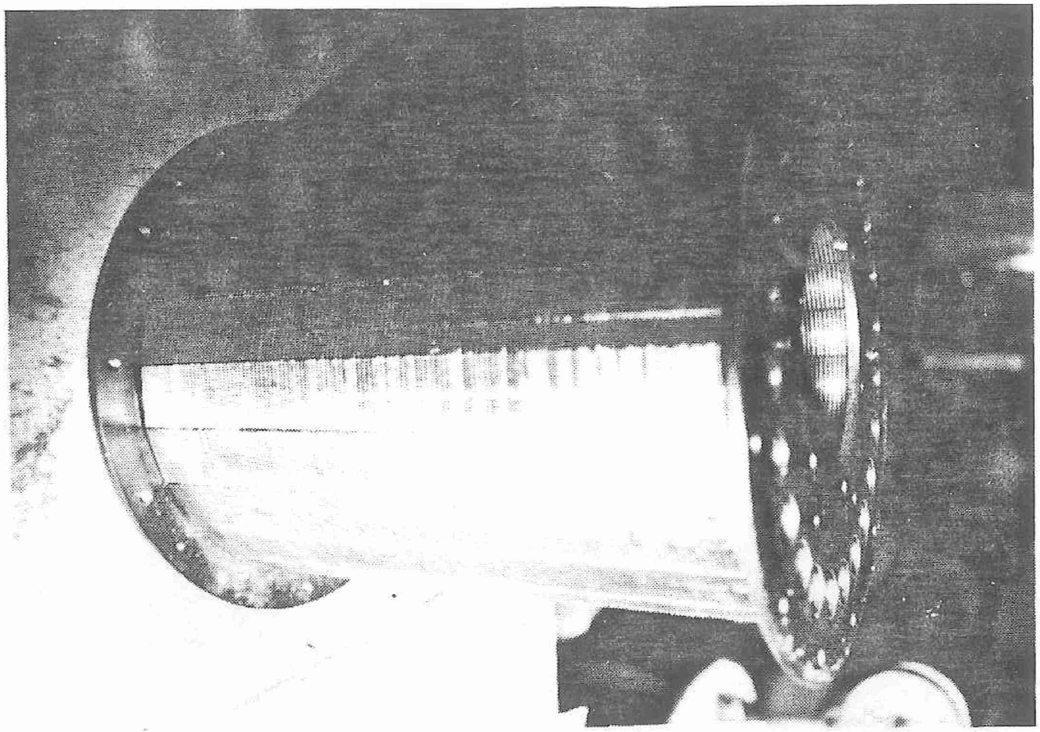
C PRESS ITEM 14 (ROLL PIN) INTO MATRIX ASSY (4 PLACES) USE ITEM 14 TO POSITION GASKET ITEM 8 USE PRESSURE ATTACHMENT OF HEADERS P/U ITEM 1 TO PRESS ROLL PIN TO ITS FULL INSERTION DEPTH

D LOCATE AS SHOWN FOR G218833

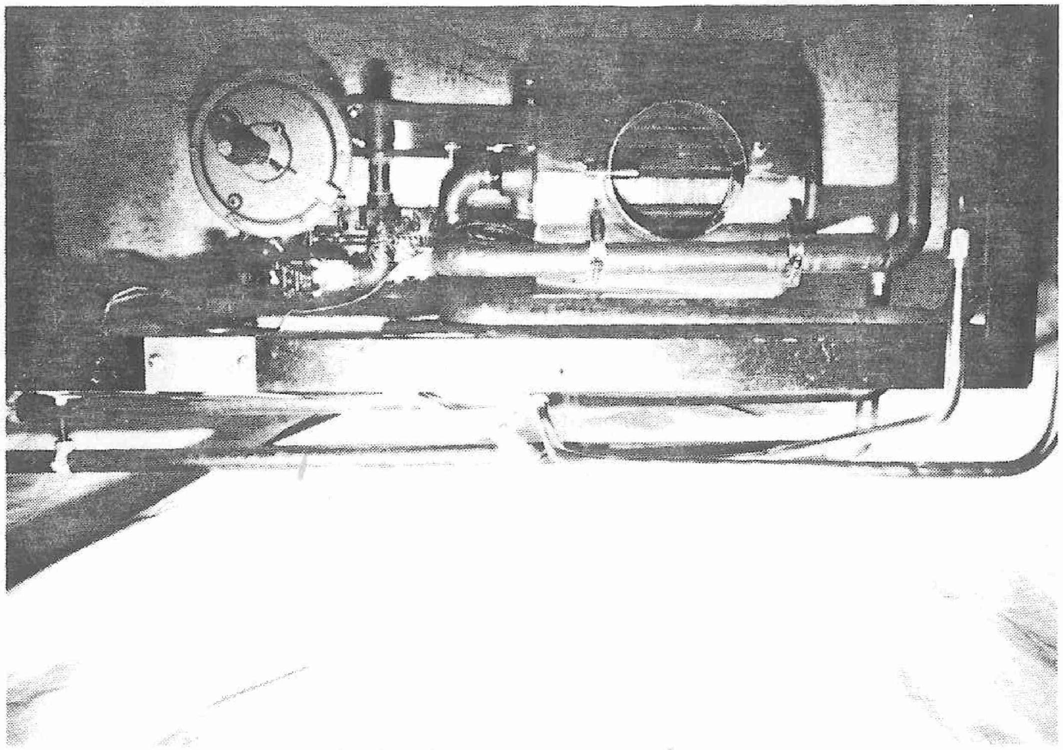
E LOCATE AS SHOWN FOR G218841, G218885

F SEE TABULATION

Figure 3.23 Thermal Fluid Heater Heat Exchanger Assembly



(A) Finned Tube Heat Exchanger With Jacket Removed



(B) Finned Tubes Exposed

Figure 3.24 Photographs Showing Finned Tubes of Heat Exchanger Through Stack Opening

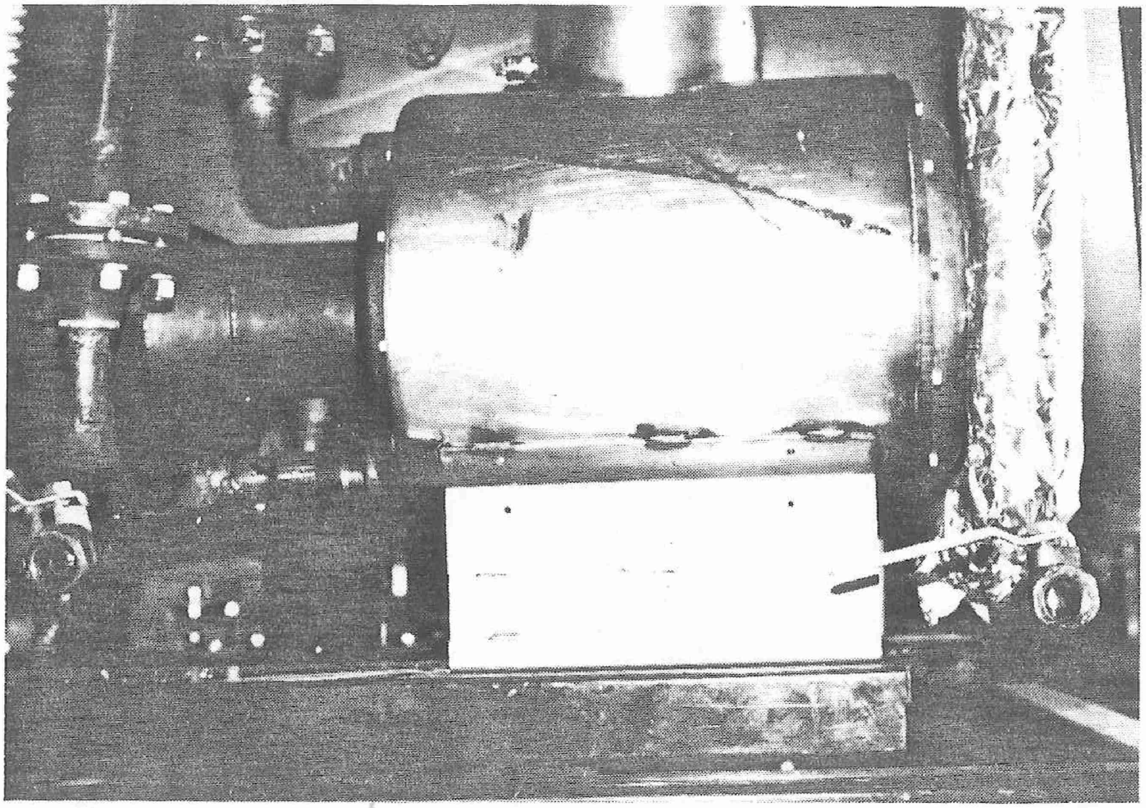


Figure 3.25 Photograph of Fluid Heater Heat Exchanger Installed in MATCH Demonstration System

The fluid heater and associated burner performed well in the preliminary testing at Tecogen, with ~300 hrs. cumulative testing. It is necessary to assure proper draft control for clean combustion; however, due to the tight fin-spacing in this unit. In subsequent testing, poor draft control led to fuel rich operation with soot formation and rapid plugging of the fluid heater. Deposition of soot leads to a further reduction in air flow, and a run-away situation rapidly.

As a result of this experience, it is recommended that a less-compact fluid heater be used with much wider flow spaces on the combustion side. This heater will not only be much less prone to plugging, but will also be much easier to clean in the event of accidental plugging.

In addition, draft control similar to that used on residential furnaces should be incorporated to isolate the oil burner from particular site-specific installation variations and from ambient variations (such as wind velocity).

As a final recommendation, gasketed joints should be eliminated in the fluid heater with welded connections used wherever possible.

These changes will greatly improve the reliability of the fluid heater/burner subsystems.

Hot Oil Pump. The hot pump is a SIHI Series ATNA centrifugal pump used with success by the Fulton Thermal Corp., Pulaski, NY on their commercial and industrial thermal fluid heaters. The pump is rated for pumping hot oil up to 610°F and reliability in commercial/industrial service has been excellent. In Figure 3.26, a photograph of the pump used on the MATCH demonstration system is presented. The pump has an impeller diameter of 6.1 inches.

The available pump had a much larger capacity than required for the MATCH system, with a 10 hp motor and 3300 RPM speed. For the MATCH system, the 10 hp motor was replaced by a 1/2 hp, 1730 RPM motor. With this motor, the rated flow of 48 gal/min at 11 psi head was more than adequate for the MATCH demonstration system. It is recommended that a smaller pump be used in future MATCH systems.

Solenoid Valves. Standard off-the-shelf solenoid valves were used for on-off control of the hot oil flow through the appliances, in response to thermostatic control. The J.D. Gould, Inc. (Type G-1, 303 1/4" orifice) valves used were rated for 400°F. In one months test operation at a fluid supply temperature of 450°F, no valve failures occurred. However, in operation at a fluid supply temperature of 500°F, the valves failed after about 8 hours of operation, due to melting of the plastic insulation in the solenoid coils. The valves thus must be considered marginal and it is recommended that valves with a 500-550°F rating be used.

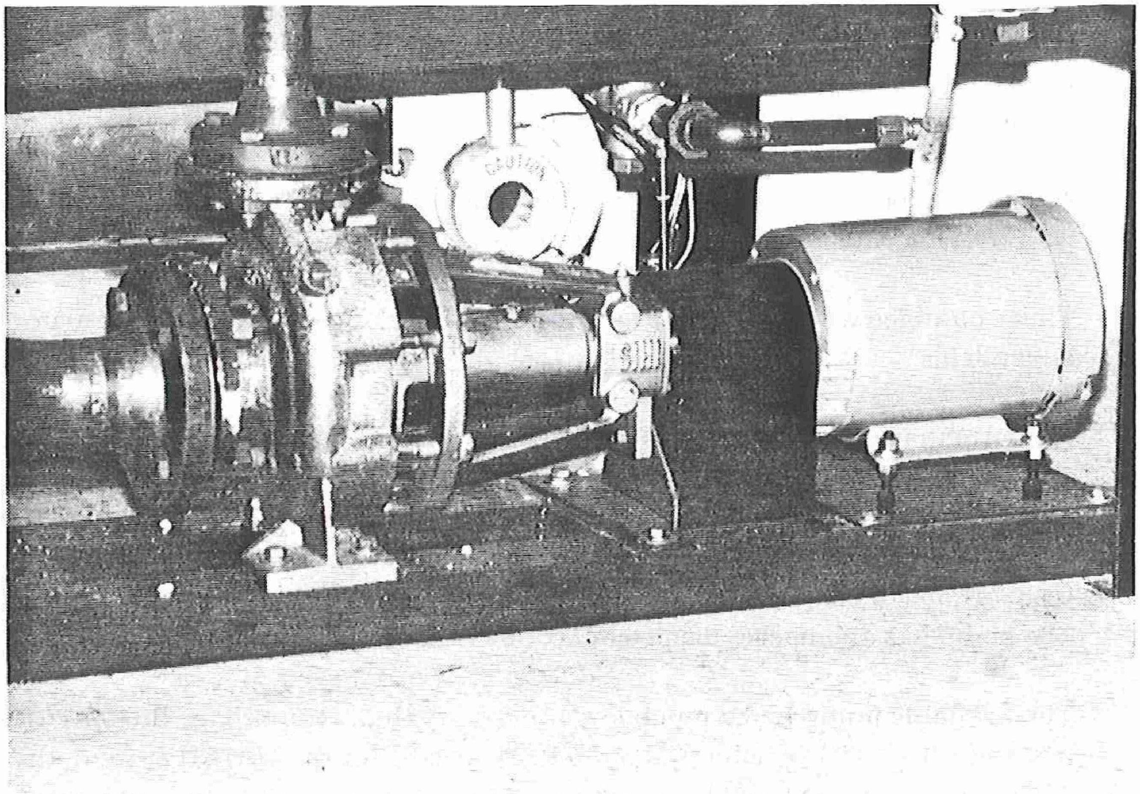


Figure 3.26 Photograph of Hot Oil Pump in MATCH Demonstration System

This will require a higher temperature insulation in the solenoid such as teflon, a longer valve stem to separate the valve body and solenoid, or a bellow sealed valve. Since the current valve is almost adequate, a combination of higher temperature insulation and increased coil separation from the valve body should provide a reliable, long life, and low cost solenoid valve for the MATCH system.

Electrical System and Controls. The MATCH demonstration system electric schematic is given in Figure 3.27. The demonstration system uses 240V AC, 3ϕ power because of the availability of a 1/2 hp motor for the pump with this rating for the demonstration system. Otherwise, 110V AC power would have been used.

The system operation is very simple. The cook starts and shuts-off the kitchen by a single button contractor. This switch stars up the circulating pump and oil burner. Individual thermostats open the solenoid valves on the appliances. The burner continues operating until it reaches the set-point temperature where the system thermostat on the hot-oil turns the burner off. The burner is then turned on-off by the system thermostat, which has about a 25°F deadband in response to the cooking load on the system. The pump operates continuously when the system is on.

On start up, oil circulates through the fluid heater and supply loop until the set point temperature (450°F) of the system is satisfied and the burner cycles off. The individual appliances are switched on at their respective thermostats. Independent temperature control for each appliance are then maintained automatically with its thermostat turning the solenoid valve on and off in response to the appliance temperature and thermostat setting.

For cool down purposes, a separate manual-operated burner contractor is included in the demonstration system, permitting circulation of the oil without operation of the burner. The oven blower also has a separate manual switch so that the oven can be operated as both a convective and non-convective oven. This switch is standard on the commercial oven modified for the system.

Electrical power measurements were made on the system with the following results:

Circulating Pump	775 watts
Oil Burner	460 watts
Oven Blower	630 watts
Solenoid Valves (Four)	230 watts
TOTAL	2095 watts

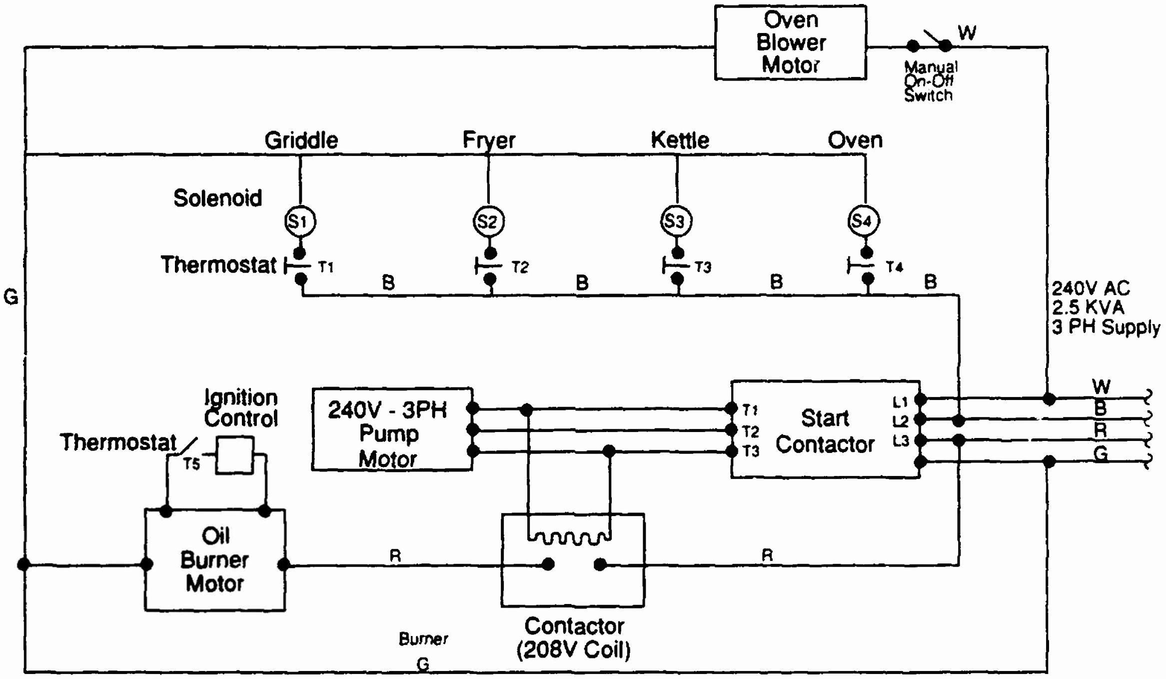


Figure 3.27 MATCH Electrical Schematic

3.3 MANUFACTURING COST ANALYSIS

A cost analysis of the MATCH thermal fluid system was prepared based on the cost of components used to fabricate the prototype. The summary of the cost estimate is shown in Table 3.4. The detailed cost breakdown for the cooking appliances and piping are presented in Tables 3.5 to 3.8.

The cooking appliance costs shown are selling prices and include manufacturer's overhead and typical markup on direct labor and material. All hardware and components required for a complete cooking appliance like temperature sensors, temperature controls, legs, casters, heat transfer fluid valves, etc. are included in the material cost, as shown in the tables.

TABLE 3.4. Manufacturing Cost Estimate Summary (Dollars)

A. Fluid Heater	
1. Heat Exchanger	$ 5,500
2. Burner	300
3. Pump	1,000
4. Expansion Tank	200
Subtotal	7,100
B. Appliances (Cooking Modules)	
1. Fryer	2,038
2. Griddle	2,000
3. Oven	2,480
4. Kettle	2,200
Subtotal	8,718
C. Piping and Installation	
1. Materials	1,080
2. Labor	4,000
TOTAL MANUFACTURING COST	**$20,898**

TABLE 3.5. Fryer Cost Estimate (Dollars)

ITEM	COMPONENT	MATERIAL	LABOR
1	*Drain Valve*	$ 40	
2	Casters and Legs	70	
3	Baskets (2)	22	
4	Labels and Tags	8	
5	Crumb Tray/Screen Basket Supports	8	
6	Thermal Insulation	28	
7	Sheet Metal	60	20
8	Hardware	16	
9	Electrical Components (Wire, Switches)	20	
10	Oil Temp. Control	150	
11	Heat Exchanger Tank	200	
12	HTF Oil Piping/Connectors	20	
13	HTF Control Valve	60	
	Material Cost	699	
	Labor for Component		20
	Labor for Unit Assembly		60
	Labor Subtotal		80
	Overhead (3* Labor)	240	
	Manufacturing Cost	1019	
	SELLING PRICE **(2 X Manufacturing Cost)**	**$2038**	

TABLE 3.6. Griddle Cost Estimate (Dollars)

ITEM	COMPONENT	MATERIAL	LABOR
1	Steel Platten (2 ft*3ft)	$ 270	
2	Hardware	20	
3	Sheet Metal	60	20
4	Electrical Components	10	
5	Temperature Control	120	
6	HTF Control Valve	60	
7	HTF Piping/Connectors	20	
	Material Cost	560	
	Labor for Component		20
	Labor for Unit Assembly		90
	Labor Subtotal	110	110
	Overhead (3* Labor)	330	
	Manufacturing Cost	1000	
	SELLING PRICE **(2 X Manufacturing Cost)**	**$2000**	

TABLE 3.7. Convection Oven Cost Estimate (Dollars)

ITEM	COMPONENT	MATERIAL	LABOR
1	Oven Cavity Assembly with HX Coil	$ 275	5
2	Thermal Insulation	15	
3	Sheet Metal (with Frame)	60	30
4	Racks/Support	40	
5	Doors	60	30
6	Controls	30	10
7	Thermostat	120	
8	Air Movement Motor	50	
9	Blower Impeller	10	
10	HTF Control Valve	60	
11	HTF Piping/Connectors	20	
	Material Cost	740	
	Labor for Component		75
	Labor for Unit Assembly		50
	Labor Subtotal	125	125
	Overhead (3* Labor)	375	
	Manufacturing Cost	1240	
	SELLING PRICE (2 X Manufacturing Cost)	**$2480**	

TABLE 3.8. Kettle Cost Estimate (Dollars)

ITEM	COMPONENT	MATERIAL	LABOR
1	Tank	$ 350	30
2	Base Cabinet w/Frame	150	30
3	Drain	60	
4	HTF Control Valve	60	
5	HTF Piping/Connectors	20	
6	HTF Control Valve	60	
7	Thermostat	120	
	Material Cost	760	
	Labor for Component		60
	Labor for Unit Assembly		25
	Labor Subtotal	85	85
	Overhead (3* Labor)	255	
	Manufacturing Cost	1100	
	SELLING PRICE (2 X Manufacturing Cost)	**$2200**	

TABLE 3.9. Piping and Installation Material Cost Estimate (Dollars)

A. Piping (1) 30 ft, 3/4 inch dia. (2) 6 ft, 1 inch dia. (3) 4 ft, 1- 1/2 inch dia.	$ 100
B. Fittings (1) Flanges 4, 9 in. dia. 150 lbs 1, 1 - 1/2 in. dia. 150 lbs 1, 2 - 1/2 in. dia. 150 lbs (2) Gaskets (Flexitallic) 2, 1 in. dia. 1, 1- 1/2 in. dia. 1, 2- 1/2 in. dia. (3) Elbows 25 Various sizes (4) Reducers, tees, stub ends, etc. (5) Shut off valves - 2	500
C. Heat Transfer Fluid	250
D. Insulation	200
E. Miscellaneous electric wiring	30
TOTAL	**$1080**

4. TESTING

The overall system and the cooking equipment were assembled and installed in accordance with the design described in Section 3. Inspection of all welds and joints was done to ensure that the entire system was free of leaks. All pipework including manifolds on the heater were adequately insulated to prevent heat loss and injury. After checking for total absence of water in the pipework, the system was filled with the thermal fluid from the lowest point in the system in order to prevent air pockets from forming. The system was filled slowly, closing all opened bleed and drain valves as the fluid reaches them. The operation of the pump was checked by circulating the cold fluid. The liquid level was checked after running the pump for five minutes. The pump was run for five minutes at a time until all entrained air had been removed and the liquid level remained constant. The pressure gauge readings were checked during this process to ensure pressure stability.

After several hours of operation, all connections flanged, weldments and compression fittings were checked for tightness. It was found that the weldments were secure; however, some of the compression fittings and flange gaskets had minor leaks. To ensure no leakage from the system, the flange gaskets were changed to "flexitallic" metal gaskets and the compression fittings were welded. Subsequent inspections of the system showed no leaks. It is recommended in future systems that welded fittings be used wherever possible. Where connections must be broken, it is recommended to use bolted flange connections with "flexitallic" metal gaskets.

4.1 NATURAL GAS-FIRED OPERATION (Bread-Board System)

The heater was initially fired and operated with natural gas. With the burner firing at the proper fuel rate and the pump running, the gauges were checked to ensure that the pressures remained stable. The firing was continued until the operating temperature of the fluid was reached. Throughout the initial warm-up, the expansion tank was watched to detect the formation of froth. No frothing was observed indicating absence of water of the thermal fluid. Once the unit was up to the set-point temperature, the fluid level in the expansion tank was checked to ensure that a proper tank size was used. The flows through all the cooking equipment were then checked for tightness by opening the flow valves. The energy used and time taken to heat up the system from room temperature to set point temperature, and standby energy consumption were determined for the fluid heater and the complete system (heater and cooking modules). The test results for both the fluid heater and complete systems are summarized in Table 4.1.

TABLE 4.1. System Performance - Gas-Fired

Firing Rate	253,000 Btu/hr
Emissions (as measured)	
CO_2	7.35%
O_2	6.5%
CO	90 ppm
Fluid heater heatup - 70°F to 450°F	
Heatup time	8 min.
Heatup energy	30,000 Btu
Standby energy	37,000 Btu/hr
System (Fluid heater and cooking modules) heatup - 70°F to 450°F	
Heatup time	23 min.
Heatup energy	99,000 Btu
Standby energy	82,000 Btu/hr

4.1.1 Cooking Modules Testing-Natural Gas Fired

The four cooking modules - oven, fryer, griddle, and kettle were tested for preheat time and energy consumption, standby energy consumption, water-boil efficiency, and cooking performance. During preheat, the oven and griddle were heated up without any load, the fryer was heated up with 40 lbs of cooking oil and the kettle with 19 gallons of water. The preheat time and energy consumption was determined to heat up the cooking module up to the set-point temperature. The set point temperature for the fryer, griddle, and the oven was 350°F. The kettle was et at the maximum setting, even though the temperature reached by the load (water) was 212°F. The results of the start-up and standby tests are summarized in Table 4.2.

The test procedure and results for water-boil and cooking tests for the four cooking modules are discussed below.

Fryer. In the water-boil efficiency test, the quantity of energy required to boil water from the fryer was determined, and expressed as a percentage of the quantity of energy input to the fryer during the boil-off period. The fryer was operated with a known weight of water contained in the fryer and the thermostat set to the maximum setting. After a specified weight of water was boiled off, the water-boil efficiency was calculated. The following equation was used to calculate the water-boil efficiency:

$$EEF_{wb}(\%) = W \cdot E_{vap} \cdot 100/E_{input}$$

where

W = weight loss of water, lbs.
E_{vap} = heat of vaporation of water, Btu/lb
= 970 Btu/lb
E_{input} = energy input to the fryer, Btu

The total gas energy consumed during the water-boil test was not used as the energy input to the fryer. The standby energy required by the fluid heater to maintain the set-point temperature (37,000 Btu/hr) was subtracted from the total energy consumed to determine the energy input to the fryer. Three water boil tests were made. The average water-boil efficiency measured was 97%. The high water-boil efficiency indicates low standby losses from the fryer.

Measured water boil efficiency (average) = 97%

TABLE 4.2. Cooking Modules Startup Tests - Natural Gas-Fired

	Fryer	Oven	Griddle	Kettle
Heatup				
Time, min	17 (350°F)	14 (350°F)	0.9 (350°F)	22 (212°F)
Energy, kBtu	14	22	4	36
Standby Energy Rate, kBtu/h	1.3	2.2	14	22

Cooking tests were performed with frozen shoe-string potatoes. In this test, the energy consumption and time were monitored while the fryer was used to cook several loads of frozen shoestring potatoes to a condition of acceptable doneness with the thermostat set at 350°F. The tests were done for heavy, medium and light-load conditions. The acceptable doneness was determined by weight loss and visual inspection of cooked fries. Average results of medium-load testing are shown below.

Cooking Performance

Load Size	3 lbs (1.5 lbs. per basket)
Cook Time	3 min.
Weight Loss	28%
Recovery Time	5 min.
Cycle Time	8 min.
Production Rate	22.5 lbs/hr
Average Input Rate	25,000 Btu/hr

The french-fry production rate is low compared to the fryers used by the gas food chains which have about 2.5 to 3 times higher production rate. If higher production rates are desired, the heat transfer area between the thermal fluid and the cooking oil or the operation temperature of the thermal fluid will have to be increased.

Oven. The cooking tests performed on the oven included the water-boil test for determining cooking efficiency, white sheet cake test for determining cooking uniformity and potato-bake test to determine production capacity.

The water-boil test was done according to the standard method developed by the Pacific Gas & Electric Company for the evaluation of convection ovens. It consisted of placing two hotel pans on each rack with ten (10) pounds of water in each pan. With the thermostat set at 350°F, the oven was operated for three (3) hours while monitoring the energy consumption and the water temperatures during the test. The oven was turned off at the end of the test period and the final water temperature in each pan was recorded. Within five minutes after recording the water temperature, each pan was covered with a lid, removed from the oven and weighed. The final weight of the water was recorded by subtracting the weight of the pan and the lid from the weight of the covered pan containing the water. The energy absorbed by the water was calculated by the following equation:

$$E_{water} = W_i * C_p * (T_f - T_i) + W_{w.l.} * E_{vap}$$

where

W_i = Initial weight of water, lbs.
E_{vap} = Energy absorbed by water, Btu/hr
C_p = Specific heat of water = 1.0 Btu/lb.-°F
T_f = Average water temperature at the end of test, °F
T_i = Average water temperature at the start of test, °F
$W_{w.l.}$ = Weight loss of water, lbs.
E_{vap} = Heat of vaporization of water, Btu/lb
= 970 Btu/lb

The water-boil efficiency was calculated by dividing the energy absorbed by the energy input to the oven. The energy input to the oven was determined by subtracting the fluid heater standby energy consumption from the total energy consumption. The water-boil efficiency measured was about 50%.

Measured water-boil efficiency = 50%

In the cooking uniformity test performed with white sheet cakes, the oven was preheated to 350°F and the cavity air temperature was allowed to stabilize. Four sheet pans, each with eight (8) pounds of white cake batter, were placed on the four racks in the preheated oven. The cakes were then examined for color, and their weight and temperatures were measured. All the cakes were uniformly browned even though slightly higher temperatures were measured for the cake in thee top rack compared to the one in the lowest rack.

Griddle. The water-boil efficiency of the griddle was determined by measuring the energy required to boil water off the griddle surface. The ratio of energy absorbed by the water to the energy input to the griddle was the water-boil efficiency. The procedure followed was that recommended by the Pacific Gas and Electric Company. A retaining wall was built around the entire griddle surface. The griddle was turned on and the thermostat control was set about 212°F. This was to ensure continuous energy input to the griddle. The energy input and time were monitored. The water-boil efficiency was measured to be 81%.

Measured water-boil efficiency = 81%

The cooking performance of the griddle was evaluated by cooking 1/4 lb, 20% fat, pure beef hamburger patties with a nominal diameter of 5 inches. The cooking capacity was determined by a full-load test, comprising six loads of 24 patties. This represented a loading density of our patties per nominal square foot of cooking surface. Pre-weighed, frozen (-3°F) patties were sequentially placed on the cooking surface, cooked for a predetermined period of time on the first side (2.5 minutes), sequentially turned over, cooked for a predetermined period of time on the second side (2.5 minutes), and sequentially removed from the griddle surface. Energy consumption and elapsed time were recorded for the test period. Average cooking performance results are given below.

Cooking Performance

Patty size/weight	5" dia, 0.25" thick, 0.25 lb.
No. of patties	24
Weight (uncooked)	5.68 lb.
Weight (cooked)	3.94 lb.
Patty cook time	5 min.
Recovery time	nil (390°F after cooking)
Average input rate	95,000 Btu/hr
Cooked product quality	well-done burgers

Kettle. The cooking test done was to simmer three (3) gallons of tomato sauce mixed with one (1) gallon of water, for a period of approximately two hours. During the cooking test, the thermostat was set at 210°F to duplicate the surface temperature conditions of a steam-jacketed kettle. In general, the sauce did not stick to the kettle surface, except for some sticking observed at the air-liquid interface.

4.2 DIESEL-FIRED OPERATION (Final Prototype System)

The tests performed with diesel fuel duplicated most of the results obtained with natural gas. The diesel-fired system was different from gas-fired in that it had an external combustion chamber. The system heat-up rate, energy consumed during heat-up, and standby energy consumption rate for the diesel-fired system are summarized in Table 4.3.

TABLE 4.3. System Performance - Diesel-Fired

Firing Rate	280,000 Btu/hr
Emissions (as measured)	
CO_2	9.40%
CO	50 ppm
Fluid heater heatup - 70°F to 450°F	
Heatup time	8 min.
Heatup energy	26,600 Btu
Standby energy	55,900 Btu/hr

4.2.1 Cooking Modules Testing - Diesel-Fired

Startup and standby tests were performed with the diesel fuel as with natural gas. The results are summarized in Table 4.4 below.

TABLE 4.4. Cooking Modules Startup Tests - Diesel-Fired

Heatup	**Fryer**	**Oven**	**Griddle**	**Kettle**
Time, min.	18 (350°F)	11 (350°F)	0.9 (350°F)	23 (212°F)
Energy, kBtu	28	10	3	-
Standby Energy Rate, kBtu/h	1.3	2.2	14	22

The results of the water-boil efficiency and cooking tests performed with diesel were very similar to those obtained with natural gas. The tests included cooking french fries in the fryer, sheet cakes in the oven, and tomato sauce in the kettle. Two additional tests were performed on the oven - totaling white bread to check uniformity, and baking potatoes to check cooking capacity and speed. In the white bread test, four pans containing twenty pieces of white bread in each pan, were placed in the oven preheated to a thermostat setting of450°F. The pans were removed after fifteen minutes. The bread slices in all the four pans were evenly colored demonstrating uniformity of heat transfer and cooking.

In the potato test, a five pan load of 100 potatoes (20 potatoes in each pan) were bakes at an oven temperature of 400°F. Thermocouples were placed in two potatoes per pan, with the location of the thermocoupled potatoes varied in each pan. The temperature of the potatoes was measured as a function of elapsed time. The baking time was 43 minutes, with average final temperature of 190°F.

5. SYSTEM SAFETY ANALYSES

The Modular Appliance Technology Centralized Heating (MATCH) Field Kitchen using a pumped liquid approach has, in its design and testing, proven to be a very safe and reliable system. The central combustion system possesses the overall safety and reliability of a typical residential oil burner. The appliances used for cooking are as safe as any gas-fired cooking equipment which has been approved by ANSI and is used in commercial food service kitchens. All electrical components are UL approved and the wiring conforms to the National Electrical Standards.

The MATCH Field Kitchen is considered much safer than the field kitchens and cooking equipment currently used. In the current field kitchens, each appliance contains at least one gasoline field burner. These burners have exposed flames, and their products of combustion are exhausted directly into the cooking area. These field burners must be lit outside the cooking area and carried, while burning, into the cooking area and placed into the cooking equipment. Additionally, the current field burners require a procedure of ignition, preheating, vaporizing and finally combustion which must be performed manually.

The MATCH system uses a single commercially available and is approved oil burner which fires into an enclosed combustion chamber. The products of combustion are vented outside the cooking area. The burner and combustion chamber are located in a fixed position either adjacent to or remote from the cooking appliances. The burner contains an electric spark ignition and the required ignition/combustion safety controls. The burner is started by a single switch which is located remote from the burner.

Although the design and testing have indicated in general the MATCH system is safe there are, however, specific items which have been identified as potential safety problems. These potential safety problems and their recommended corrective action is presented here:

- **Fuel Supply System**

The fuel tank was originally located directly behind the kettle for convenience. This location could have allowed diesel fuel to splash into the kettle, thereby, contaminating the food being cooked. At the suggestion of the Natick Lab Safety Officer, the fuel tank was relocated to a safe and remote location outside the cooking area.

It was also recognized that the fuel supply system should have a spring loaded shut-off valve which is held open by a cable connected to a fusible link. The fusible link should be located near the oil burner and capable of causing a closure of the safety valve in the event of a fire outside the combustion chamber. It is recommended that future systems incorporate this safety feature.

- **High Temperature Surfaces**

It is realized that certain hot surface temperatures must exist on cooking equipment such as the griddle cooking surface, the cooking oil of the fat fryer and the heating coil in the convection oven. All other surfaces which could be normally contacted by operating personnel must be insulated or shielded. In the MATCH System prototype most of the piping system has been insulated, however, exposed connections to the cooking equipment and solenoid valves have not been protected. The outside of the kettle jacket which can reach temperatures as high as 400°F is also currently unprotected.

The exhaust pipe from the pumped liquid heat exchanger has exposed surface temperatures of 500°F to 600°F. the exhaust pipe has been surrounded with an expanded metal sleeve which eliminates the possibility of direct contact with the high temperature surface.

It is recommended that in future systems all exposed piping, connections and solenoid valves should be protected with appropriate insulation, expanded metal shields or surrounded by a fan cooled enclosure.

- **Hot Liquid Leaks**

The fluid selected, Multitherm PG-1, for the pumped liquid system is non toxic and FDA approved for ingestion. Leakage from the hot circulating heat transfer fluid does, however, have the potential for two types of hazard. First, if the leak occurred in any exposed piping or fittings the hot liquid could spray out at the operator causing burns. Secondly, if the leak caused liquid to impinge on a hot surface, like the combustion chamber, fire could result.

It is recommended in the first type of hazard that all exposed piping, connections and valves be contained in a fan cooled metal enclosure. This would contain any leak and eliminate the possibility that hot liquid contact the operator.

In the second type of hazard, the metal enclosure would help, however, there would still be the possibility of a leak igniting on a hot surface. To insure safety, it is recommended that a flame detector and a foam spray system be installed in the underside of the cooking equipment cabinets.

A summary of the potential safety hazards are summarized together with the recommended action in The Hazard Analyses Report presented in Table 5.1.

The Risk Assessment in the Hazard Analyses is reported in terms of definitions presented for Hazard Category Table 5.2 and Frequency of Occurrence Table 5.3.

TABLE 5.1. Hazard Analysis Report, M.A.T.C.H. Field Kitchen

Hazard	Effect	Risk Assessment	
		Category	Level
1. Fuel Tank Location	Food Contamination	II	E
2. No Fuel Safety Shut-Off	Sustained Fire	I	E
3. Contact Hot Piping	Burn	III	C
4. Contact Kettle Jacket	Burn	III	B
5. Contact Flue Pipe	Burn	III	C
6. Leak from Exposed Piping	Burn	II	D
7. Leak of Fluid Under Cabinets	Sustained Fire	I	E

Recommended Action	Effect	Status of Action
1. Relocate Fuel Tank Outside System	Eliminate Contamination	Included in Prototype
2. Add Spring Loaded Valve and Fusible Link	Stop Fuel Flow	Recommended
3. Insulate or Enclosure Piping, Fillings, Valves	Eliminate Contact	Partially Included in Prototype
4. Add Expanded Metal Outside Jacket	Eliminate Contact	Recommended
5. Add Expanded Metal Outside Flue Pipe	Eliminate Contact	Included for Prototype
6. Enclose all Piping (Exposed)	Contain Spray	Recommended
7. Add Flame Detector and Foam System	Extinguish Fire	Recommended

TABLE 5.2. Definition of Terms - Hazard Category

Category I: Catastrophic	Death or system loss
Category II: Critical	Severe injury, severe occupational illness, major system damage
Category III: Marginal	Minor injury, occupational illness, minor system damage
Category IV: Negligible	Less than minor injury, occupational illness or less than minor system damage

TABLE 5.3. Definition of Terms - Frequency of Occurrence of Hazard(s)

Description	Level	Specific Individual Item
FREQUENT	A	Likely to occur frequently
PROBABLE	B	Will occur several times in life of an item
OCCASIONAL	C	Likely to occur sometime in life of an item
REMOTE	D	Unlikely but possible to occur in life of an item
IMPROBABLE	E	So unlikely, it can be assumed occurrence may not be experienced

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

A technical evaluation, design and cost analysis which was performed clearly indicated the economic and technical feasibility of the MATCH Field Kitchen concept using a Pumped Liquid System. Subsequent operation and testing of the MATCH Field Kitchen using both diesel and gas burners proved the feasibility and cooking potential of the kitchen. the operation and testing also showed that the MATCH Field Kitchen is a reliable and safe system.

6.2 RECOMMENDATIONS

Although the feasibility, safety and reliability of the MATCH Field Kitchen have been proven the following modification, which have been previously discussed, are recommended to improve the performance, cost, safety and reliability of future systems:

- The hot fluid piping connections, where ever possible, should be welded. If connections are required to be broken bolted flange fittings with "flexitube" metal gaskets should be used to eliminate fluid leakage.
- A pressure regulator added to the hot fluid supply loop would maintain constant pressure and constant flow through each appliance regardless of the number of appliances in use. This will result in more consistent cooking.
- The liquid heater should be redesigned to have less restriction in the combustion side flow passages to reduce soot plugging during off spec burner operation. Also, the removable headers and the threaded pipe connections should be eliminated to minimize leakage.
- The thickness of the griddle cooking surface should be increased from 0.109 inches to 0.25 inches to reduce temperature drop, improve the temperature control and improve temperature uniformity.
- Increase the heat transfer surface area by 100% by increasing the size or number of fire tubes. This will improve recovery time and increase potato frying production to 60 lbs. 1 hr.
- Select a smaller pump with a motor which operates at 110 VAC 1ϕ to reduce system cost.
- Use solenoid valves with a rating good to 500°F to 550°F. This will allow the system to operate reliable at a higher temperature without solenoid valve "burn-out."
- Add a spring loaded shut-off valve to the fuel supply line. Hold the valve open with a cable which has a fusible link in it which will melt and force the valve to close in the event of a fire.
- Add insulation or enclose all exposed hot fluid piping, valves and fittings to protect personnel from contacting the hot surfaces.

- Add an expanded metal jacket or insulation outside the kettle jacket to protect personnel from contacting the hot surface.
- Add a flame detector and foam spray system under the appliance cabinets to extinguish any fire which might have the remote possibility of starting.

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