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This report describes the requirement for a small, lightweight water and space heater and the two units of an oil-fired steam boiler which were constructed to meet this requirement. A description of controls function, system operation, and operating procedure is included.

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Steam	9					
Boilers	9					
Heat Transfer	10					
Raytheon HTM	10					
Fuel Oil	10					
JP-4	10					

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TECHNICAL REPORT

72-58-GP

LIGHTWEIGHT, COMPACT

SPACE HEATING/WATER HEATING SYSTEM

FINAL REPORT

by

W. Hapgood

Raytheon Company
Microwave and Power Tube Division
Waltham, Massachusetts
PT-3221

Contract No. DAAG17-71-C-0118

Project Reference:
66-00308-R151

January 1972

GENERAL EQUIPMENT AND PACKAGING LABORATORY
U. S. ARMY NATICK LABORATORIES
Natick, Massachusetts 01760

FOREWORD

Work covered by this report was performed under project No. 66-00308-R151, which authorized development of a lightweight water and space heater operable on either JP-4 or fuel oil. Upon delivery of the end item, Natick Labs will further evaluate it in terms of its application in the Bare Base Program.

Contract DAAG17-71-C-0118 was awarded Raytheon Company on 3 June 1971, requiring delivery of two units on 3 December 1971 with a final report due 3 January 1972.

The project officer for this contract was Mr. John Greendale of the Organizational Equipment Branch, General Equipment and Packaging Laboratory.

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ABSTRACT

This report describes the requirement for a small, lightweight water and space heater and the two units of an oil-fired steam boiler which were constructed to meet this requirement. A description of controls function, system operation, and operating procedure is included.

LIGHTWEIGHT, COMPACT
SPACE HEATING/WATER HEATING SYSTEM

INTRODUCTION

The increased need for mobility in the armed forces leads to an increased emphasis on small, lightweight, utility and power units of many types. One particularly heavy unit is normally the heater for latrines and washrooms; high BTU requirements, the use of liquid fuel, and multiple heat loads (both of type and location) result in a fairly heavy boiler. A lighter boiler would be of value for this application. In addition, the control functions should be as simple to operate as possible, since experienced field service may not always be immediately available.

The particular device required for this task was to meet the following specifications:

BTU output	150,000 BTU/hr into hot water or steam
Fuels	No. 2 fuel oil, diesel, or JP-4 interchangeably
Weight	75 pounds max
Size	1 x 1 x 4 ft

SYSTEM DETAILS

1. APPROACH

The unit supplied was a vertical arrangement of oil burner controls, combustion chamber, heat transfer module, steam pressure vessel, and tap water heating coil (see Figure 1). Two 3/4-gph Masters nozzles were used in each unit, each with its own flame retention head. They are operated from a common compressor, secondary air blower, and oil pressure regulator, and are controlled by separate oil solenoids. Two nozzles were used since smaller nozzles are more efficient than large ones; the resulting flame shape was more suitable to simple combustion chambers, and modulation control resulted in less cycling and higher average combustion chamber temperatures to reduce smoke generation.

The oil burner controls included an oil pressure regulator, two oil solenoids, and the two nozzles in the oil circuit, as shown in Figure 2. An air compressor supplies 5 psi of air to the nozzles, and a fan mounted on the same motor supplies secondary air to the flame retention heads. This air is used to cool the outer jackets as well. A Fenwal direct spark ignition package is used for ignition and flame safety. Three steam pressure switches control the nozzles between high and low fire and provide a safety back-up pressure limit. The low water cut-off function is provided by a stack limit (see Figure 3).

The combustion chamber was a lightweight, stainless steel, double-walled, air-cooled unit lined with fiber refractory insulation. Air passing between the walls cools the exterior of the unit.

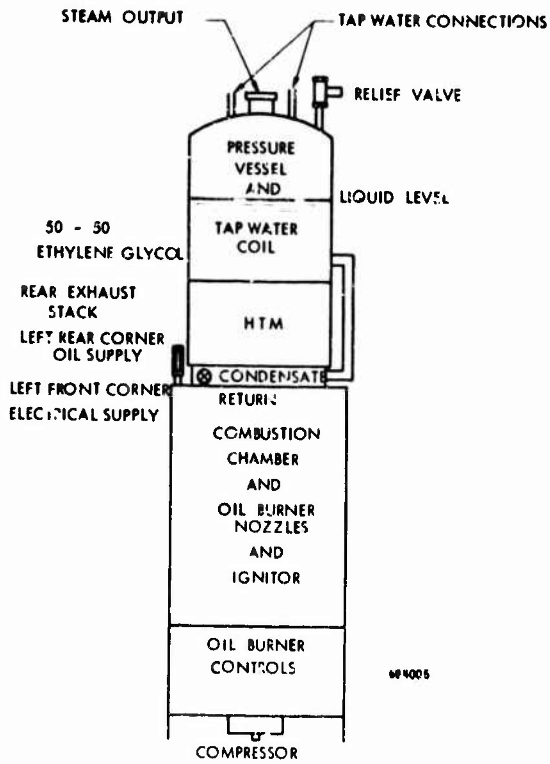

Figure 1. Diagram of Space/Water Heater

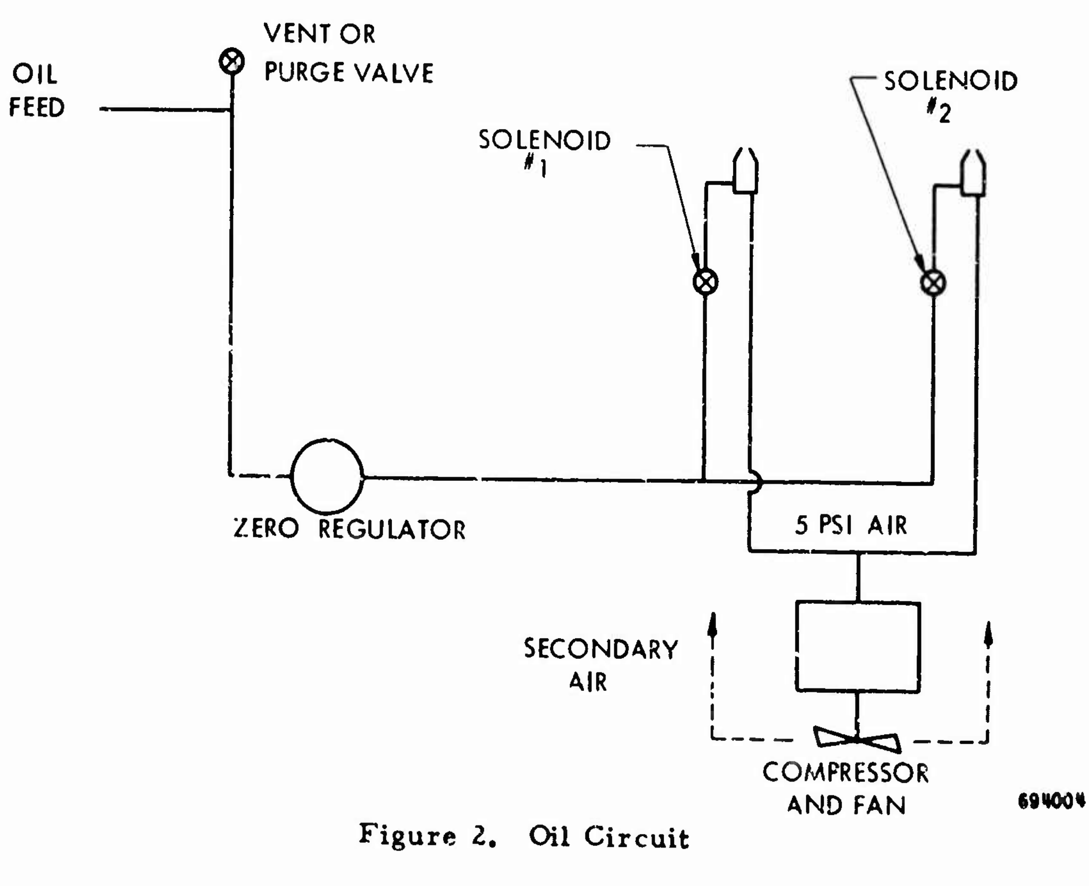

Figure 2. Oil Circuit

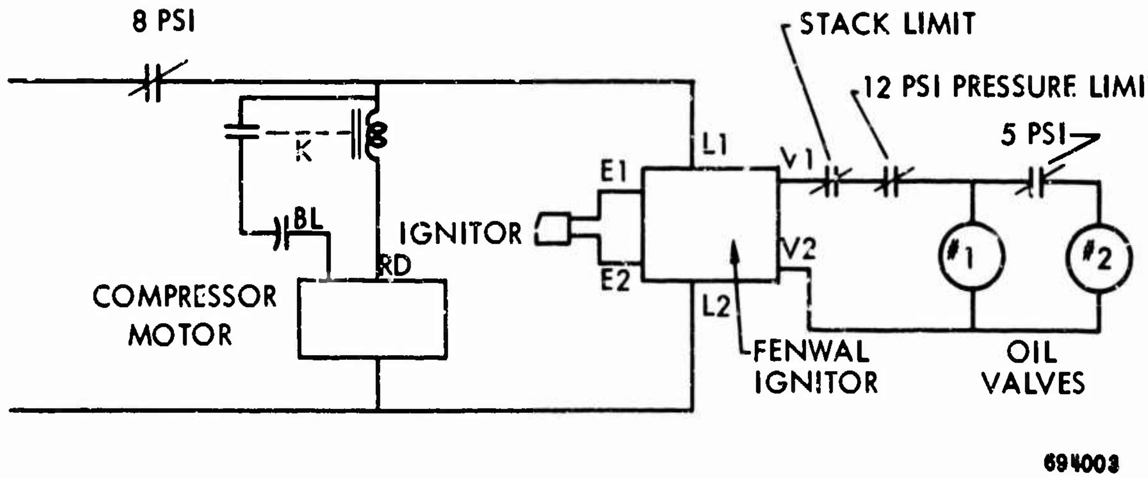

Figure 3. Electrical Diagram

The heat exchanger was the Raytheon Heat Transfer Module, a ball matrix exchanger of high effectiveness. A special design of this unit, tailored to the expected input of 200, 000 BTU/hr, weighs just 12 pounds and operates at 80% efficiency.

The pressure vessel above the heat exchanger contains a sufficient quantity of water/antifreeze mixture to allow reasonable cycling rates on the burners. The instantaneous water heater coil for tap water generation was also included. Because steam is used as a heat transfer media, this coil can be very small and light; it is connected to the top flange of the pressure vessel, which is removable for service or replacement. The charge for the unit is a 50% solution of ethylene glycol and water, with standard inhibitors; this mixture gives excellent freeze and corrosion protection, allowing the unit to be sealed at the factory.

2. SYSTEM OPERATION

Operation of the combustion equipment is quite straightforward. Power is supplied to the high pressure switch. If initial pressure is less than its setting, the compressor/fan and ignition module are turned on. The No. 1 oil solenoid is controlled by the ignition board and is opened as long as flame is proven. If the pressure is below the low pressure setting, the No. 2 oil solenoid will be operated after a delay of five seconds. The total firing rate is 1-1/3 gph. As the pressure rises, the No. 2 nozzle cuts out at 5 psi; at 8 psi the No. 1 nozzle cuts off, as well as the compressor motor. At low loads, the unit will cycle between the off and half-firing rate; at medium loads, the unit will cycle between the half and full firing rate; at heavy loads, the unit will fire full continuously.

The steam generator and pressure vessel consist of a lightweight water tube boiler topped by a steam space which includes a copper coil for heating tap water. The liquid level is kept at the top of the risers and below the coil, resulting in very high heat transfer rates on the coil. The liquid charge is a 50% mixture of ethylene glycol and water with standard inhibitors; this results in freeze protection adequate for both shipping and use, and allows the tap water heater units to be sealed at the factory, and the air excluded. Additional air purging in the field, if required, is accomplished by briefly opening the safety relief valve while the unit is under pressure to release any air admitted during shipping. This is the only normal maintenance required, and would be evidenced by low heat output at heavy loads.

For use as a space heater, the large plug at the top of the pressure vessel can be removed and steam piping to a steam coil added (see Figure 4). The condensate return line is brought to the left front corner and should include an air purge valve (manual) and a valve or solenoid to control condensate flow from a room thermostat. This technique allows control of the steam flow to the steam coil without use of heavy steam valves; shutting off the condensate line causes the steam coil to gradually fill with water, cutting off the heat output. Alternatively, the steam coil fan can be used to control room temperature. The steam coil returns its condensate by gravity, and must, therefore, be located above the boiler; and the steam line should be pitched back toward the boiler if possible.

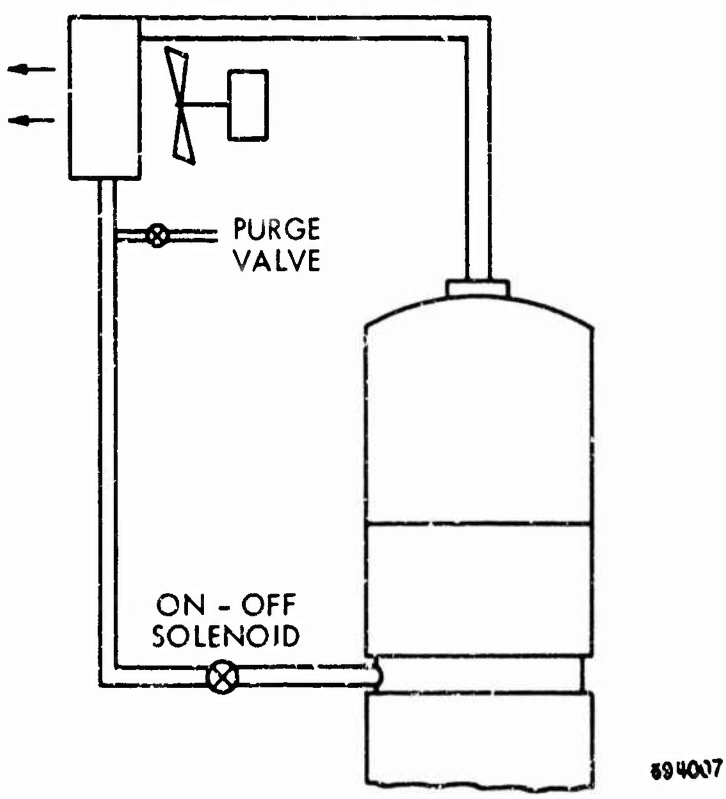

Figure 4. Steam Hook-up

3. INSTALLATION

The unit should be placed on a level floor. The stack connection is the most important and should be run full-size to an outside vent; a rain cap is advisable. Increase the vent size if several units are vented in common, and do not allow the exhaust from one unit to blow directly into the vent from another. Stack temperatures of 500° F should be expected.

Electrical power of 120 volt, 60 Hz is required for operation. The load is about 3 A. The correct polarity should be observed (white = common, black = hot, green = chassis ground). Incorrect polarity can result in safety lockout. Power should come from an accessible disconnect switch.

Fuel oil No. 2, diesel or JP-4, must be under pressure or under gravity flow to the top of the unit. For ease in startup and air purging, a vent valve at the top of the unit is recommended. The line down to the burner is large enough to back purge air to the vent valve. Maximum flow rate will be 1.35 gph of No. 2 fuel oil. The flow rate of JP-4 is slightly higher due to the change in density.

4. CONNECTING THE LOADS

For use as a tap water heater, simply attach cold water supply to either of the 1/2 in. tube connections at the top of the boiler; run the other to a good quality mixing valve and to the fixtures (see Figure 5). The water line up to the mixing valve should always be under pressure; the shutoff before the boiler should not be used as the service valve. For loads requiring more than 150,000 BTU/hr, connect two or more boilers in parallel; use equal size lines to distribute the flow evenly.

For use as a steam source for space heating, remove the 1-1/2 in. plug at the top of the unit; remove the 1/2 in. plug at the left front of the pressure vessel; drain and save the antifreeze solution charge. Run a steam line directly from the steam outlet at the top of the unit to the steam coil to be heated. For loads up to 100,000 BTU/hr, 1 in. line is sufficient; for larger loads, use 1-1/2 in. line. Install the steam coil above the boiler, and drop the condensate return line down several inches below the steam coil. Install a vent valve at this point to vent the air at startup. This valve can be a manual valve as long as it shuts off tightly. Pipe the condensate back to the boiler. Install a manual valve or electric solenoid valve if it is desired to be able to shut off the steam to the coil. A 1/2 in. line here is adequate. Keep both the steam line and the condensate return as short and small as possible, as large piping volume leads to poor response. Replace the charge through the steam connection or relief valve fitting if preferred.

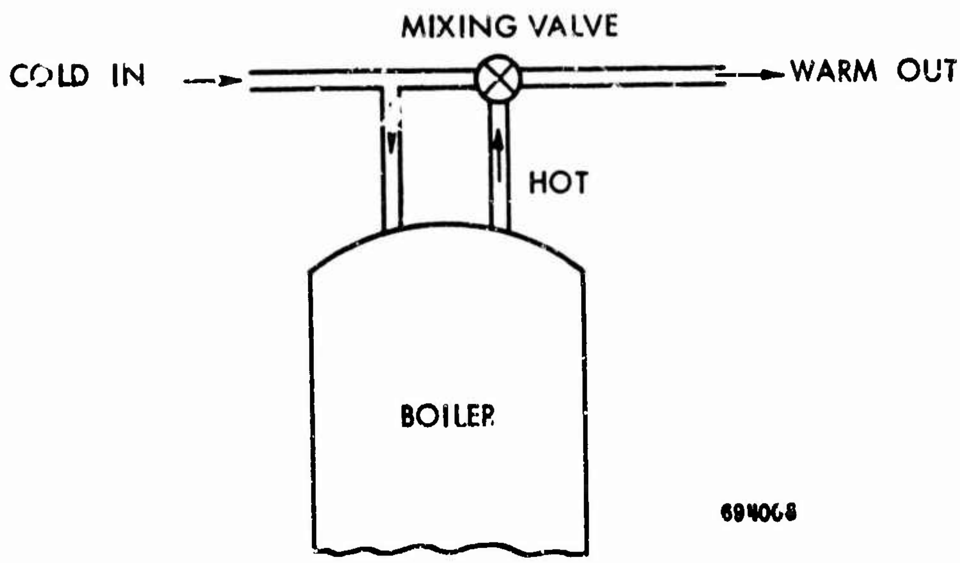

Figure 5. Tap-water Hookup

5. STARTUP

Startup includes initial ignition, clearing oil lines of air, and removing noncondensibles from the steam chamber. With the oil supply connected and purged, apply electrical power. The unit should light on one nozzle, and add the second nozzle a few seconds later. If the unit locks out due to air in the oil lines or failure to ignite, wait a minute, disconnect the electrical line and try again. If oil is getting to the nozzles, oil vapor will be seen at the stack outlet. Do not make repeated trials for ignition once this occurs, since the problem is more likely to be in the ignition system. If the unit ignites but locks out after a few seconds, check the polarity of the power supply; the white lead should be at neutral or ground potential. Finally, after the unit has run a few minutes and has cycled off, apply a load by opening a water faucet. A heavy draw of hot water should cause the unit to run continuously; if it cycles, shut off the faucet, wait for the unit to cycle off, and briefly release the safety relief valve until steam comes out. Wait one minute and repeat; now try the tap water supply. A unit installed as a space heater must also be vented below the steam coil with the condensate line open (thermostat calling for heat).

6. OPERATING INSTRUCTIONS

Normal operation consists of maintaining the oil supply. If the unit is continuously hot, it will not require purging or adjustment, even if the type of fuel used is changed. If the unit locks out, the electrical power must be removed to reset the control. If the output drops, purging the steam chamber may be necessary. Lockouts in a previously satisfactory installation may be corrected by replacing the ignitor electrodes; a spare is supplied. This is accomplished by removing the front skin and the control door under it.

To remove the unit from service and protect it from freezing, proceed as follows. With the unit on, turn on any heating load thermostats so that heat is blown from the steam coil. Turn off the tap water supply main to the unit. Open a tap water faucet; some steam will come out as the internal coil clears itself of water. Finally, shut off electrical power and fuel to the unit, leaving the water main off and a faucet open.

RESULTS AND CONCLUSIONS

The goals of the program have been met, since the required output has been measured into a water load using both No. 2 fuel oil and JP-4 as fuel, with clean combustion (see Table 1). The weight of the first unit delivered was actually somewhat under 75 pounds dry, the second unit was strengthened somewhat to improve both ruggedness and appearance. Further work could be done in this area to improve the ruggedness or reduce the weight; for example, approximately 1/4 of the package weight is due to the air compressor motor; a lighter version of this component would make a large difference in system weight.

The control system as used seems highly satisfactory, since no operating controls are necessary and no adjustments need be made in normal operation. The use of an antifreeze charge eliminates the possibility of freeze-up during idle periods and the inconvenience of draining and refilling. The generation of tap water is essentially automatic, although a good mixing valve is required to control output water temperature. The use of a small, sealed steam vessel puts limits on the type of space heating steam coils which can be used with the system; low internal volume steam coils located above the pressure vessel are required. However, when this is done, control of the heat output by condensate return control is possible.

The air atomizing nozzles result in very clean combustion and high efficiency; there is normally no noticeable smoke puff on either ignition or shut down.

Table 1. Performance Chart

1. Firing Rates

High Fire	Low Fire
1.35 gph No. 2 fuel oil	0.80 gph No. 2 fuel oil
11.0% CO_2	5.7% CO_2
0.004% CO	0.002% CO
600° F stack temperature	500° F stack temperature
80% efficiency	77% efficiency
151,000 BTU/hr output	86,000 BTU/hr output

2. Outputs

150,000 BTU/hr high fire, 85,000 BTU/hr low fire into either steam or hot water.

Water temperature at least 125° F at full output with 40° F inlet water.

Steam pressure controlled between 4 and 8 psig.

Flow rate	3.5 gpm	High fire
	2.0 gpm	Low fire

3. Dimensions

Height	48 in.
Cross-section	12 x 12 in., plus stack pipe
Weight	75 lb dry
Ignitor gap	3/32 in.