Image Cover Sheet

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TITLE

REPORT ON PROPANE FIRED LIQUID HEATING UNITS

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DCIEM No 96-CR-16

Report on Propane Fired Liquid Heating Units

Made to
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DCIEM

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96.02.21

1. A Review of Heating Unit Designs Supplied to DCIEM

Carleton has supplied two versions of heating units to DCIEM. Figure 1 is a schematic of the first. Figure 2 shows the second.

1.1 Version 1

1.1.1 Design

1.1.1a <u>Fuel Control</u>

In version 1, propane from an external cylinder flows through an on/off valve and pressure regulator to two valves in parallel, a manual valve to set the idle burn rate, and a solenoid valve. The solenoid valve is normally open, so that the propane flow is high unless the controller supplies power to close it. All propane then flows to a nozzle directed at the throat of a venturi. The jet of propane gas entrains air, and the venturi recaptures some of the kinetic energy of the resulting fuel/air mixture, generating enough pressure to ensure forced draught for the device regardless of wind conditions or orientation.

1.1.1b <u>Combustion and Heat Capture</u>

The fuel air mixture enters a manifold and is distributed to three thimble shaped catalytic screens on which combustion occurs. Combustion is initiated by a piezoelectric sparker. Combustion heat is transferred to two finned aluminum "hot plates", then through thermoelectric modules to two aluminum "cold plates". The cooled exhaust exits the unit through a rubber hose.

1.1.1c Liquid Circulation

The cold plates have channels to carry the circulating liquid. Liquid exiting the cold plates flows past a thermistor, to the heat transfer garment(s), then to a diaphragm pump and back to the cold plates to be reheated.

1.1.1d Electricity Production

The design has no battery. A small percentage of the heat flowing through the thermoelectric modules is converted to electricity. The pump and control system are connected in parallel to the thermoelectric modules.

1.1.1e Control System

The controller senses the exiting liquid temperature, and compares it with a setpoint provided by the user through a potentiometer. The LED display shows the set point and the actual liquid temperature. If the liquid is too cold, the controller cuts power to the solenoid valve, causing the fuel flow to go high. Conversely, if the water is too hot, the controller applies power to the solenoid, reducing the fuel flow to the idle rate. If the liquid temperature exceeds an upper limit, an alarm sounds.

1.1.2 Performance of Version 1 and Operating Difficulties

1.1.2a Start Up

Because of the intended uses of the device, it was decided early on not to use a battery. This decision resulted in many of the performance characteristics of the device. No electricity is available at start up, and the voltage and current available depend on the temperatures of both the hot and cold plates. At start up, the liquid flow is zero, so successful start up depends on the unit's exploitation of the temperature difference between hot and cold plates soon after combustion is initiated. Once sufficient power is available to start the pump, the cold plate temperature drops quickly, and the available electrical power increases dramatically. Start up of the unit from a cold condition, when the cold plates were cold, is quite reliable. Unfortunately restart from a warm condition is unreliable, because of the reduced initial temperature differential. The operator needs to confirm that start up occurs, and act appropriately if it has not.

1.1.2b Safety Concerns

Because the combustion is initiated by a piezoelectric spark, and because a certain heat flow is required to generate sufficient electricity to operate the pump, the unit has an idle burn rate, below which the device will not operate. When low heat output is required, version 1 arrives at this minimum burn rate in an effective manner. Since the fuel solenoid

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valve requires electricity to close, as the voltage drops the solenoid opens before the pump stops, and the device recovers before failure. Unfortunately, this simple scheme can not include a means of automatically shutting off all fuel flow.

Fuel flow continues if any one of the following conditions occurs:

1- one of the lines to the garment becomes kinked, pinched or disconnected
2- the garments are unable to remove the heat produced at the idle burn rate
3- start up is unsuccessful

In conditions 1 and 2 the unit overheats, possibly burning the user or destroying itself and causing a fire. In condition 3, unburnt propane/air mixture emanates from the unit, potentially resulting in an explosion hazard. For all these conditions, the onboard alarm provides insufficient protection. It may not even operate if electricity is not being produced.

Version 2 was conceived to rectify these safety concerns.

1.2 Version 2

1.2.1 Design

1.2.1a <u>Fuel Control</u>

In version 2, the fuel control system is per version 1, except additional valving has been added. A normally closed solenoid valve has been installed to shut off all fuel flow. There is also a manual push button valve to initiate fuel flow at start up.

1.2.1b <u>Combustion and Heat Capture</u>

Combustion and heat capture for version 2 is the same as in version 1.

1.2.1c <u>Liquid Circulation</u>

Liquid circulation in version 2 is the same as in version 1.

1.2.1d <u>Electricity Production</u>

Electricity production is version 2 is the same as in version 1.

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1.2.1e Control System

In version 2, the controller senses the exiting liquid temperature, and compares it with a setpoint provided by the user through a multiposition switch. To save power, the LED display has been eliminated. If the liquid is too cold, the controller cuts power to the normally open solenoid valve, causing the fuel flow to go high. Conversely, if the liquid is too hot, the controller applied power to the solenoid, reducing the fuel flow to the idle rate. Version 2 also includes an additional thermistor to sense the cold plate temperature. If either the exiting liquid temperature, or the cold plate temperature exceeds trip levels, the controller cuts power to the normally closed solenoid valve, and all fuel flow stops. There is no alarm.

1.2.2 Performance of Version 2 and Operating Difficulties

1.2.2a Start Up

Version 2 must start up under the same electrical power limitations as version 1. A result, warm restart is no more reliable than that for version 1. Nevertheless, safety is improved because the operator has to hold a manual valve open until successful electrical power is available.

1.2.2b Safety Concerns

With version 2, a failed start does not result in an unsafe condition. The high temperature trips also take care of problems with any interruption of liquid circulation, so that the system safely shuts down. Note that these trips are not redundant at present, but there is no reason why they cannot be made so if required.

1.2.2c Normal Operation

Unfortunately, version 2 requires higher power production from the thermoelectrics to operate. Instead of the minimum idle burn rate being established by the opening of a normally open solenoid valve, this design senses the available voltage, and cuts power to the high flow solenoid to shift the unit into high heat production. However, since the main trip solenoid must be maintained open whenever the unit is running, the minimum allowable voltage must be higher. There are also two solenoids to power now instead of one. The net result of this increase in the electrical requirement is that version 2 units have been able to operate only at close to maximum heat output, or not at all, depending on the pump efficiency. Unfortunately we have also discovered that there is a rather large variation in the efficiency of the pump we selected for the system. The prototype version 1 unit happened to have a particularly good pump. We were not so lucky with subsequent version 2 units.

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1.2.2d Catalytic Combustion

We also experienced difficulties getting all three catalytic elements to start on version 2 units. Heating to the point of starting combustion on these screens is accomplished by the flame front set off by the piezoelectric spark ignition. Screens that failed to light at the start, sometimes remained inactive while combustion progressed on other screens. Units that started this way would not come to self sustaining operation. Exhaust quality was also a concern, particularly for units where not all screens were burning. But even for units with all screens operational the exhaust smell indicated that we did not have sufficient catalyst for good combustion.

2. Attempts Made to Correct Heating Unit Shortcomings

The additional features incorporated into version 2 looked after the safety concerns inherent with version 1. Accordingly Carleton's efforts have been focused on attempting to make version 2 operational. We have made several attempts at this task over the past year, and these are outlined below:

- The electronic components were changed to result in a circuit able to control the unit at lower voltages. Control system operation at voltages just above 1 volt was demonstrated.

- In an attempt to reduce the total power draw, a system unit was modified per figure 3. The fuel control included only the manual start up valve and one normally closed solenoid valve. The manual idle valve and high flow solenoid valve were deleted. The idle burn rate was established by pulsing the single solenoid valve.

Unfortunately none of the above steps have proved sufficient. We have reduced the power consumption of the solenoid valve, control circuit, and pump as far as is practical. The design is still unworkable. It is apparent that in order to make field practical units, the combustion chamber, including the arrangement of the catalyst, needs to be redesigned to result in reliable start up and more complete combustion. The temperature achieved on the hot plates will also have to be higher to generate more electrical power.

3. Recommendations

Based on this experience, we recommend that further attempts to develop a field useable heating unit based on this technology be discontinued. This recommendation is made in consideration of the amount of effort which is likely to be required for success, the technical risks which will be faced, and the existence of an alternate technology which appears more forgiving.

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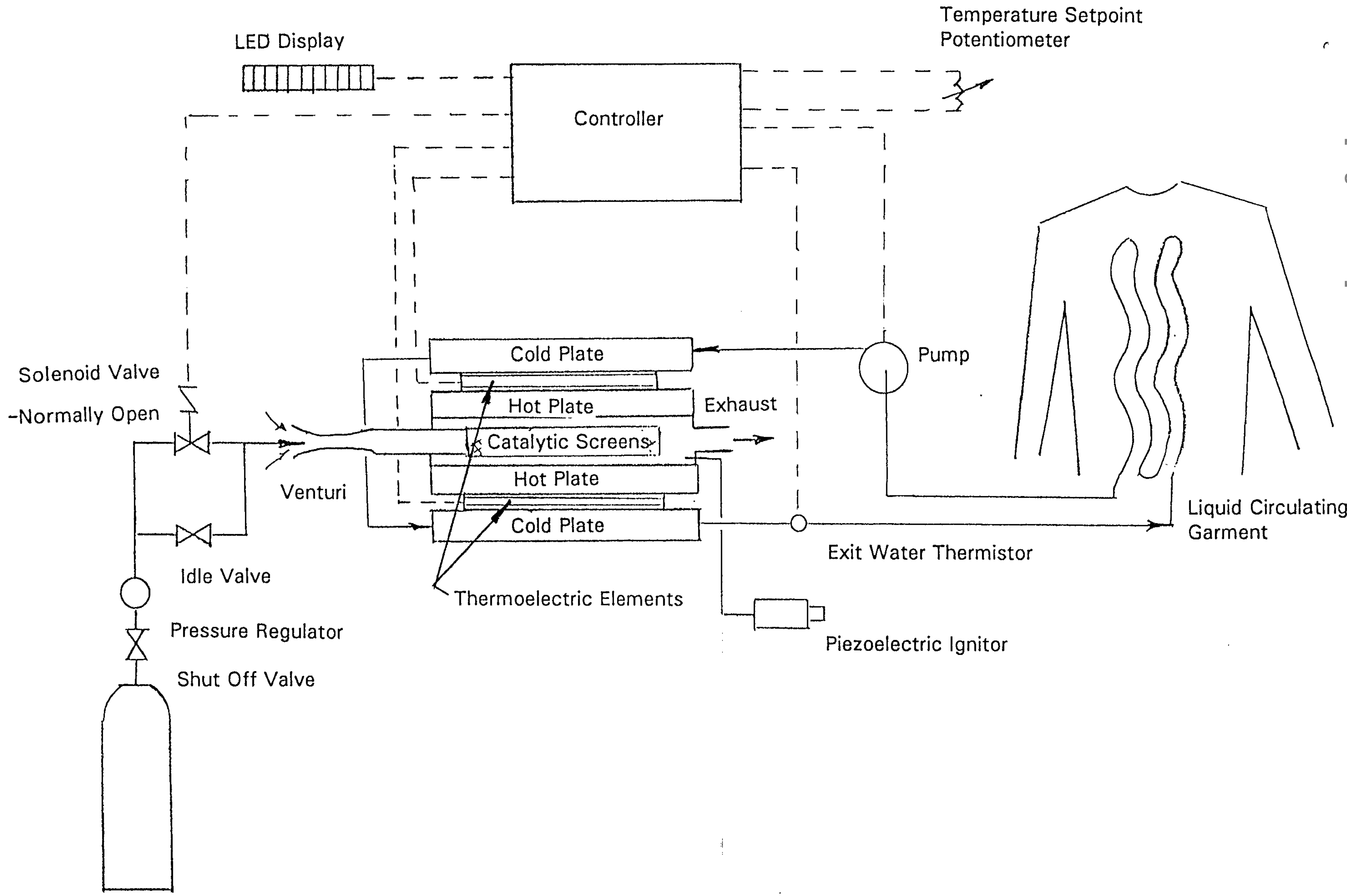
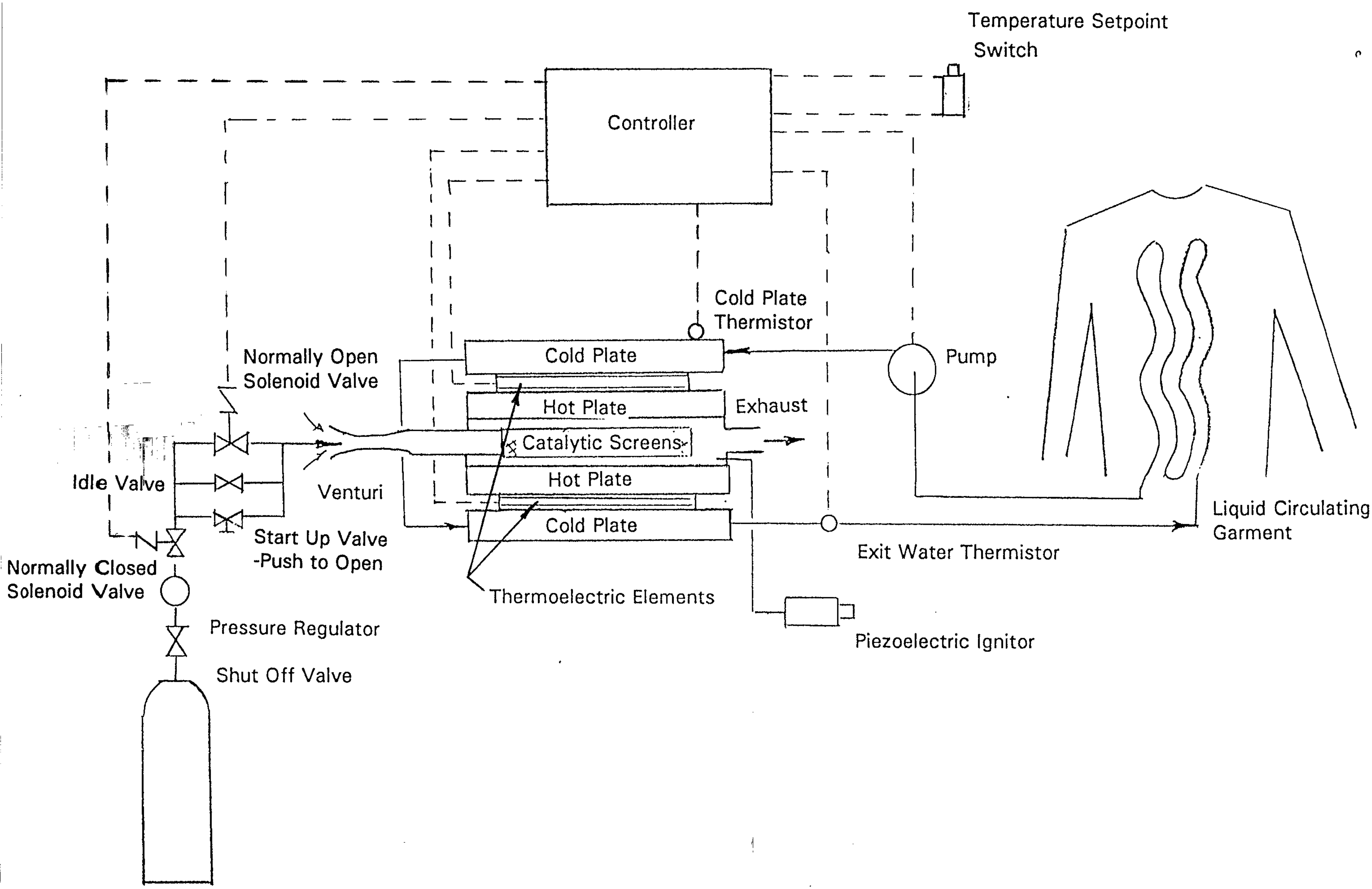
Carleton Technologies has entered into a cooperative arrangement with groups expert in the emerging technology of direct methanol fuel cells. These devices are 25% efficient at present. For this application we need less than 10 Watts of electricity, or 5% efficiency in a 200 $Watt_{thermal}$ fuel cell. No part of a methanol fuel cell operates at more than 60 C. The fuel is convenient and inexpensive. Start up from 10 C is straightforward. The exhaust from existing cells has been very clean. There are difficulties to be handled with respect to stripping CO_2 from the liquid side of the cell, and in water capture and recirculation from the anode to the cathode, but in our judgement these challenges will be more easily overcome than those remaining with the catalytic propane unit. A key factor will be the availability of sufficient electrical power. A heater based on a de-tuned methanol fuel cell will be quite forgiving. One based on catalytic propane combustion and thermoelectric power production needs to be set up just right to operate.



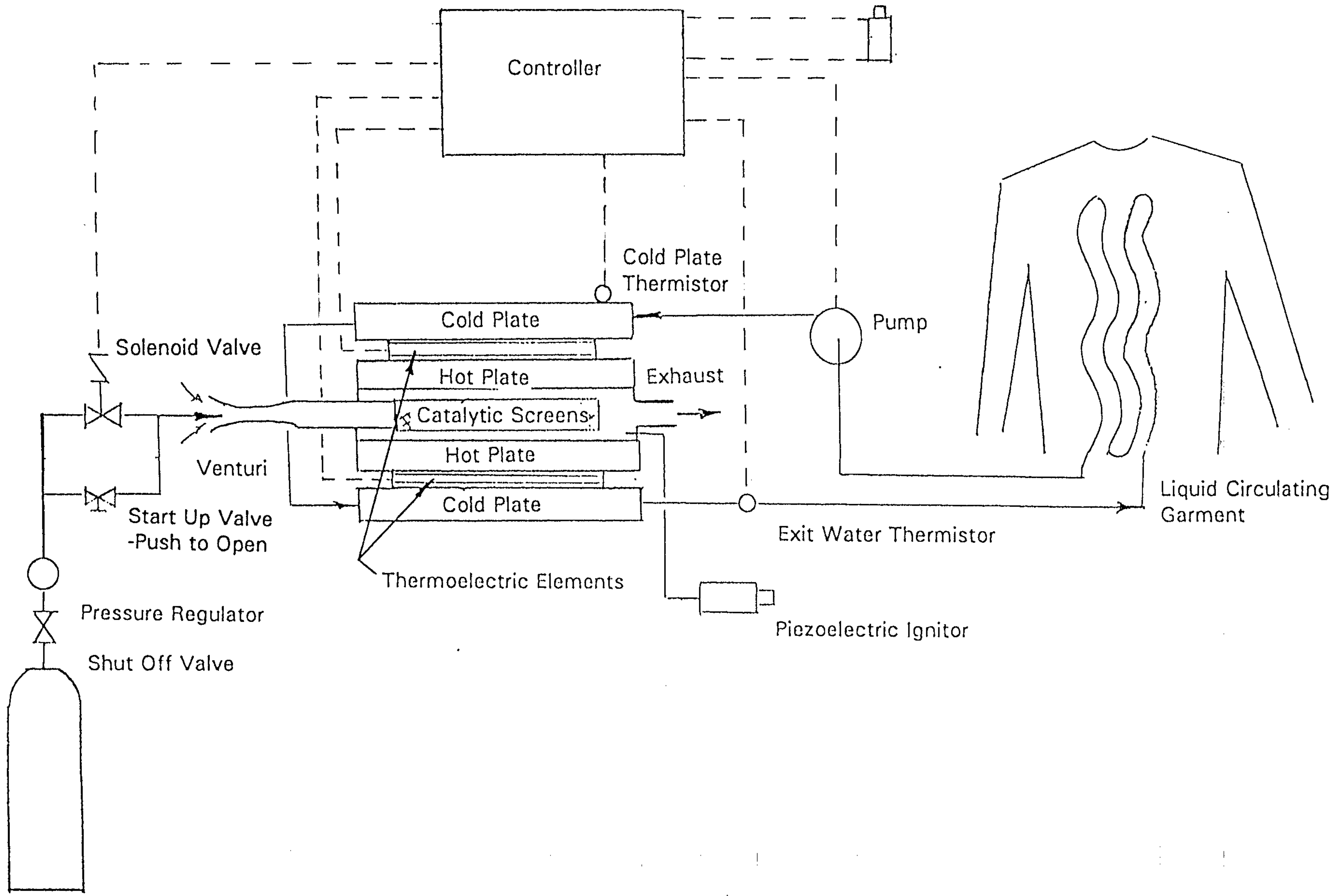
Schematic of Version 1
Liquid Warming Unit

Figure 1



**Schematic of Version 2
Liquid Warming Unit**

Figure 2



Schematic of Version 2 Unit With Single Solenoid Valve

Figure 3

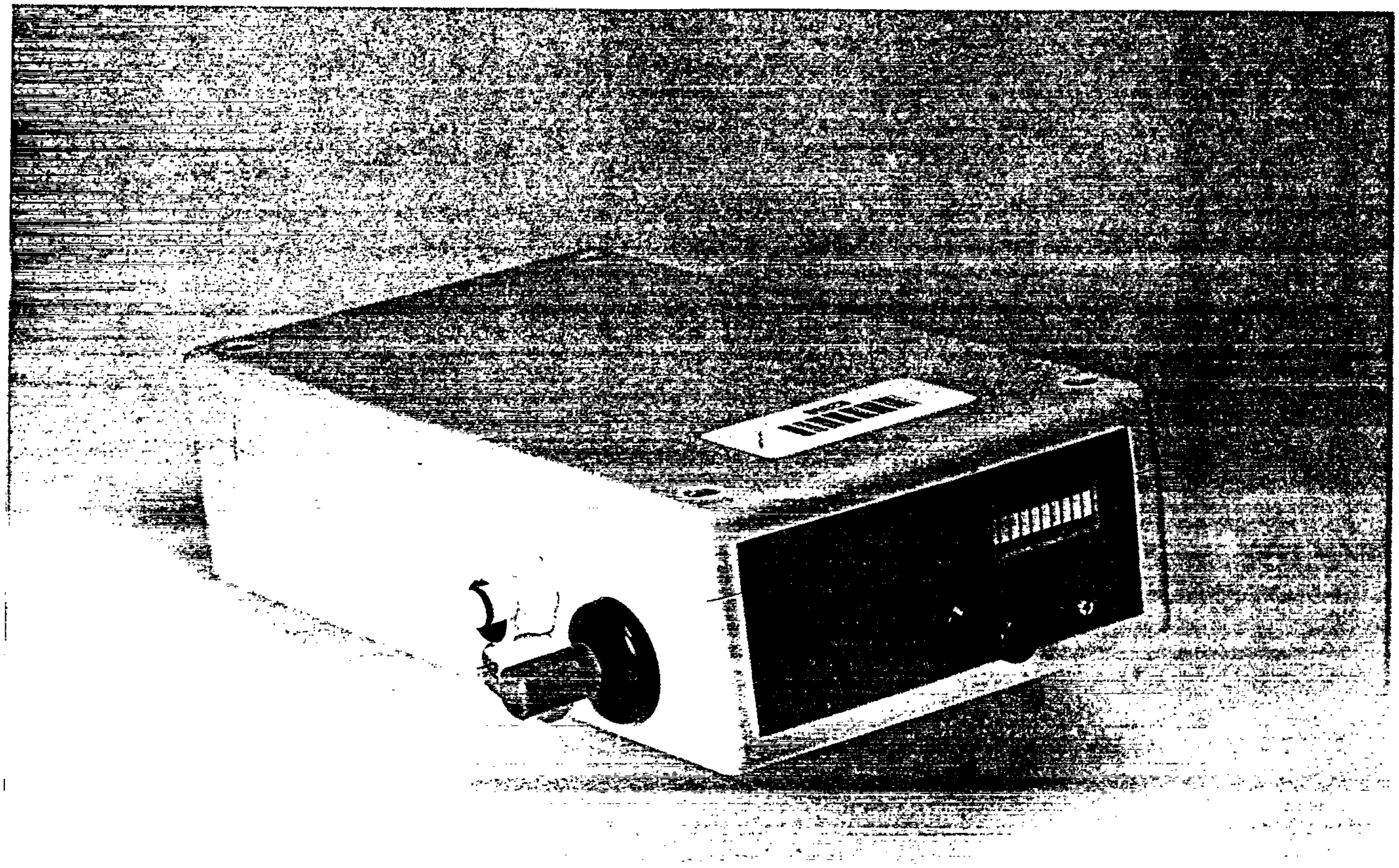


Figure 4 - Version 1 Liquid Heating Unit

Note LED temperature display and temperature set point knob on end, piezoelectric element and connectors on side.

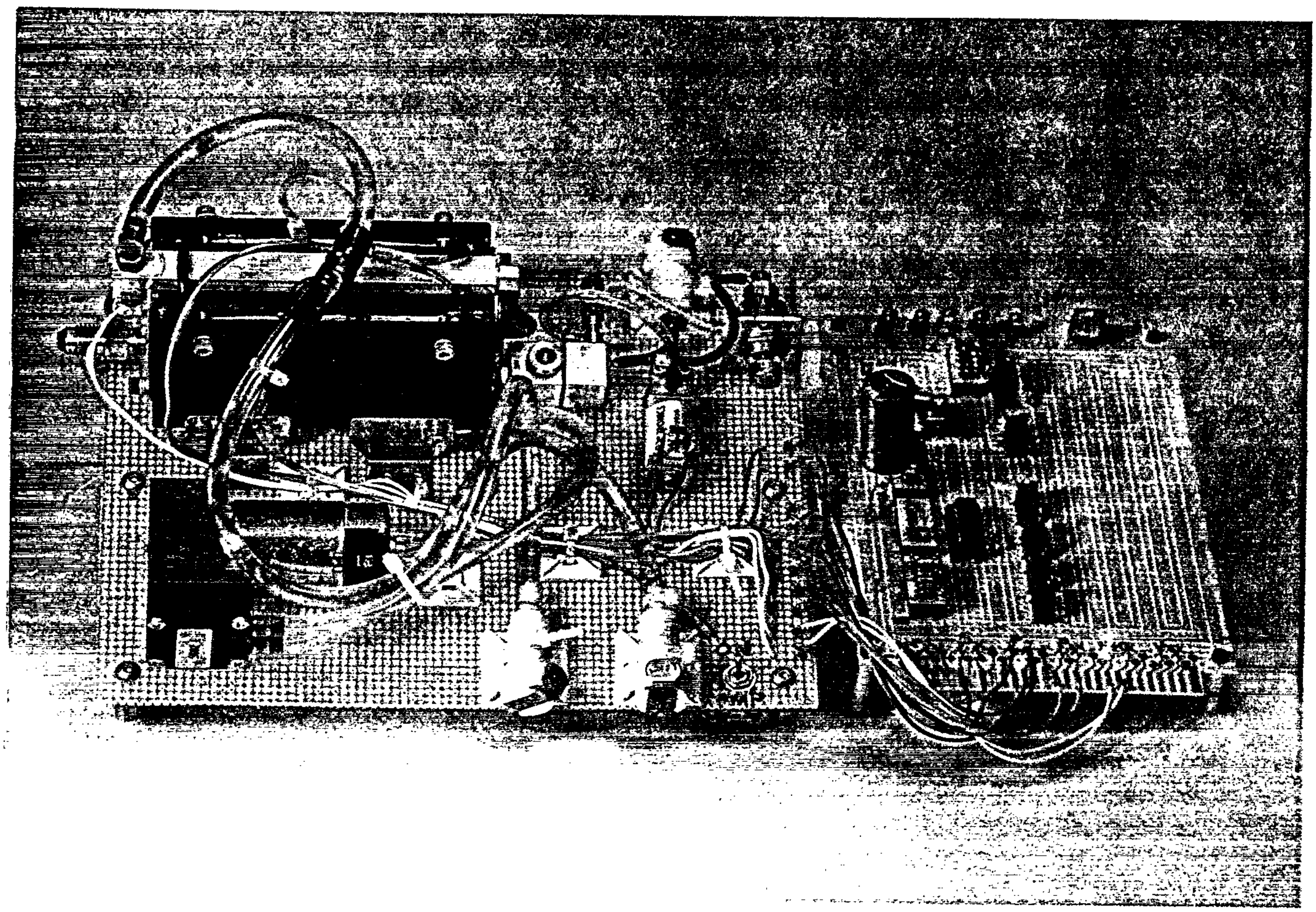


Figure 5 - Bench Top Liquid Heating Unit, Version 2 with Single Fuel Solenoid

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