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RESIDENTIAL GAS-FIRED SPACE-CONDITIONING RESEARCH AND DEVELOPMENT AT BROOKHAVEN NATIONAL LABORATORY*

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ABSTRACT

Brookhaven National Laboratory has work on-going involving industrial development of gas- and oil-fired space heating equipment.

An analysis of the energy situation indicates that there are significant opportunities to reduce energy waste. These opportunities involve the elimination or reduction of unnecessary consumption and the development of more efficient equipment. Various options exist for the development of advanced space-conditioning equipment having improved efficiency. The three basic approaches are (1) to increase the capacity of the heat exchanger, (2) to operate with a reduction in excess air, and (3) to reduce standby and cycling losses. The ideal operation of a conventional boiler or furnace is to allow the heat exchanger to operate in the condensing mode at the temperature where the latent heat of vaporization of water vapor in the flue gas is recovered. The resulting efficiency can reach close to 95%.

The gas-fired research and development work presently on-going involve the following: (1) a variable firing rate gas burner, (2) a gas-fired pulse combustion furnace capable of firing 40,000 to 90,000 Btu/hr, (3) a gas-fired pulse combustion boiler with an output of 36,000 Btu/hr, (4) a gas-fired heat pipe furnace firing at 60,000 Btu/hr, and (5) a nonelectric Rankine cycle gas furnace. A materials program is also underway to identify cost-effective materials for condensing oil- and gas-fired systems, and a study has just been completed that identifies technology for improving the efficiency of heating systems. The method for laboratory and field testing that will assist in commercialization of new, advanced equipment is presented.

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RESIDENTIAL GAS-FIRED SPACE-CONDITIONING RESEARCH AND DEVELOPMENT AT BROOKHAVEN NATIONAL LABORATORY

The management and staff of Brookhaven National Laboratory are dedicated to supporting the U. S. Department of Energy in the research, development, and demonstration (RD&D) of energy systems that can make more effective and efficient use of scarce resources. Our analysis of the energy situation indicates that waste can be significantly reduced both by eliminating or reducing unnecessary consumption and by developing more efficient devices and systems to deliver the energy that is required. The heating, cooling, and ventilating of residential and commercial buildings accounts for about one-sixth of the nation's oil consumption, one-fourth of its natural gas consumption, and a large fraction of its peak electrical load. Work is being done at Brookhaven on hardware development and energy analysis in the area of gas- and oil-fired space-heating equipment. More efficient furnaces and boilers have a high priority on DOE's National Plan for conservation.

Various options for the development of advanced space-conditioning equipment with improved efficiency include (1) reconfiguring existing concepts within the present state of the art, (2) making improvements or modifications that require technological advances, or (3) inventing new types of equipment. In considering these options, certain technical issues must be addressed. The factors that limit the efficiency of present equipment must be identified, and the prospects for mitigating them must be examined. Where technological advances are required, the risks involved become an issue, including financial risks and the possibility of adverse environmental impacts.

Three basic approaches are available for increasing the efficiency of conventional furnaces: (1) increasing the capacity of the heat exchanger, (2) operating with reduced excess air, and (3) reducing standby and cycling losses. The ideal way to operate a conventional boiler or furnace is to allow the heat exchanger to operate in the condensing mode at the temperature where the latent heat of vaporization of water vapor in the flue gas is recovered and the resulting overall efficiency can reach close to 95%. Figure 1 is a typical dew-point curve demonstrating the improvement potential after the dew-point has been reached. It shows that the efficiency can be increased by a maximum of 13% over that of an efficient boiler.

Figure 2 shows the technical boundaries for both oil- and gas-fired equipment. Block 1 delineates present technology in the field, where the seasonal efficiency ranges from 50% or less to a maximum of about 75%. The lower firing rate for oil is limited to about 0.6 gph by the use of pressure atomization. Gas burners using 60,000 Btu/hr are not manufactured. Block 2 represents new technology potential for highly efficient equipment operated just shy of the condensing mode. New technology is required to provide burner/heat exchanger combinations to reach that goal; the associated risk would be classified as moderate. Block 3 represents an alternative method of obtaining high seasonal efficiency by allowing the Btu input into a heat exchanger to be low or variable in order to load-follow the Btu demand. This necessitates developing alternative means of atomizing fuel oil coupled with new load-following control systems applicable to both oil and gas. Development to a point where the systems would be cost-effective with regard to the marketplace as well as to fuel saving would be classified as high in risk.

Block 4 represents the ultimate fully condensing conventional system. The associated risk for a gas system to operate in a fully condensing mode is moderate. The main areas of concern would be in the development of cost-effective new materials, and an approved method of handling the condensate. The risk for an oil system is significantly greater because fouling and corrosion are more likely to occur.

Cycling losses can be reduced in several ways. One method is to provide a high-input burner matched to a small heat exchanger. The mass of the heat exchanger is made small so that in the off-cycle periods the heat will be pulled out of the heat exchanger just after burner shutdown. This provides for very low off-cycle losses, and thus makes the seasonal efficiency close to the steady-state efficiency.

The other extreme is to provide a continuous, low, or load-following burner, which would increase the fractional on-time of the system and thus bring the seasonal efficiency close to the steady-state efficiency. Between these two extremes are many other burner/heat exchanger combinations that would increase the seasonal efficiency. Alternative means of fuel combustion such as pulse combustion, fluidized-bed combustion, catalytic combustion, etc., when properly matched to a heat exchanger, will also improve the seasonal efficiency.

Condensing systems have been tried in the past, but with only minimal success. Fuel costs were too low to justify the added cost and complexity of installing them. Oil-fired condensing systems have additional, more significant problems compared with gas-fired systems: (1) the condensate has a low pH, and the sulfur concentrations are higher than with gas, causing rapid corrosion of all metals; (2) the combustion process produces carbon (soot), which is intolerable when operating the heat exchanger in a wet mode. For practical operation with oil, a blue-flame or nonfouling yellow-flame burner must first be developed so that the amount of carbon formed in the heat exchanger is minimal, because carbon would combine with the condensate water and foul or plug the entire heat exchanger. The sulfur content of oil is high enough to mandate use of a noncorrosive material for the heat exchanger. Also, the presence of sulfur and alkalides in the oil condensate will necessitate a method of condensate collection, treatment, and disposal. All three of these problems must be solved before an oil-fired system can be allowed to operate in the condensing mode. Therefore, the risks of producing the complete system are high.

The sulfur content of gas is low enough that the condensate will not be too corrosive. Stainless steel has been used in the condensing areas of the heat exchanger with little or no problems. Finding a cost-effective material with good heat transfer is the most significant barrier to oil-fired condensing systems. The plan for condensate disposal must take into account whether the liquid can be put directly into the waste system or must first be neutralized. The flue gases will be vented directly to the outside, not through a chimney, and some local codes do not permit this.

Costs for condensing systems are expected to run 50% more than for conventional equipment, but the increase in efficiency should make the payout period only one or two years longer. In new construction the lack of need for a chimney makes condensing systems more competitive. As the cost of fuel increases, the consumer drive to attain high heating efficiency will increase.

To increase the seasonal and steady-state efficiencies of gas heating systems, one method is to use highly efficient power burners, that is, burners that will use forced and controlled primary and secondary air and will operate close to the stoichiometric limit without producing carbon monoxide. One research and development effort, at Foster-Miller Associates, is aimed at developing a variable-firing-rate gas burner that can operate at 10,000 to 120,000 Btu/hr with extremely low excess air. The burner can be cycled on and off at a fixed firing rate, or it can be made to vary and load-follow the Btu loss of a structure and thus to increase the fractional on-time and therefore the seasonal efficiency. The burner employs a zero-pressure regulator coupled to fixed-ratio gas and air ports. The air is used as the master control, with the gas acting as the slave, so that when the inlet air is increased or decreased, the gas flow tracks, maintaining almost a constant air/fuel ratio. By the time the fuel/air reaches the flame holder, it is completely mixed and no further air is required. The flame is ignited and is stabilized on the surface of the flame holder. This burner, matched to the proper heat exchanger, would produce a high seasonal efficiency noncondensing system or could be used in a condensing system. (See Figure 3.)

BNL has two pulse combustors under development, a furnace at Shock Hydrodynamics and a boiler at Yankee Engineering. Pulse combustion is receiving emphasis because it can provide, with moderate ease, a condensing system with a low mass and high seasonal efficiency. The turbulent exhaust gases, caused by internal explosions, scrub the side of the exhaust tube and thus increase the heat transfer rate by a factor of $\sim$4 over that of conventional heat exchangers.

The purpose at Shock Hydrodynamics is to create a gas-fired pulse-combustion furnace capable of firing between 40,000 to 90,000 Btu/hr, and a major consideration is to ensure minimization of the noise level, as harmonics and vibrational noise are very difficult to control in a furnace. After numerous permutations, the final pre-production unit employs a tuned spherical combustion chamber with a primary and secondary heat exchanger. The system starts easily, has stable operation over the range, and has a total unmuffled sound power level of ∿75DBA which drops to the low 60's when the inlet and exhaust are decoupled. The final furnace is being constructed by American Appliance of California and will undergo laboratory and field tests during the 1979/1980 heating season. (See Figure 4.)

The purpose at Yankee Engineering is to develop a condensing pulse-combustion boiler that fires at ∿36,000 Btu/hr. The entire combustion chamber plus resonator is surrounded by water and has a sealed combustion system that uses the exhaust gases to preheat the incoming combustion air. Exit temperatures as low as 70°F are attainable. The boiler provides hydronic space heat as well as domestic hot water when coupled with a separate water tank, and the system can also be fitted with a fan coil unit to provide an integrated furnace/domestic hot water system. The boiler has been undergoing laboratory tests and will be field tested in 1980. (See Figure 5.)

A gas-fired heat-pipe warm-air furnace is being developed by Thermacore. A heat-pipe furnace has a low mass, a compact and fast reacting heat exchanger, and a minimum of two heat-exchanger surfaces of the water-filled heat pipe between the combustion air and distribution air sides. The heat exchanger will be coupled with a power burner having a screen flame holder with an output of 60,000 Btu/hr. The system is designed to be able to operate in the condensing mode. (See Figure 6.)

A Rankine-cycle furnace called Turbo Therm, developed by Thermal Research and Development Corp., incorporates an inlet damper and a vent damper, has no need for electricity, and has a high efficiency. Natural gas is used to power the steam boiler; the steam goes through a Terry turbine, driving the air distribution fan, and then goes through a heat exchanger/condenser; the condensate returns to the boiler. The system can be fired at rates as low as 20,000 Btu/hr and as high as 150,000 Btu/hr. (See Figure 7.)

To provide the ability to run a heat exchanger in the condensing mode, cost-effective materials must be found which have good heat-transfer characteristics and the ability to withstand the corrosiveness of the oil and gas condensate. Work to develop such materials is under way at Battelle Columbus Laboratory, the Gas Research Institute, the Canadian Gas Research Institute, and Brookhaven National Laboratory. Condensing systems provide the ultimate steady-state efficiency for a conventional fossil-fuel-fired system; they have the potential to improve efficiency by 13% over that of the best system available to date. The materials developed could possibly dictate the design of the heat exchanger because of (1) forming requirement of new materials, or (2) the use of a two-stage heat exchanger. New materials could be used to develop both gas and oil condensing boilers and furnaces as well as condensing secondary flue-gas economizers for conventional noncondensing heating systems.

Field demonstrations of high-efficiency integrated space heat/domestic hot water gas-fired systems are being tested in three parts of the country. Southern California Gas Co., Brooklyn Union Gas Co., and Boston Gas Co. have installed systems and are collecting data, with A. D. Little coordinating the program. Both furnaces and boilers are being tested in the categories of advanced conventional systems, European compacts, high-efficiency noncondensing systems, and condensing systems. The initial objective of the program is to aid the commercialization of energy-efficient systems. Newly developed gas systems will also be tested. The program is co-funded by Brookhaven National Laboratory, the Gas Research Institute, and the New York State Energy Research and Development Authority.

A report of a study just completed by Battelle Columbus Laboratory is entitled Survey of Available Technology for the Improvement of Gas-Fired Residential Heating Equipment. Available technology was surveyed as to its possible application to more efficient gas-fired comfort heating and water heating in residences. Objectives were (1) to evaluate energy-saving modifications and design approaches, including both retrofit and new systems, and (2) to identify RD&D required to bring to the marketplace those concepts that have a reasonable payback period. A principal recommendation covering several specific concepts was further study of condensing heat-exchanger systems. RD&D was recommended on both mechanical and aerodynamical valve pulse combustors, radiant burners, catalytic systems, heat-pipe systems, self-powered heating systems, and gas-fired heat pumps.

Oil-fired equipment is also being developed under the BNL Space-Conditioning Program. Blueray Systems, Inc., has developed a line of blue-flame oil burners, and is commercializing both furnaces and boilers. As discussed above, the variable or low firing offers the potential for significantly increasing the seasonal efficiency of systems. Four systems are being developed: (1) an exhaust-gas recirculation blue-flame burner, (2) an electrically heated Wisker wire prevaporizing burner, (3) an ultrasonic atomizing burner, and (4) an air atomizing burner. All these burners can fire between 0.1 and 0.6 gph. Two heat exchangers are being developed for oil-fired burners: (1) a fully condensing furnace with a secondary teflon-lined heat exchanger; (2) a low mass exchanger in which the control system pulls down in temperature after each cycle--this should provide a high seasonal efficiency. An oil-fired technology survey is being conducted similar to the gas survey mentioned earlier as well as a field demonstration program which will test all oil-fired equipment developed under this program.

All the equipment being developed for oil- and gas-fired burners and heat exchangers will undergo laboratory and field tests during 1980 to 1982. It is BNL's intention to complete the development of gas-fired condensing systems and to determine whether oil-fired condensing systems would be practical. Commercialization of products will be initiated upon successful completion of field tests.

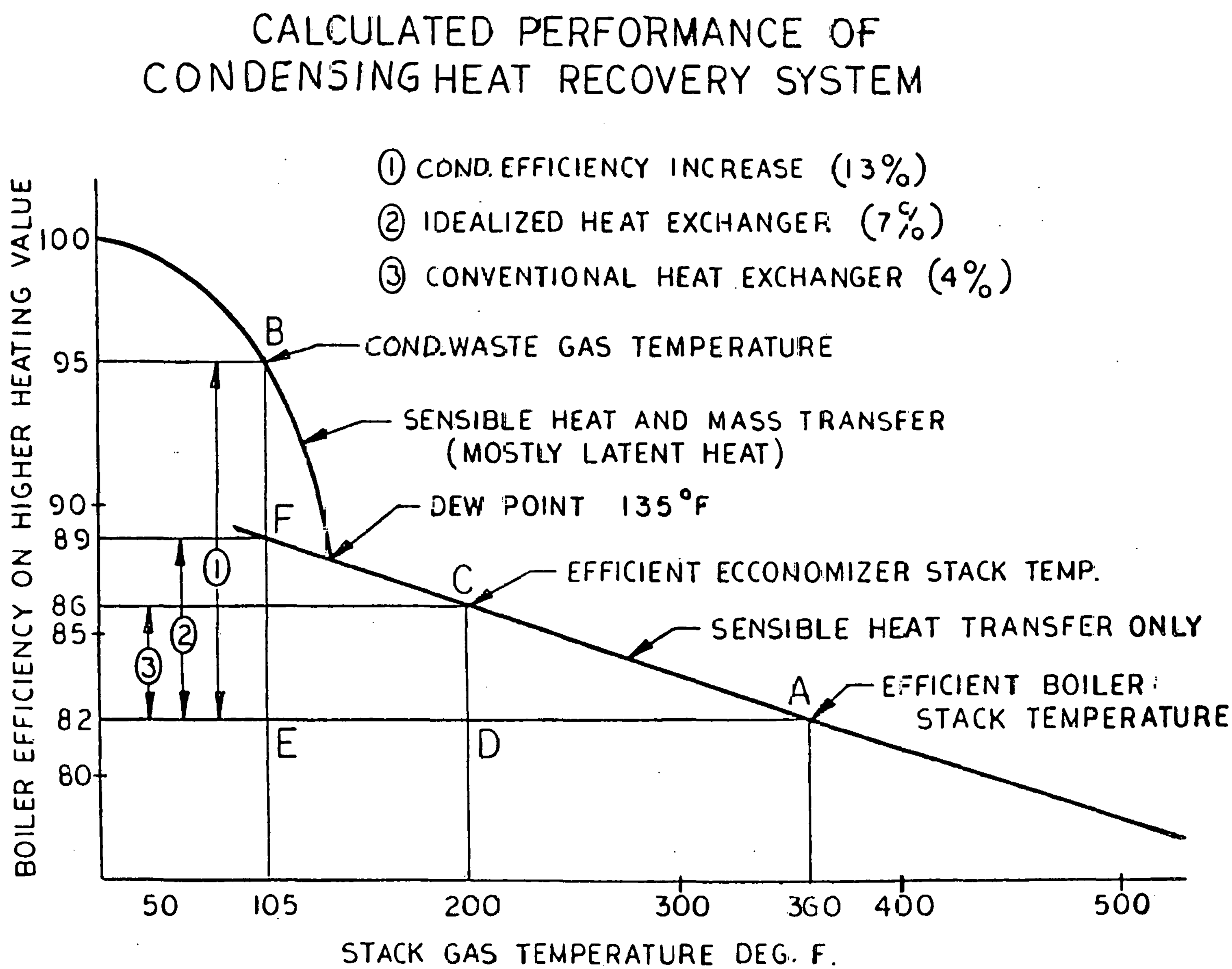
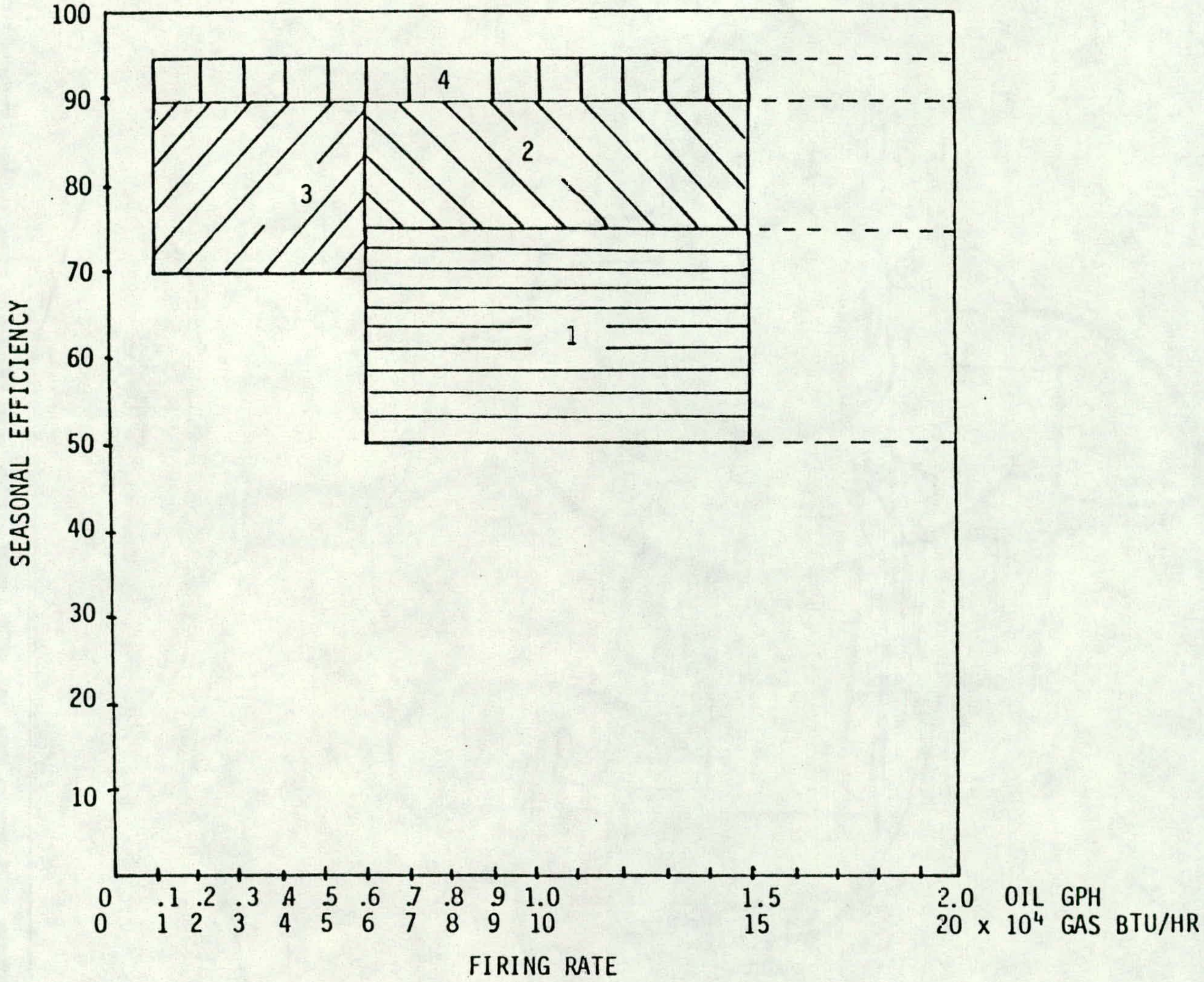

CALCULATED PERFORMANCE OF
CONDENSING HEAT RECOVERY SYSTEM
① COND. EFFICIENCY INCREASE (13%)
② IDEALIZED HEAT EXCHANGER (7%)
③ CONVENTIONAL HEAT EXCHANGER (4%)
B
COND. WASTE GAS TEMPERATURE
SENSIBLE HEAT AND MASS TRANSFER
(MOSTLY LATENT HEAT)
F
DEW POINT 135°F
C
EFFICIENT ECCONOMIZER STACK TEMP.
SENSIBLE HEAT TRANSFER ONLY
A
EFFICIENT BOILER
STACK TEMPERATURE
E
D
BOILER EFFICIENCY ON HIGHER HEATING VALUE
100
95
90
89
86
85
82
80
50
105
200
300
360
400
500
STACK GAS TEMPERATURE DEG. F.

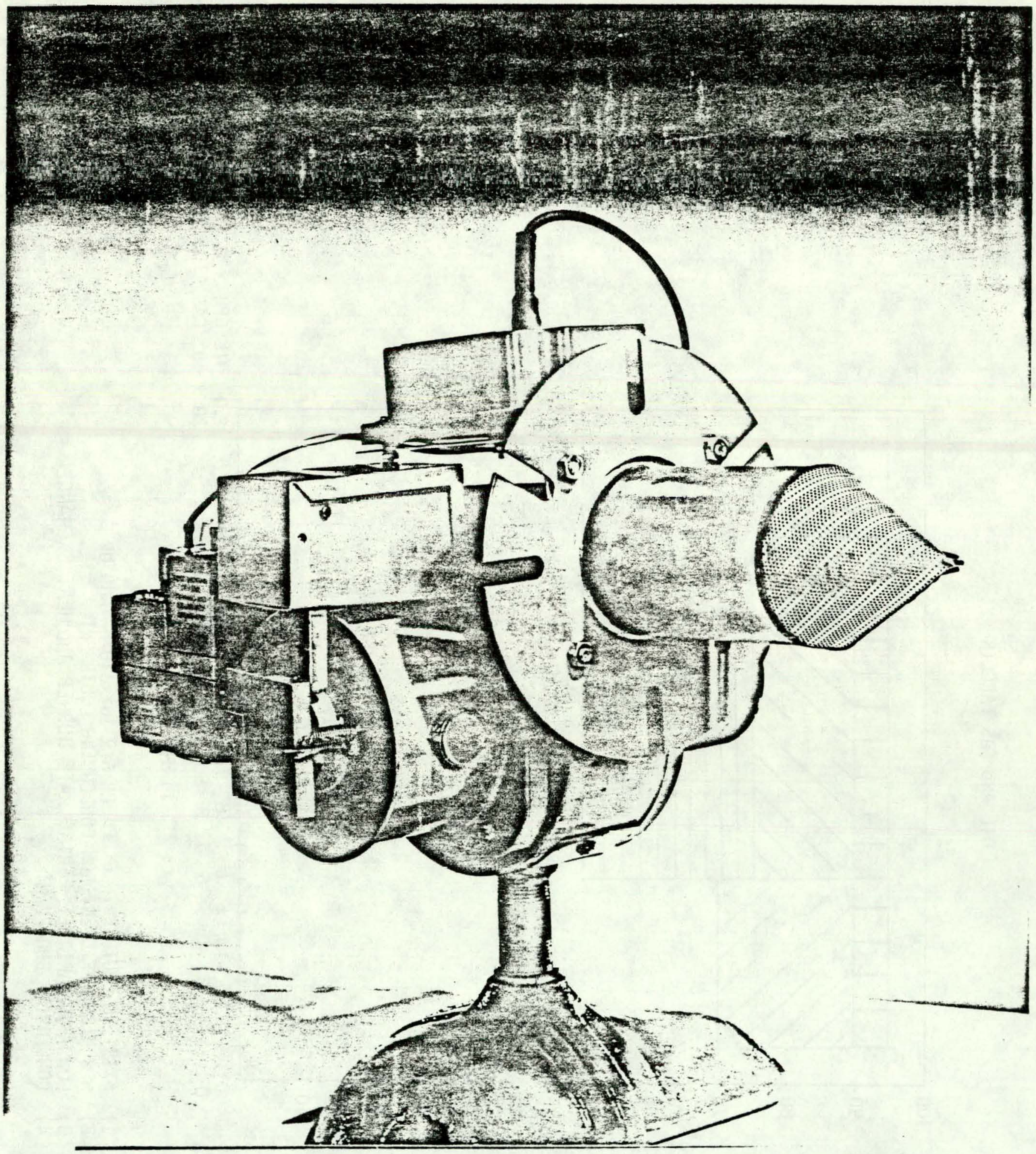
Figure 1.

OIL AND GAS TARGETS



1) EXISTING EQUIPMENT .6 GPH OR 6 x 10^4 BTU/HR AND UP
2) NEW HIGH EFFICIENT NON-CONDENSING EQUIPMENT
3) LOW AND VARIABLE FIRING RATE BURNER AND HEAT EXCHANGER
4) CONDENSING EQUIPMENT

Figure 2



VARIABLE FIRING RATE
GAS BURNER
FOSTER MILLER ASSOCIATES

Figure 3.

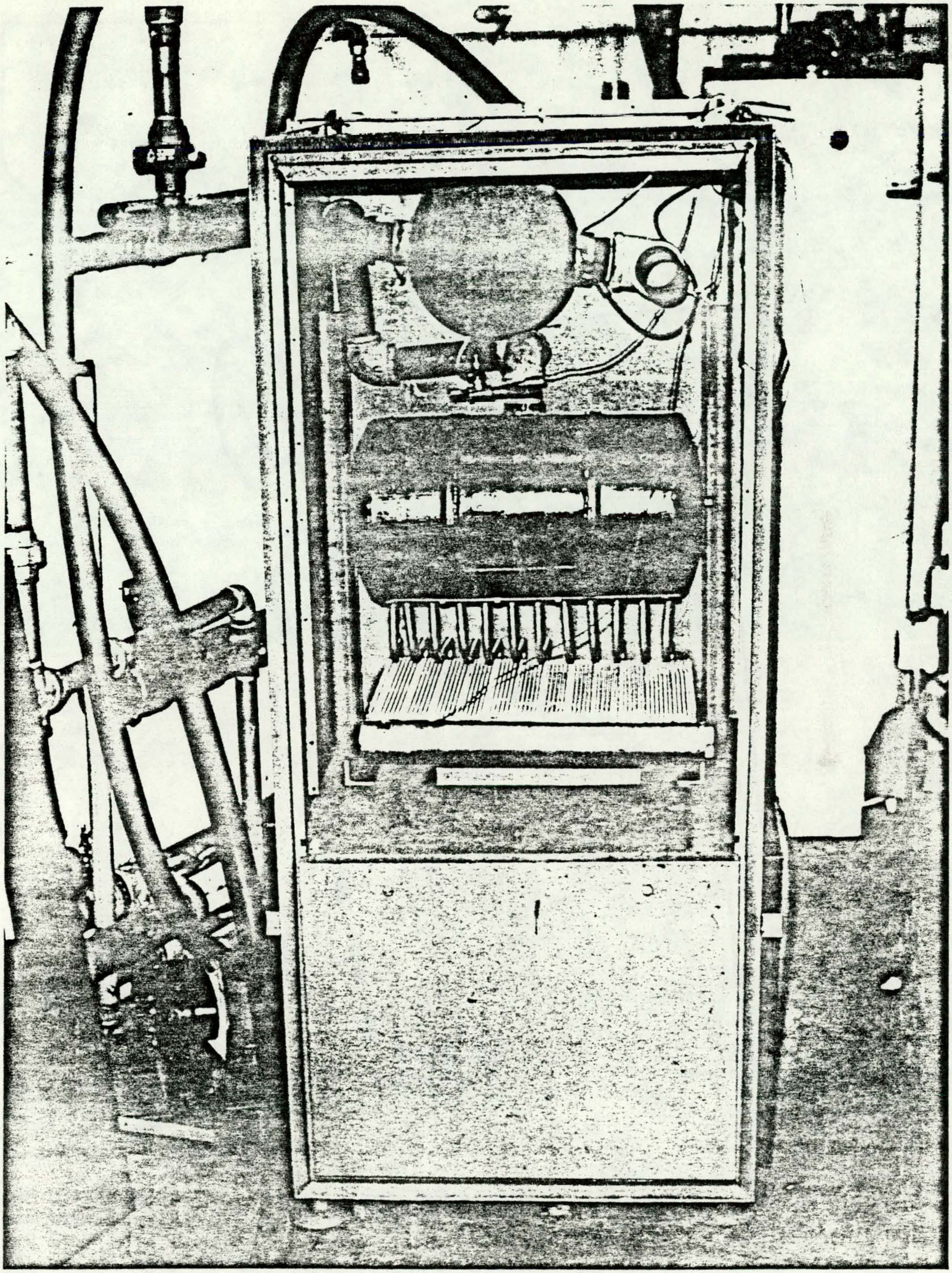


Figure 4. Pulse Combustion Furnace.

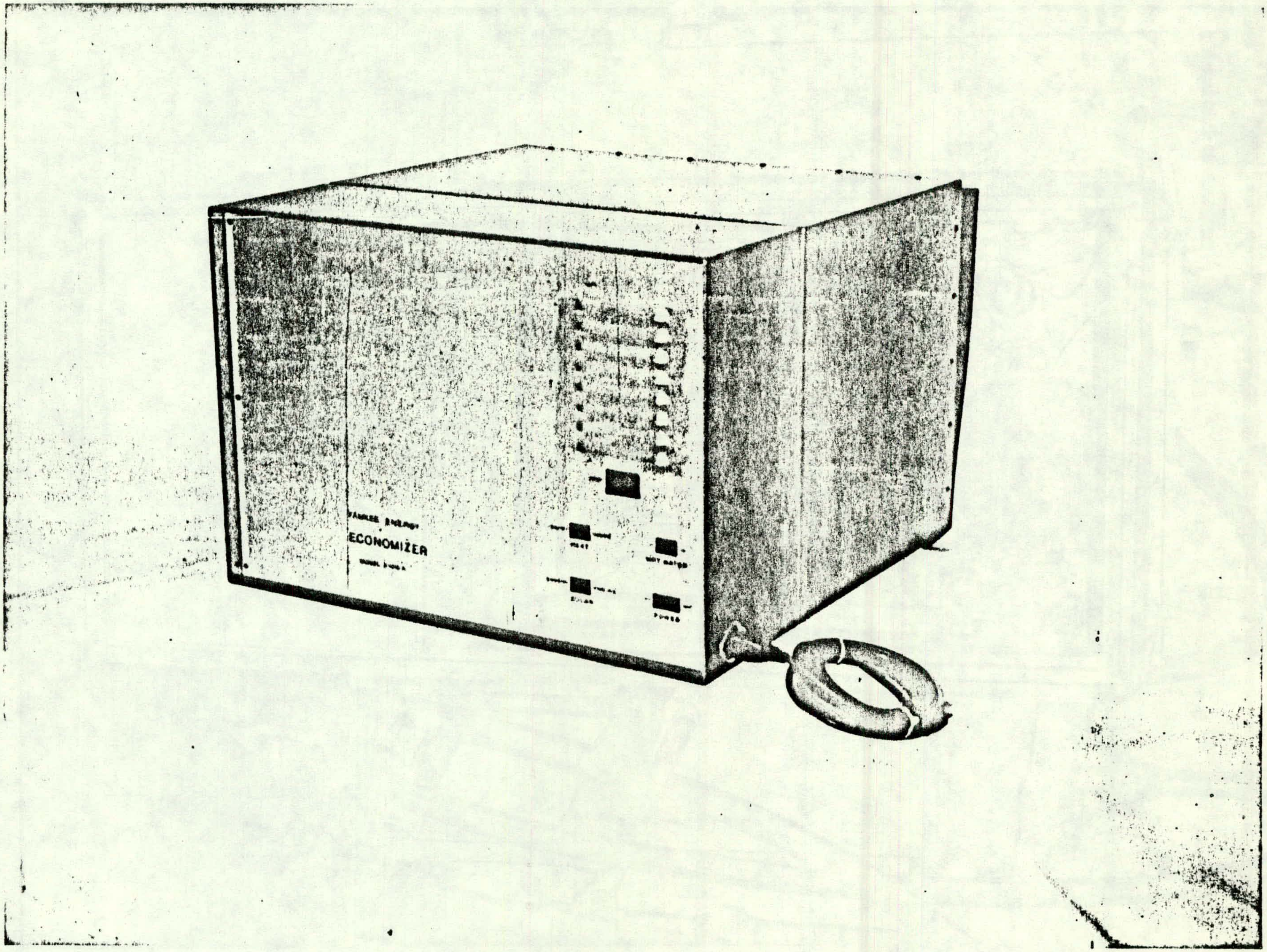
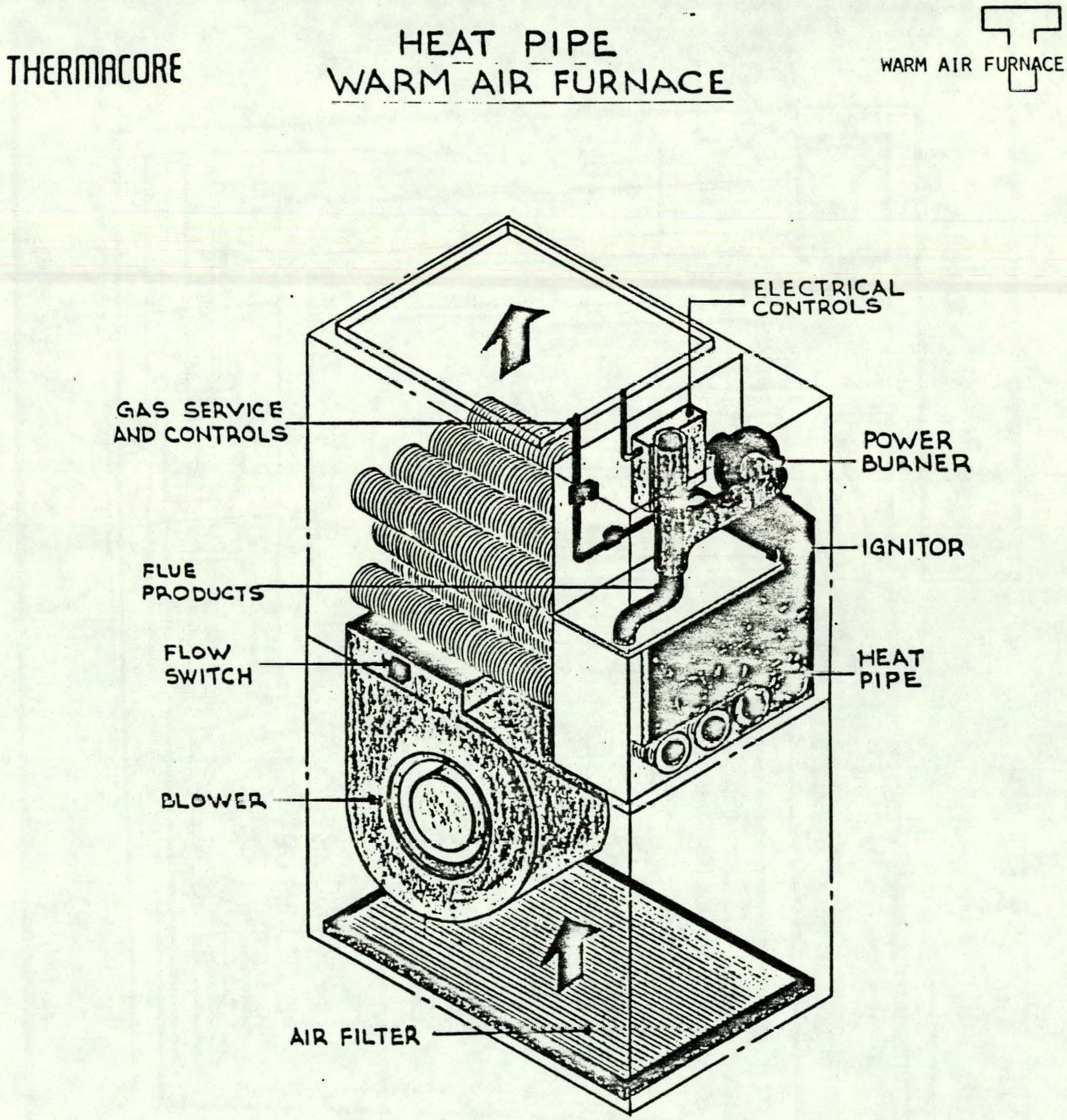


Figure 5. Pulse Combustion Boiler.



THERMACORE
HEAT PIPE
WARM AIR FURNACE
WARM AIR FURNACE
ELECTRICAL
CONTROLS
GAS SERVICE
AND CONTROLS
POWER
BURNER
IGNITOR
FLUE
PRODUCTS
FLOW
SWITCH
HEAT
PIPE
BLOWER
AIR FILTER

Figure 6.

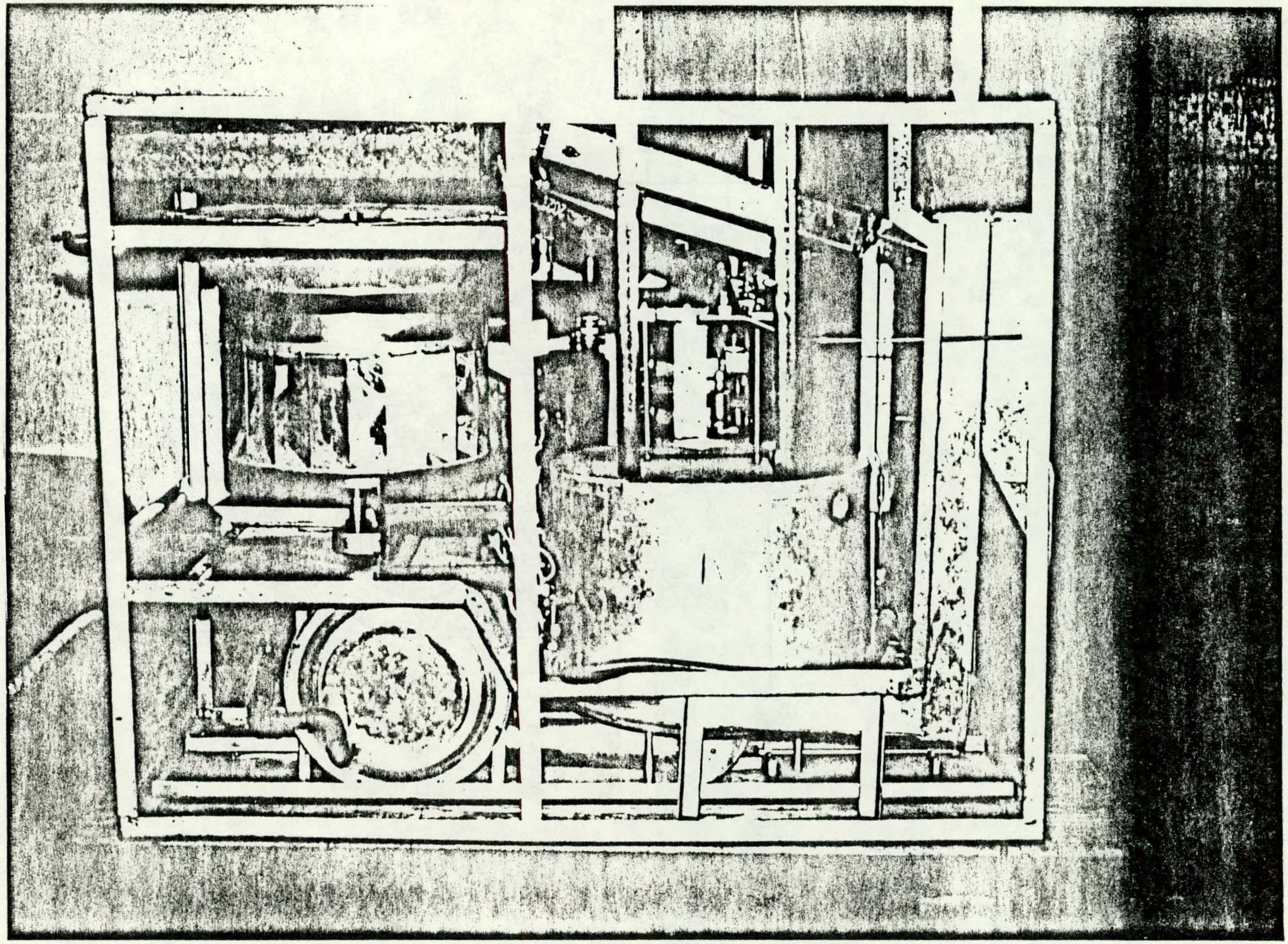


Figure 7. Self-Powered Gas Furnace.