

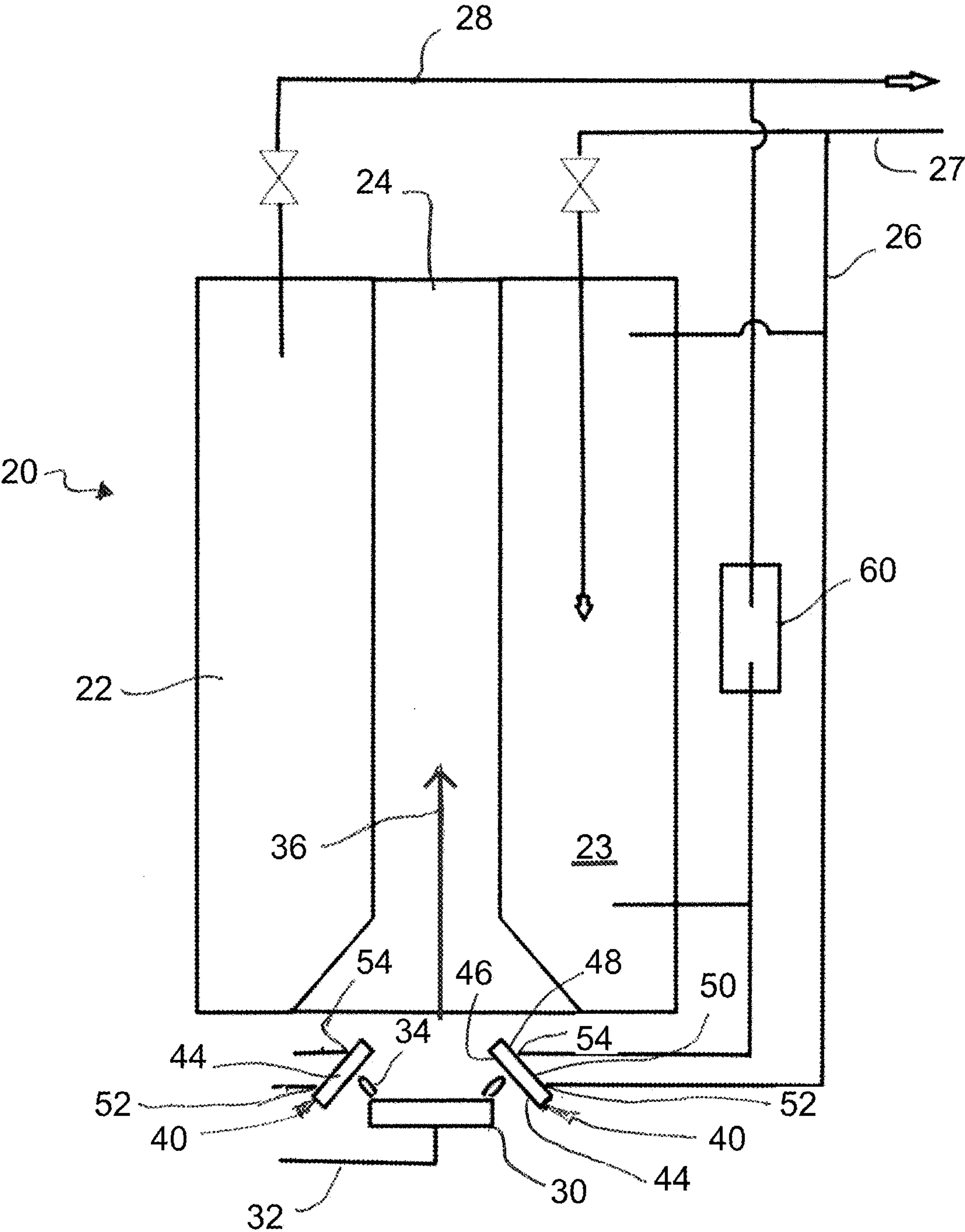


FIG. 1

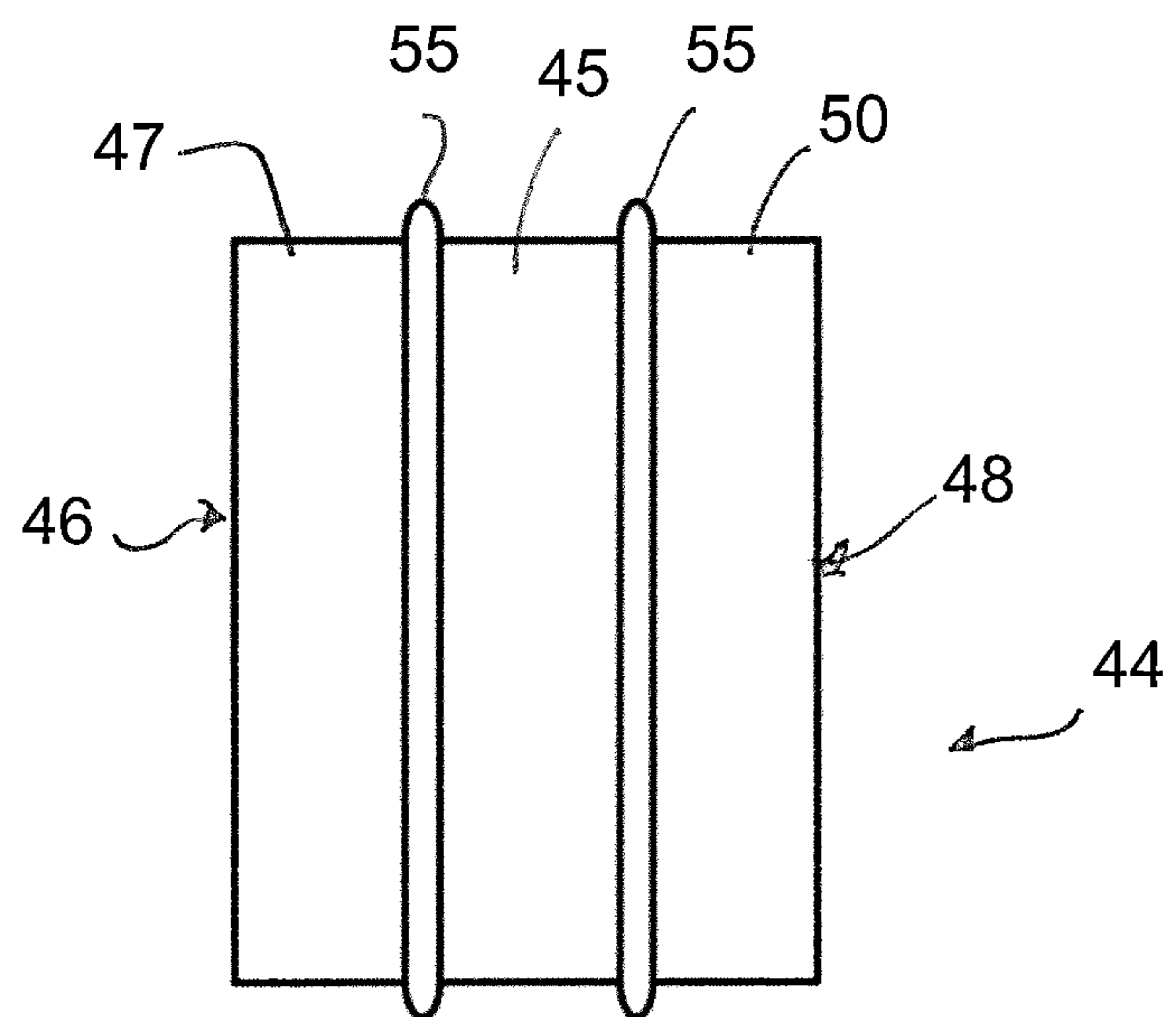


FIG. 2

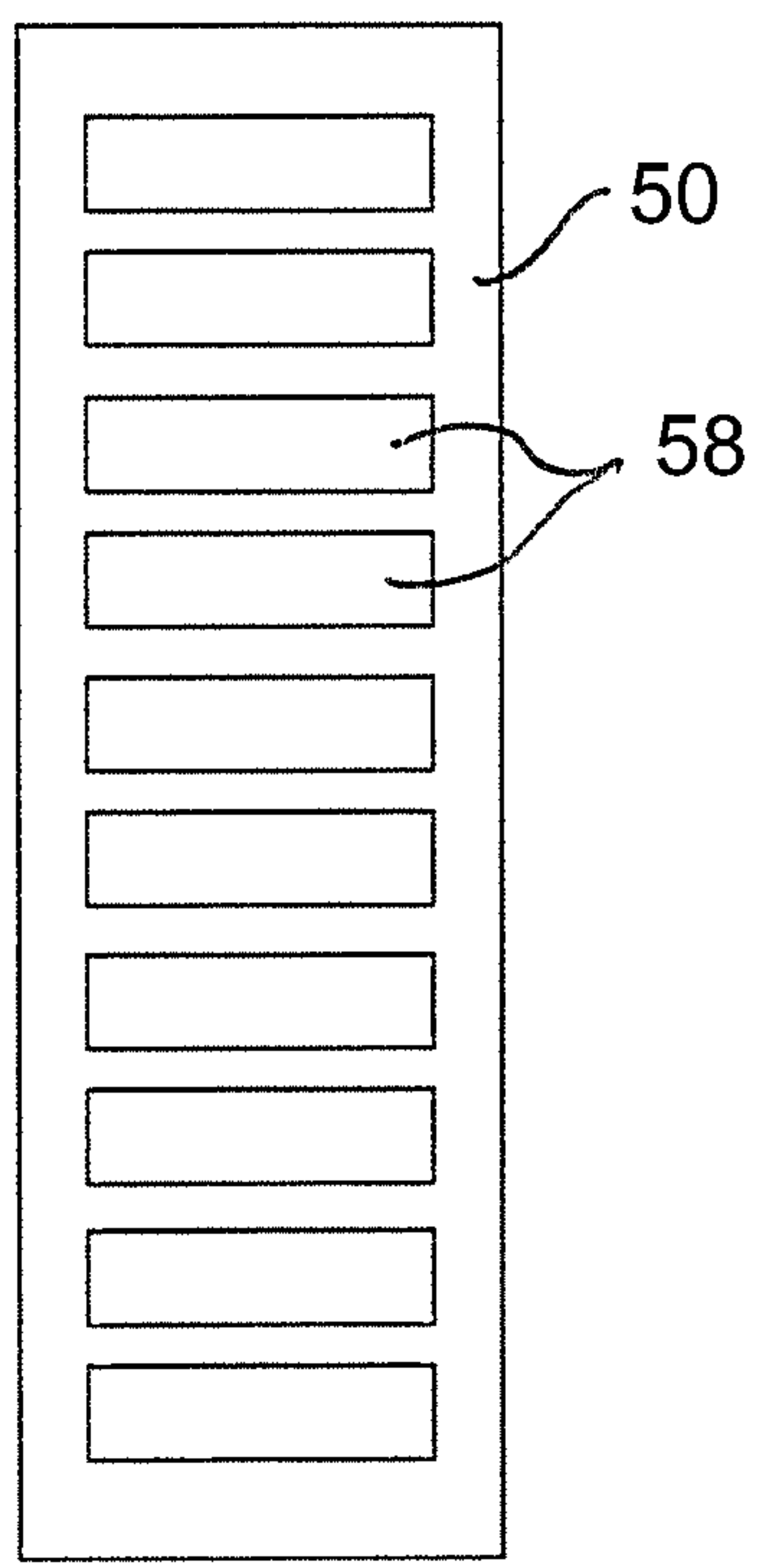


FIG. 3

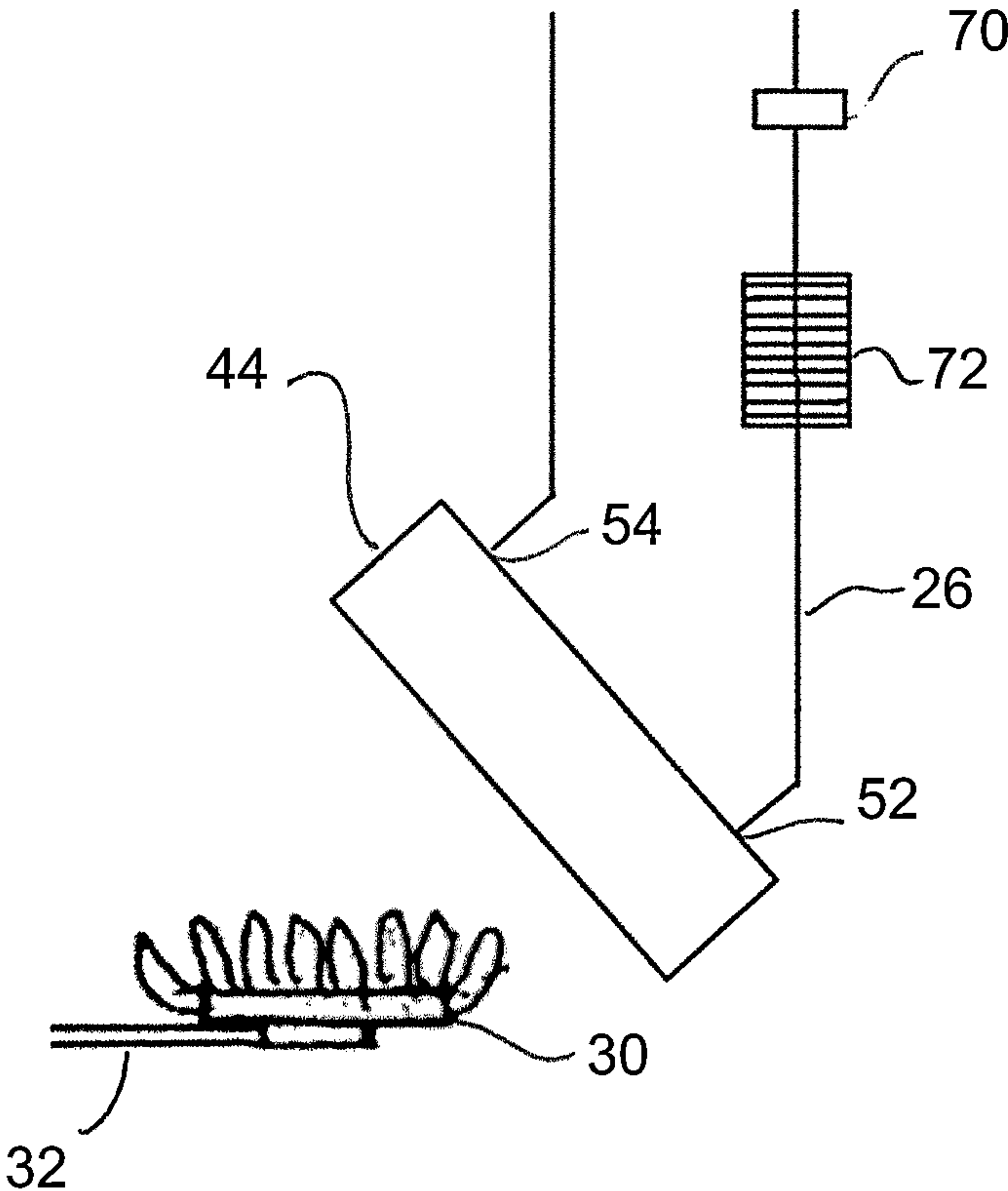


FIG. 4

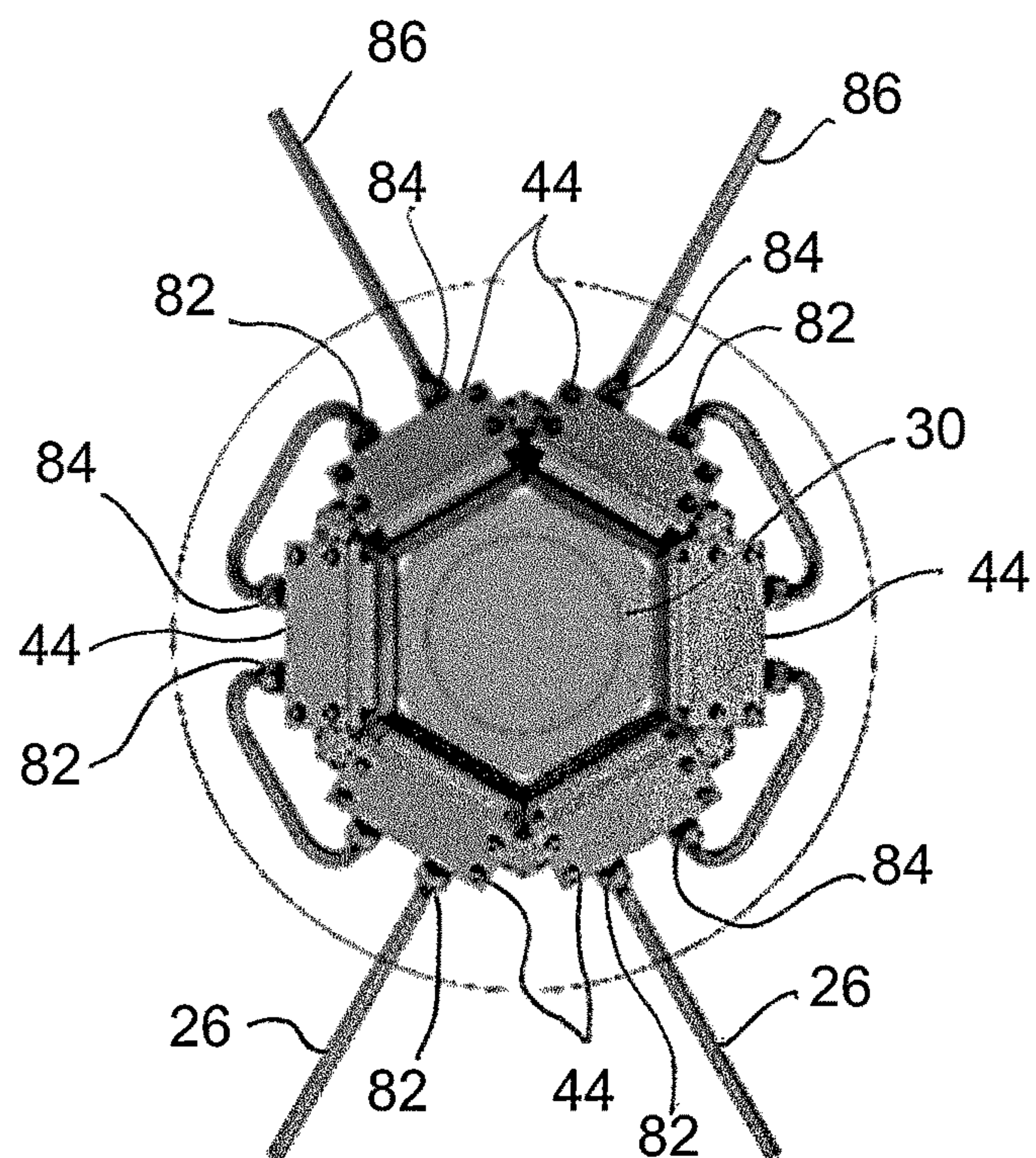


FIG. 5

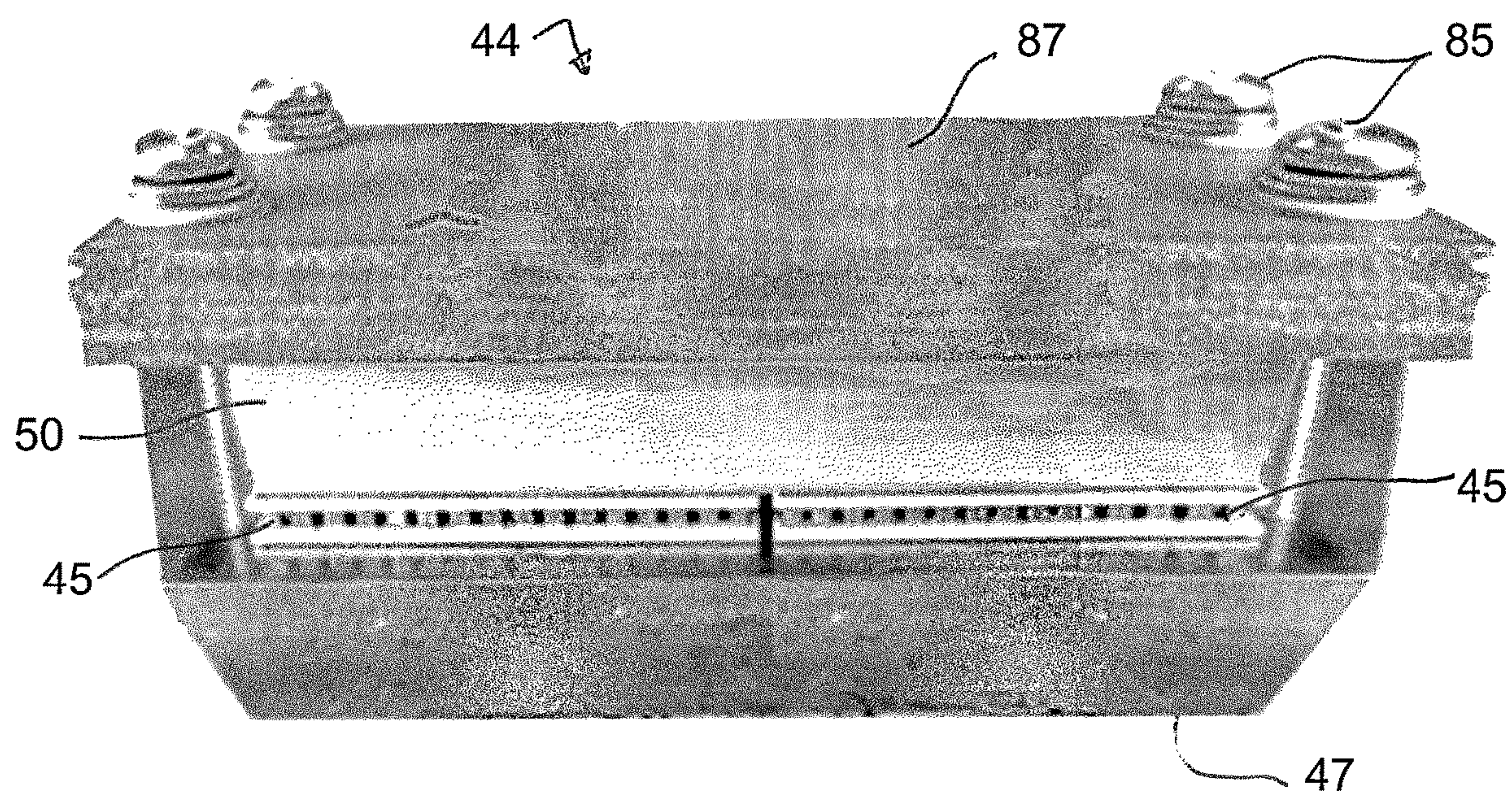


FIG. 6

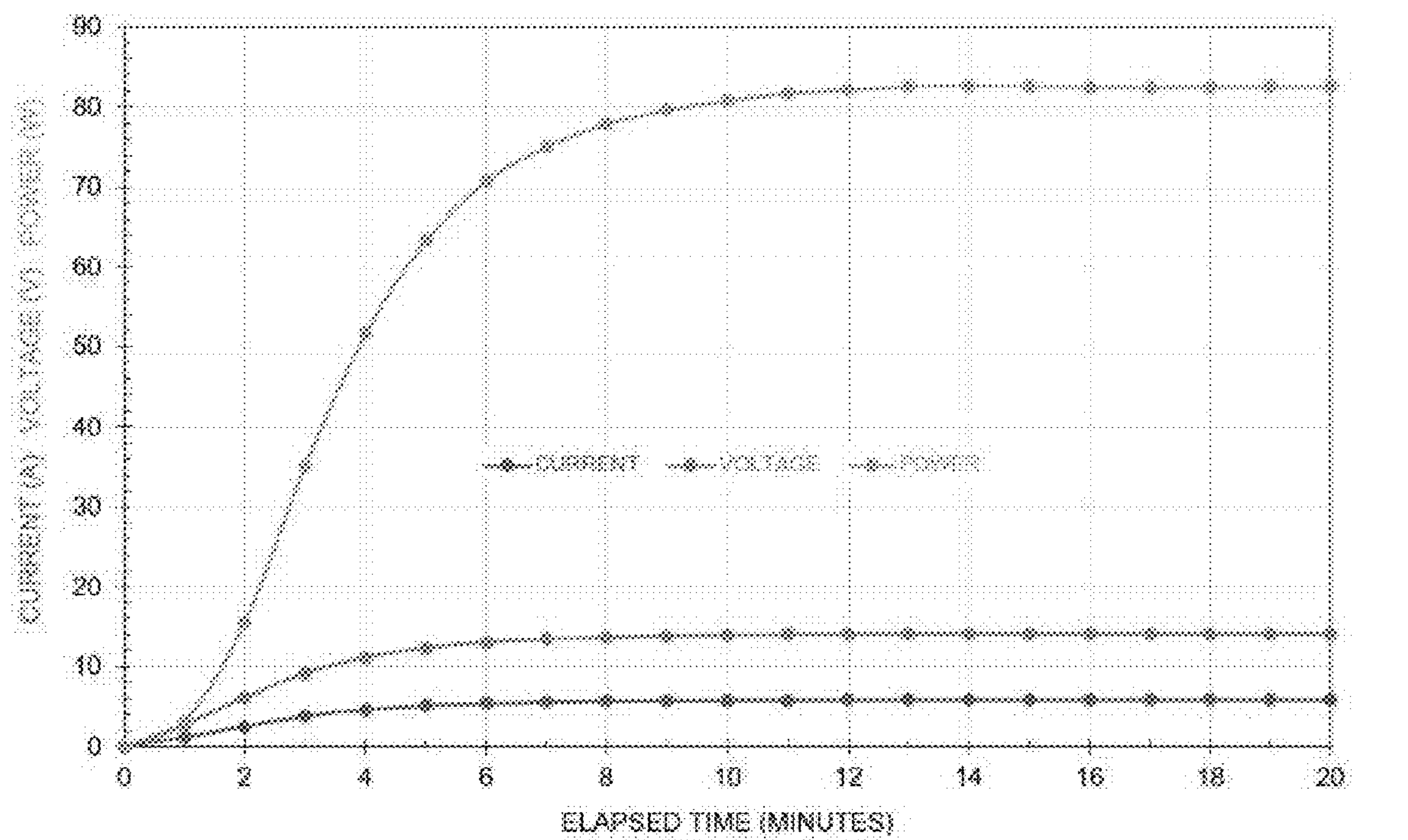


FIG. 7

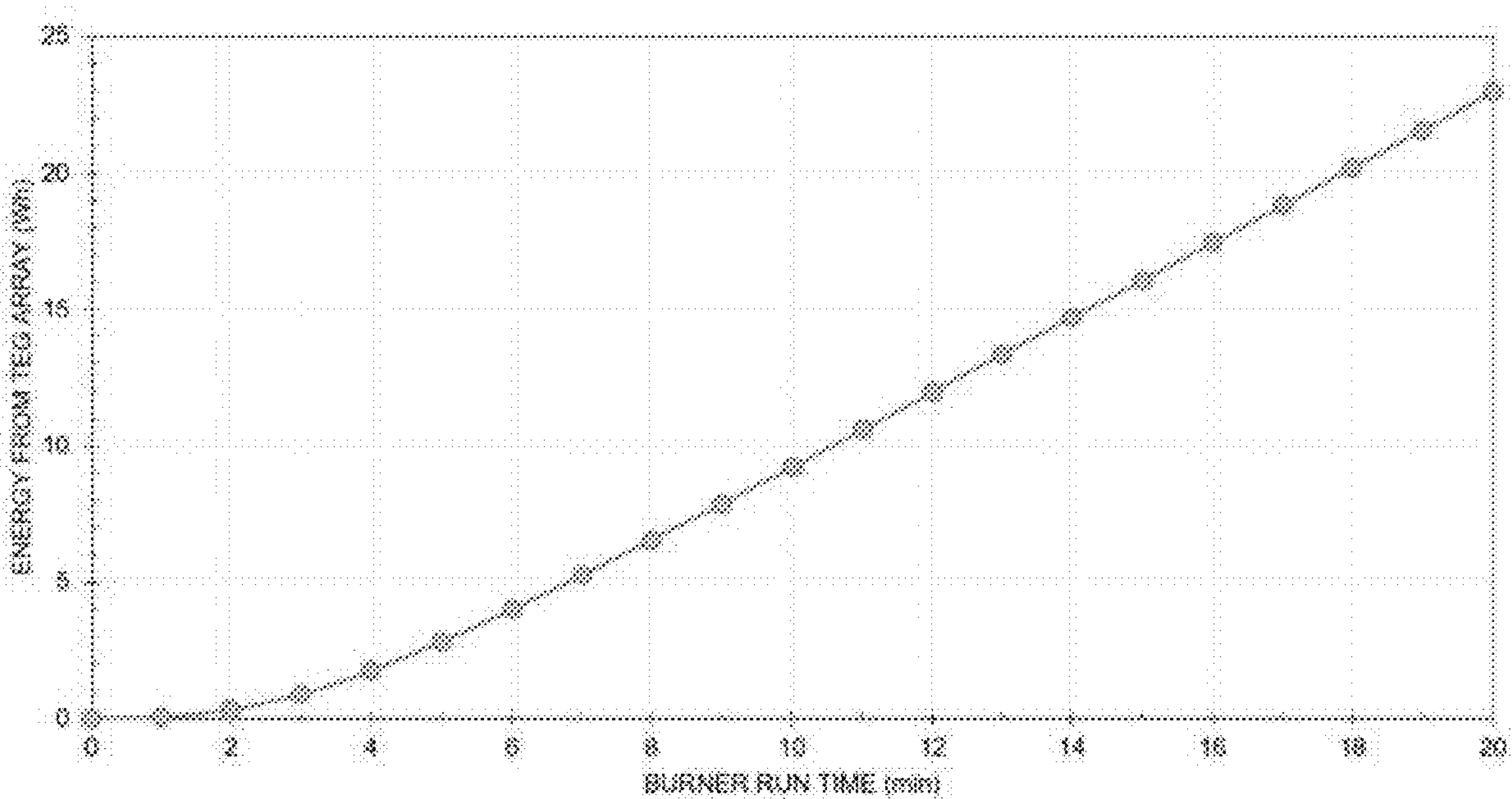


FIG. 8

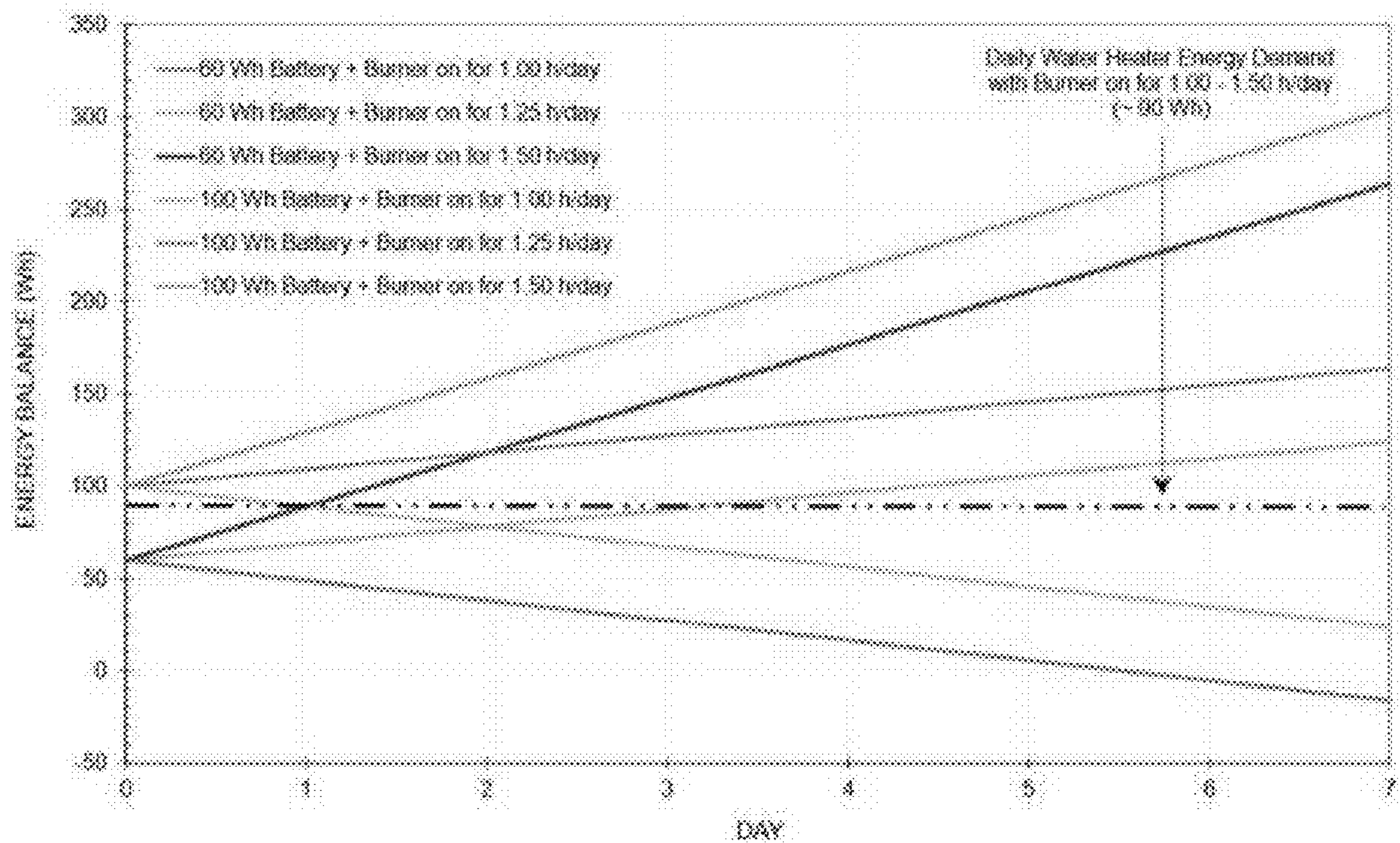


FIG. 9

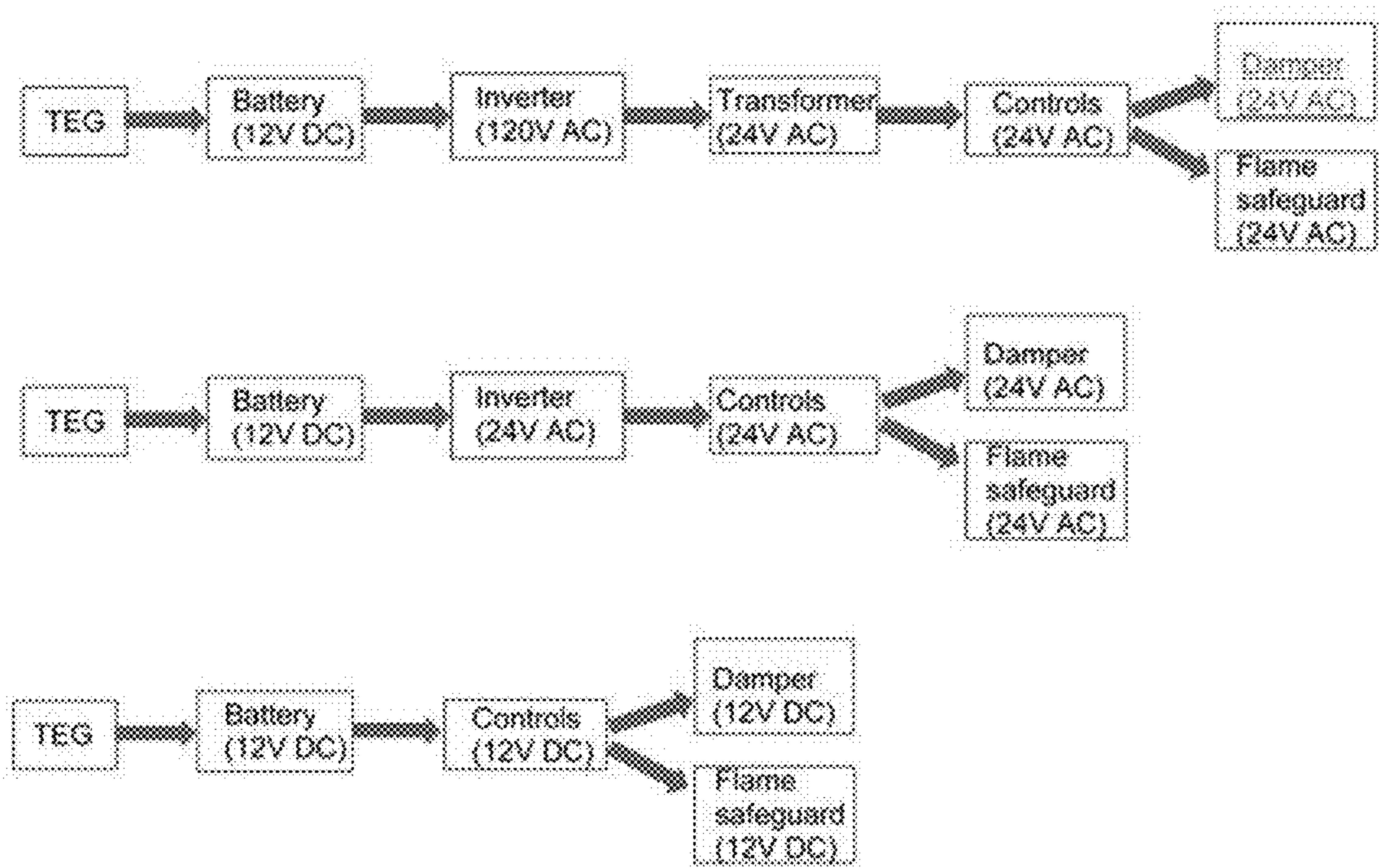


FIG. 10

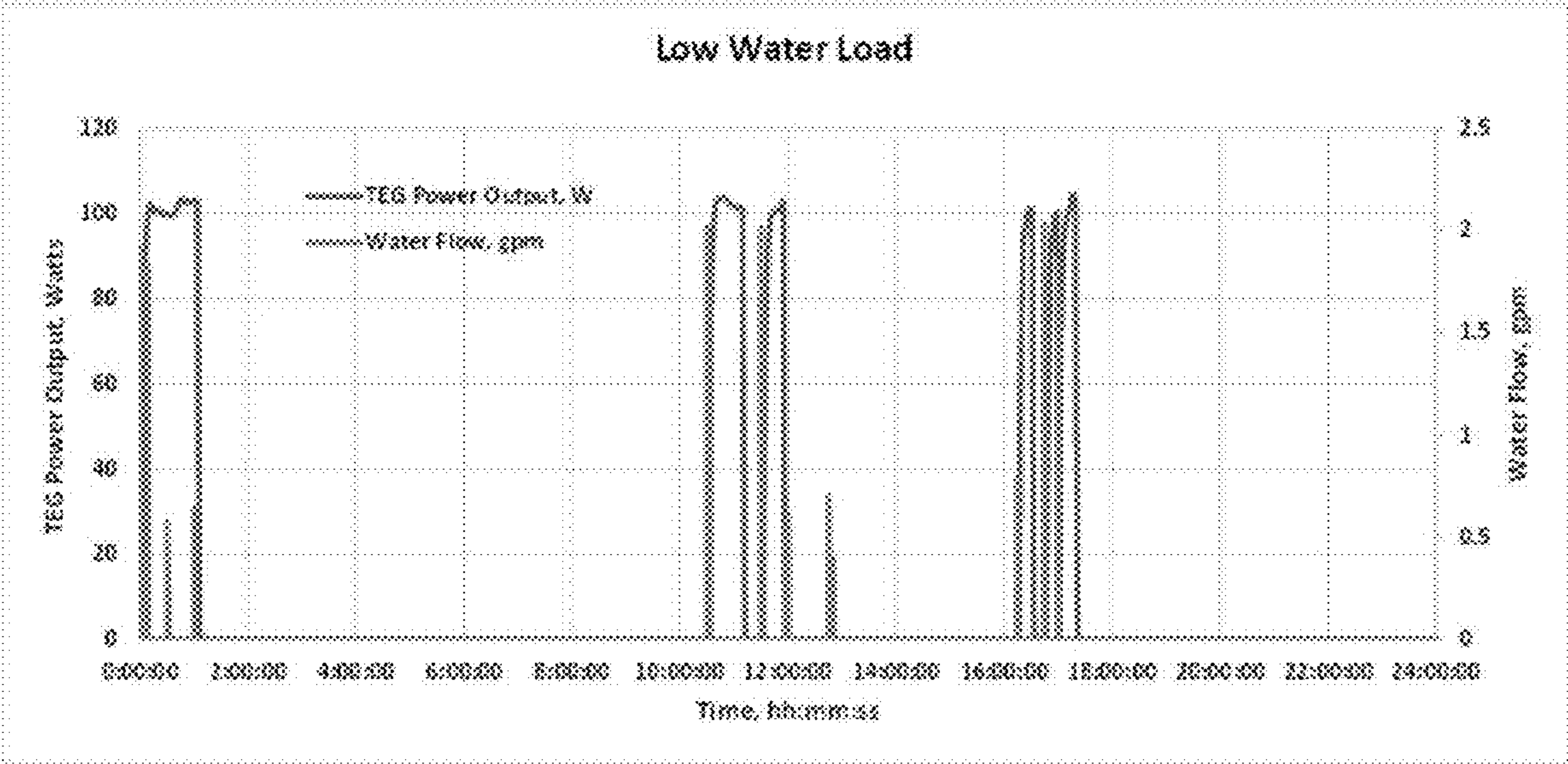


FIG. 11

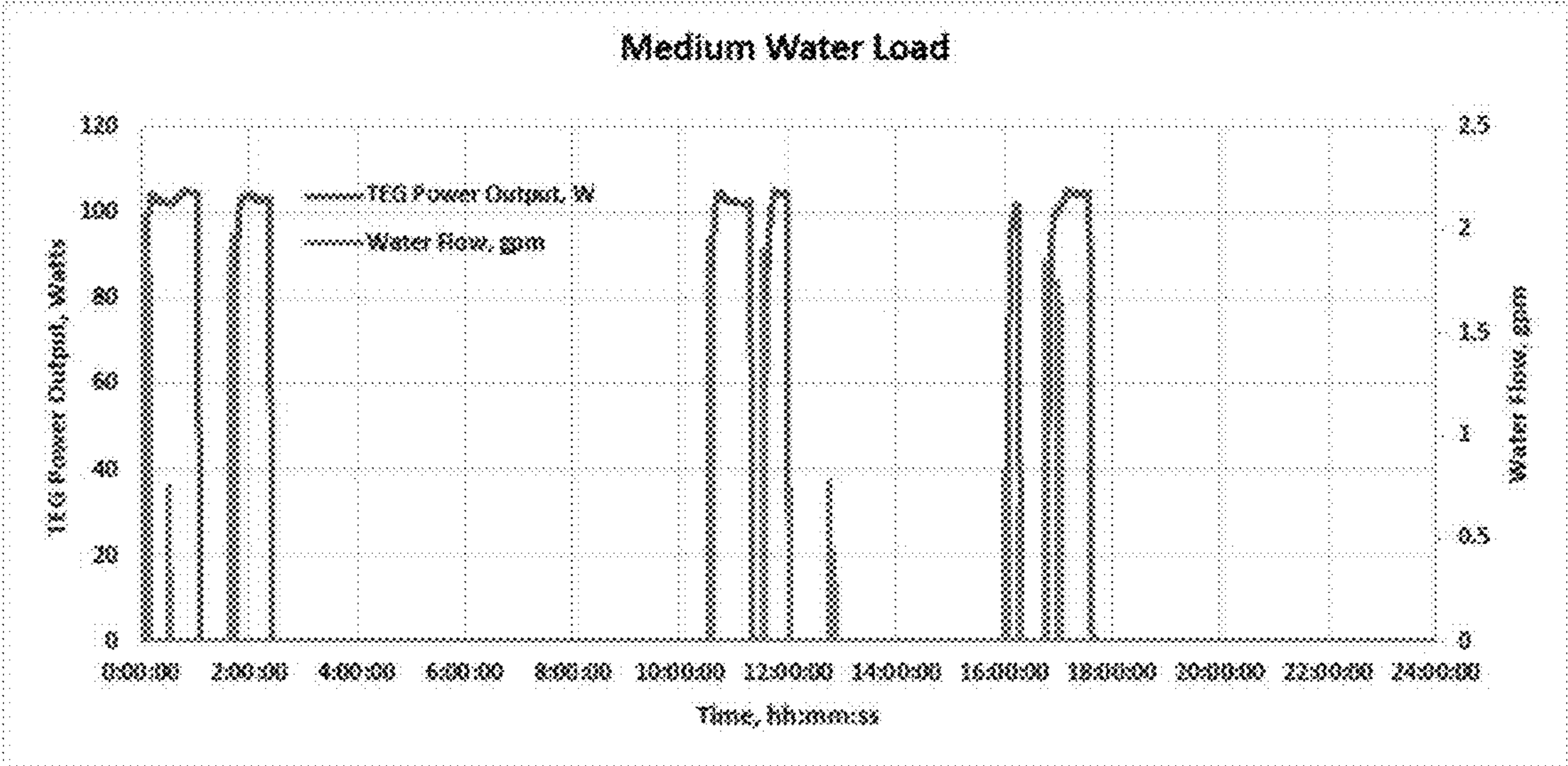


FIG. 12

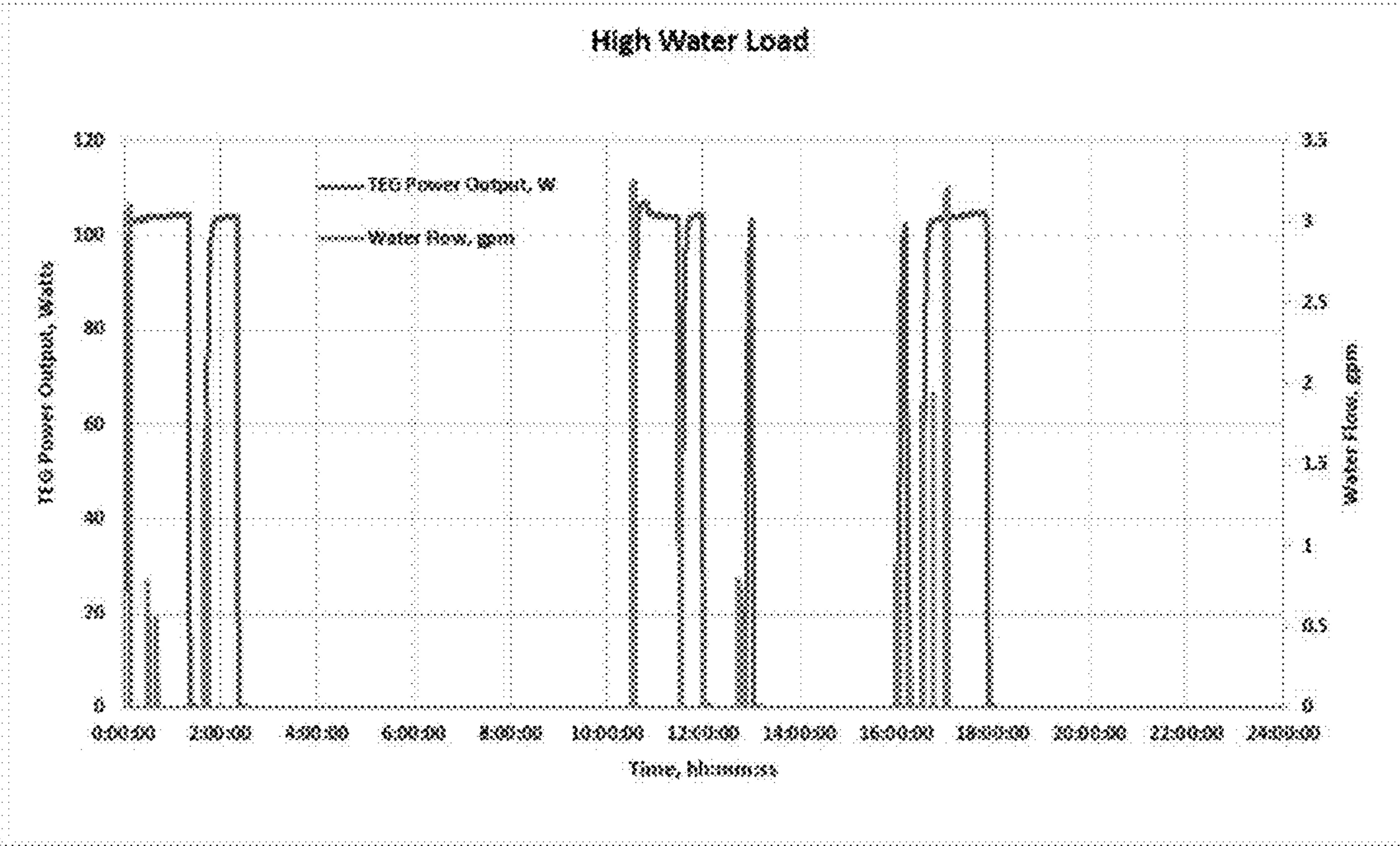


FIG. 13

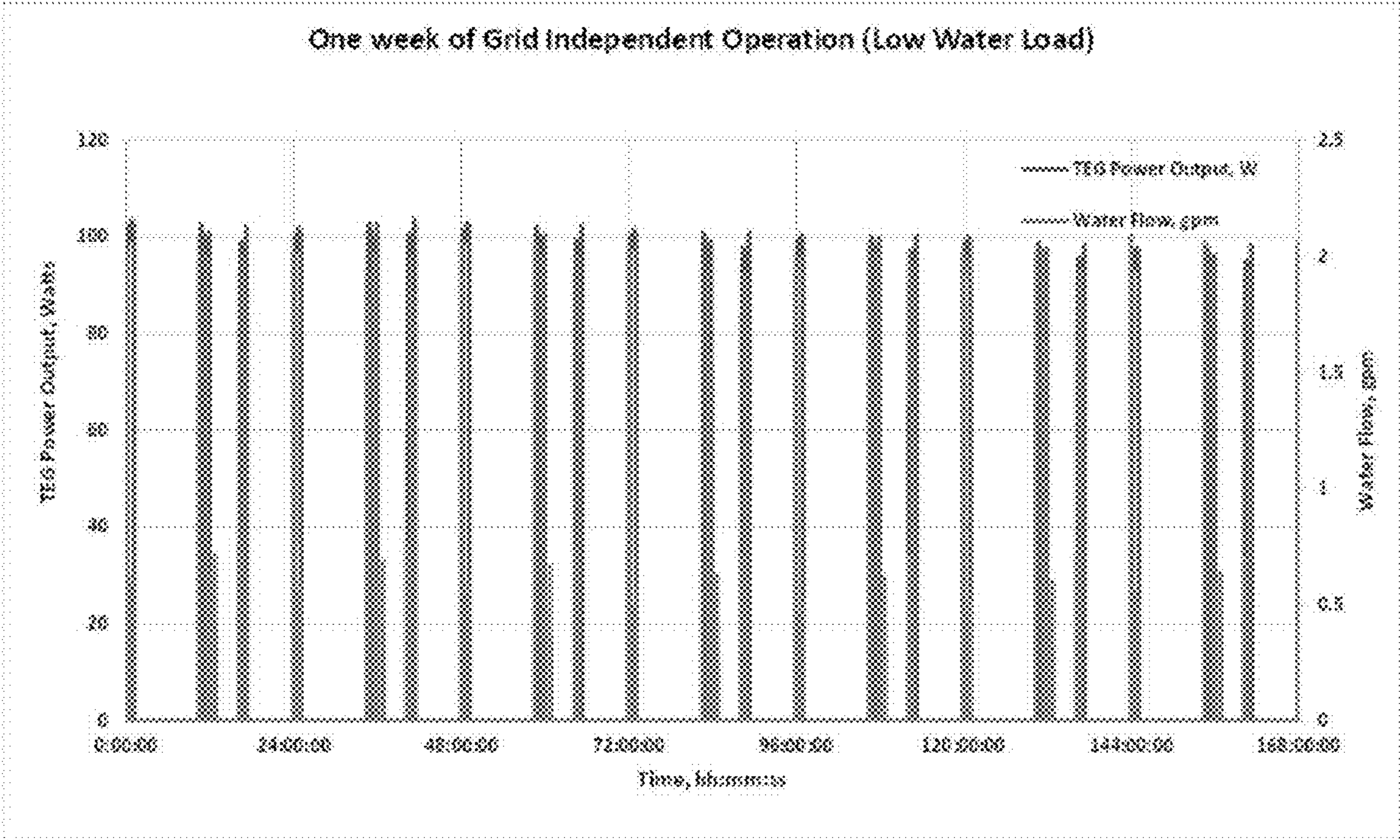


FIG. 14

GRID INDEPENDENT HEATING SYSTEM**CROSS REFERENCE TO RELATED APPLICATION**

[0001] This application claims the benefit of U.S. provisional patent application, Ser. No. 63/319,981, filed on 15 Mar. 2022. The co-pending provisional application is hereby incorporated by reference herein in its entirety and is made a part hereof, including but not limited to those portions which specifically appear hereinafter.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH

[0002] This invention was made with government support under Award Number DE-EE08686 awarded by the U.S. Department of Energy. The government has certain rights in the invention.

BACKGROUND OF THE INVENTION**Field of the Invention**

[0003] This invention relates to a grid independent heating system, and more particularly to an apparatus for producing heat and electricity with a thermal-to-electric generator (“TEG”) integrated with the apparatus, such as for use in water heater applications.

Description of Related Art

[0004] Fossil fuel driven heating systems, for example, water heaters, boilers, and furnaces, are commonly dependent on electricity for start-up, operation and safety. Electricity is often provided from a grid during normal operation of such heating systems. In case of power outages, these systems are forced to shut down leading to significant heat and/or production losses. Likewise, remote or temporary locations may lack access to the grid. Backup power generation systems are expensive and not practical in most applications. Modifications integrating boilers and furnace heating systems with thermal-to-electric (“TE”) conversion devices have been proposed in response, however, developing self-powered appliances for grid-independence has not resulted in successful products due to poor TE conversion leading to high capital costs.

[0005] Current high efficiency fuel fired appliances use sophisticated controls to optimize the operation of the appliance and extract maximum efficiency. This increases the power demand requiring the appliance to be connected to grid or another suitable power supply. There have been many research activities in the past and ongoing to use various alternative means to prove this electricity mostly using TEG and thermal photovoltaics with minimal commercial success. The challenge is to provide sufficient temperature gradient across the power generating device without sacrificing efficiency.

[0006] There is a need for a fuel fired appliance to operate without any external electricity supply. It would allow the appliance to be used during brownouts and blackouts as well as in areas without any power supply or where adding a power outlet is inconvenient, impractical or expensive.

SUMMARY OF THE INVENTION

[0007] The subject invention is applicable to a variety of fluids such as water heaters and other fuel fired heating equipment. In one embodiment applied to a storage water heater having a water storage tank surrounding a flue, a water inlet is connected to a ‘cold water’ source and fills the storage tank. The heated water flows out from the water heater tank through an outlet pipe. The water heater is preferably equipped with a temperature sensor that measures the water temperature in the storage tank and turns its fuel supplied burner on and off to maintain a temperature set point, generally between 120° F. and 160° F.

[0008] Embodiments of this invention include an apparatus for producing heat and electricity that includes a burner adapted to produce at least one of radiant heat, flame, and hot combustion gases; a liquid supply line; and a thermal-to-electric conversion device integrated with the burner and proximate to the burner, the conversion device having a first side disposed toward the at least one of radiant heat, flame, and hot combustion gases, and a second side disposed toward and in heat transfer contact with the liquid supply line.

[0009] An aspirating pancake type natural draft burner and flue are described in one embodiment of the subject invention, but many different types of burner designs, such as premixed, diffusion flame, or partial premixed, and burner types such as conventional flame type or radiant surface type, and flue arrangements can be used—with natural, forced, or induced draft.

[0010] In embodiments of a water heater, the resulting flame and products of combustion preferably heat the water in the tank or water line (for tankless heaters) and exit through the flue. In the proposed invention, at least one thermo-electric generator (TEG) module is placed proximate to the burner flame with a hot side facing the flame, preferably at an angle to the flame axis to increase heat transfer. The hot flame, radiant surface and/or combustion products heat the hot side of the TEG module. A cold side of the TEG module has a fluid cooled heat sink to create temperature gradient across the TEG thereby generating electricity. In one preferred arrangement, the heat sink is a water cooled heat sink with flowing cold water through at least one cooling channel within the heat sink, and with a cooling water inlet and outlet integrated with the water flow and storage loop of the water heater. Using flowing cold water to cool the heat sink increases cooling thereby increasing the hot to cold side temperature gradient which increases TEG output. In a preferred embodiment, a second storage tank may be used to collect hot water from the TEG during periods when the burner fires to maintain set temperature of the first storage tank. Upon demand, hot water from the second storage tank is supplied separately or mixed with hot water from first storage tank.

[0011] In embodiments, a hot side surface of the conversion device is disposed at an angle to the burner, a flame axis, and/or a longitudinal axis of the water heater or exhaust flue. The conversion device is desirably offset from the burner, such as to allow combustion products to enter the flue, and between the burner and the exhaust flue. A surface of the conversion device is tilted at an angle toward the burner, such as also tilted away from the exhaust flue or water tank/line.

[0012] The conversion device desirably includes a plurality of thermoelectric generators (TEGs), such as disposed

around the burner in an array. The array can be in any suitable shaped configuration, but preferably the array shape corresponds to the peripheral shape of the burner. One or more sections of the liquid supply line can extend through the cold side of the plurality of thermoelectric generators, or groupings thereof, before connection to a heated water outlet.

[0013] In embodiments, a heat sink is on the cold side of the conversion device, and preferably includes a plurality of cooling channels connected to the liquid supply line. The heat sink can be an aluminum, copper, or another mechanically and thermally suitable material body around the cooling channels. A thermally conductive plate can be placed on the opposing ‘hot’ side of the conversion device. The conductive plate preferably is formed of a metal, an alloy, or a ceramic.

[0014] The invention includes a water heater for heating a supply of water from or within the liquid supply line. The water heater includes the burner and thermal conversion device as described herein, and further includes a water storage tank in heat transfer combination with the burner, an exhaust flue downstream of the burner and extending along the water storage tank, an unheated or ‘cold’ water inlet pipe upstream of the water storage tank, and a heated water outlet pipe downstream of the storage tank. The liquid supply line for the conversion device is connected to the unheated or cold water inlet pipe. The liquid supply line connects to the heated water outlet pipe and/or the storage tank downstream of the conversion device. The conversion device is offset from the burner between the burner and the exhaust flue and a surface of the first side of the conversion device is tilted at an angle toward the burner, and often away from the exhaust flue and/or storage tank.

[0015] In presently preferred embodiments, the conversion device includes a plurality of TEGs disposed around the burner, wherein one or more sections of the liquid supply line extends through at least adjacent pairs of the plurality of TEG modules (or heat sinks) before connection back to the outlet pipe and/or the storage tank.

[0016] In embodiments, a pressure boosting device is in combination with the liquid supply line upstream of the conversion device, for example, to increase cooling water flow rate through the TEG modules.

[0017] The invention further includes a method for providing heat and electricity to a machine. The method includes steps of: introducing fuel and air to a burner; producing radiant heat at least partially inside the flame housing; converting thermal energy to electric energy with a thermal-to-electric conversion device integrated with the flame housing, wherein the thermal-to-electric conversion device includes a first side disposed at an angle toward and over the radiant heat; and cooling a second side of the conversion device with a cooling flow of water. The method can further includes steps of introducing heated water exiting the conversion device to a heated water outlet or storage tank of a water heater.

[0018] Other objects and advantages will be apparent to those skilled in the art from the following detailed description taken in conjunction with the appended claims and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] FIG. 1 is a schematic view of an apparatus for producing heat and electricity according to one embodiment of the invention;

[0020] FIG. 2 is a schematic view of a TEG module according to one embodiment of the invention;

[0021] FIG. 3 is a schematic cross-sectional view of a heat sink according to one embodiment of the invention;

[0022] FIG. 4 is a schematic of one embodiment of a water-cooling arrangement for a heat sink of a TEG module according to one embodiment of the invention;

[0023] FIG. 5 shows a top view drawing of an assembly according to one embodiment of the invention;

[0024] FIG. 6 shows a side view of a TEG module according to one embodiment of the invention;

[0025] FIG. 7 shows outputs from a 6 TEG array, with each array having 2 TEGs surrounding and angled towards the flame as shown in FIG. 6;

[0026] FIG. 8 shows outputs from a 6 TEG array, with each array having 2 TEG surrounding and angled towards the flame as shown in FIG. 6;

[0027] FIG. 9 shows energy balance for a system with a chemical battery connected to the output from a 6 TEG array, with each array having 2 TEG surrounding and angled towards the flame as shown in FIG. 6;

[0028] FIG. 10 shows a flowchart of integration options for TEG output with equipment controls;

[0029] FIG. 11 is a chart showing the water load and TEG power generation during one of three 24-hour test campaigns representing example low 24-hour water demand profile;

[0030] FIG. 12 is a chart showing the water load and TEG power generation during one of three 24-hour test campaigns representing example medium 24-hour water demand profile;

[0031] FIG. 13 is a chart showing the water load and TEG power generation during one of three 24-hour test campaigns representing example high 24-hour water demand profile; and

[0032] FIG. 14 is a chart showing the water load and TEG power generation during one week of operation representing a low 24-hour water demand profile.

DETAILED DESCRIPTION

[0033] The concept is described using a storage water heater as an example but is applicable to heating of a variety of fluids such as water, oil and air and other fuel fired heating equipment. FIG. 1 shows a line drawing of a storage water heater 20. The water heater has a water storage tank 22 surrounding a flue 24. Generally, a liquid supply line 26 is connected to an unheated or ‘cold water’ source line 27 that fills tank 22. The heated water flows out from the water heater tank 22 through outlet pipe 28.

[0034] The water heater 20 is equipped with a temperature sensor (not shown) that measures the water temperature in the storage tank 22 and turns burner 30 on and off to maintain a temperature set point, generally between 120° F. and 160° F. The burner 30 is supplied with fuel 32. Any suitable burner type can be incorporated in this invention. An aspirating pancake type natural draft burner is shown in FIG. 4, but many different types of burner designs such as premixed, diffusion flame or partial premixed, burner types

such as conventional flame types or radiant surface types, with natural, forced, or induced draft and flue arrangements can be used.

[0035] Referring back to FIG. 1, the resulting flame 34 and products of combustion 36 heat the water in the tank 22, and the products of combustion 36 exit through the flue 24. A thermal-to-electric conversion device 40 is integrated with the burner 30 and proximate to the burner 30. The conversion device 40 includes one or more thermo-electric generator (TEG) modules 44 having a first, hot side 46 disposed toward flame 34 and a second, cold side 48 disposed away from the flame.

[0036] In embodiments of this invention, the thermo-electric generator module(s) 44 is placed proximate to the burner flame 34 with its hot side 46 facing the flame 34, preferably at an inclined angle to the flame axis, or longitudinal axis of the water heater 20 and/or flue 24, to increase heat transfer. The hot flame, radiant surface and/or combustion products heat the hot side 46 of the TEG module 44. The cold side 48 of the TEG module 44 has a fluid cooled heat sink to create temperature gradient across the TEG, thereby generating electricity. FIG. 1 shows a preferred arrangement, where the heat sink 50 is water-cooled by flowing cooling (e.g., unheated or 'cold') water through the liquid supply line 26, from the cold water line 27 and/or storage tank 22. The water flows through at least one cooling channel within the heat sink 50 and its water inlet 52 and outlet 54 integrated with the water flow and storage loop of the water heater 20. Using flowing cold water to cool the heat sink increases cooling thereby increasing the hot to cold side temperature gradient which increases TEG output.

[0037] As shown in FIG. 1, the outlet line 54 from the TEG module 44 can be connected to a hot water side 23 of the storage tank 22 and/or be connected to the heated water outlet pipe 28 of the water heater 20. In a preferred embodiment, an optional second storage tank 60 is used to collect hot water from the TEG module 44 during periods when the burner fires to maintain set temperature of the first storage tank 22. Upon demand, hot water from the second storage tank 60 is supplied separately or mixed with hot water from the first storage tank 22.

[0038] The heat sink 50 can incorporate a thermal energy storage material. The generated electricity is integrated with the water heater's electrical supply to meet its power needs thereby making it grid independent. An electricity storage device, such as a chemical battery, can be integrated into the electrical circuit to continue supplying the needed electricity when the burner is not operating.

[0039] The TEG module 44 can be assembled in many different configurations for desired electricity generation. An example is shown in FIG. 2. A TEG component 45 is tightly sandwiched between a plate 47 of preferably high thermal conductivity material on the hot side 46 and a fluid cooled sink 50 on the cold side 48. The plate 47 on the hot side desirably spreads the heat flux to the TEG 45 surface and protects it from direct contact with the flame 34 and combustion gases 36. High thermal conductivity material 55 can be placed on either side of the TEG component to increase contact and heat transfer. Different materials may be used on the hot and the cold sides. Alternately a thin coating of a suitable material can be used in addition to or instead of the hot plate to increase chemical and thermal protection. Surface enhancements can be incorporated on hot side 46 of the

TEG module 44 to increase heat transfer. These could be fins, dimples, or other shaped protrusions or cavities.

[0040] FIG. 3 shows an example of a cross section of the heat sink 50. A straight through arrangement with rectangular fluid flow channels 58 is shown, however, a variety of cross-sectional flow channel shapes and flow paths can be used and surface enhancements within the channel and/or the outside surface could be incorporated to increase heat transfer. For air cooling, a flat plate with surface enhancements to increase convective heat transfer could be used.

[0041] FIG. 4 shows an example of the water-cooling arrangement for the heat sink 50 of the TEG module 44. FIG. 4 shows a pressure boosting device 70 such as an electro-mechanical pump to increase the flow rate of water through the heat sink 50 of the TEG module 44. Alternately, the available pressure differentials between the different points in the water path (storage tank and piping) or natural thermally driven convection can be used independently or in combination. A closed loop arrangement can also be used which circulates the cooling water within a closed flow loop. An air- or water-cooled heat exchanger 72 can be incorporated within the loop to improve cooling of the return cooling water. The heat exchanger 72 can include fins extending outward around the return cooling water pipe or a closed heat exchanger with water-to-water cooling. The heat exchanger 72 can also be integrated into the cooler zone of the storage tank. Thermal energy storage can also be incorporated into the loop.

[0042] In one embodiment, several TEGs are placed around the flame, thereby increasing the amount of electricity generated. As shown in FIG. 6, the burner 30 of the water heater is surrounded by the TEG module 44 and the TEGs are water cooled by a liquid supply line 26. In this particular embodiment, there are six separate TEG modules 44 in an array 80. Each module 44 is angled downwards towards the burner 30. The TEG modules 44 are divided into groupings of three, with each grouping being separately fed from a section or branch of the liquid supply line 26. For each grouping, the liquid supply line 26 feeds into a module inlet 82 of one module, out a module outlet 84, and then into a second module inlet 82 of the adjacent module 44. This configuration repeats until the heated water leaves the array 80 through line 86 back to the storage tank 22 or heated water outlet 54. As will be appreciated, various numbers of modules and module groupings are available for the invention, depending on need.

[0043] FIG. 6 shows a TEG module 44 according to one embodiment of this invention. A plate 47 made from metal (e.g., copper), alloy or ceramic is tightly attached on the hot side of a pair of TEGs 45 using at least one fastening means (e.g., fasteners 85 and upper/outer stainless steel plate 87) to reduce interface losses and improve heat transfer to the TEGs 45. FIG. 6 also shows an attached aluminum heat sink 50 that is tightly attached on the cold side of the TEGs 45 to reduce interface losses and improve heat transfer from the TEGs 45 to the cooling fluid. Electrical outputs can be connected in various series/parallel arrangements to vary voltage to current ratio and optionally integrated with a storage battery, and be connected to an inverter in case AC power is required.

[0044] In one embodiment, the cooling heat sink has fins or other shaped protrusions or dimples on the outside to increase surface area and heat transfer coefficient thereby improving heat removal.

[0045] In another embodiment, the heat sink has channels for at least one of water and air (meaning it can have channels for both). Separate channels for different sources of water may be incorporated. The channels could be of a variety of shapes (square, round, oval, etc.) and arrangements (side to side, top to bottom), and can be single-path or multi-path and single-pass or multi-pass, i.e., have a plurality of paths and passes.

[0046] In one embodiment, the TEG cover plate surface exposed to the flame has surface area enhancements to increase at least one of conduction, convection and radiation heat transfer from the flame and combustion products to the TEG.

[0047] In another embodiment, a thin layer of flexible high thermal conductivity material is placed between at least one of heat sink—TEG interface on the cold side and material plate —TEG interface on the hot side to improve heat transfer from TEG to the cooling fluid and from combustion gases to the TEG.

[0048] In one embodiment, at least one TEG is oriented towards the flame to maximize heat transfer from the flame and combustion products to the TEG and thus maximize TEG electrical power generation as shown in FIGS. 5 and 6. FIG. 7-9 show the outputs from a 6 TEG array, with each array having 2 TEGs, surrounding and angled towards the flame as shown in FIG. 5.

[0049] In another embodiment, the cooling fluid flowing through the heat sink is at least one of a portion of combustion air, a portion of supply water for the heater, and a separate water supply.

[0050] In one embodiment, the water from the heat sink is in direct communication and mixed with at least one of hot product water from the water heater for distribution and the water that is being heated.

[0051] In another embodiment, the cooling water to the heat sink is in direct communication and mixed with at least one of cold water supply to the water heater and the water that is being heated.

[0052] In one embodiment, at least one of cooling water supply source that needs to be returned to the original pressure, a pressure enhancing device such as an electro-mechanical or jet pump is utilized or a pressure enhancing tank such as a bladder tank.

[0053] In one embodiment, convective current generated by heated water in the heat sink is used as driving force to flow the water through the heat sink. The convective current driven flow is especially suitable in storage type water heaters that idle (fire periodically to maintain the water in the storage tank at the set temperature).

[0054] In another embodiment a closed cooling water flow loop circulates water between the heat sink and a heat exchanger in direct communication or proximate to a cooler water zone in the water heater's water path (including the piping and storage tank).

[0055] In another embodiment combustion air is used to cool the cooling water in an air to water heat exchanger. The heat exchanger can have surface enhancements, such as fins or other shaped protrusions or dimples on the air side to improve heat removal.

[0056] In one embodiment the cooling water pressure enhancing device only turns on when product water is drawn and/or when burner is on.

[0057] In one embodiment, the relative position and/or orientation of TEG module is automatically adjusted via a

temperature sensor and electrical and/or mechanical actuator to prevent overheating of components. The adjusting actuator may be driven using pressure differential of fuel, combustion air, or supply water.

[0058] In one embodiment, the TEG module position and or orientation actuator is driven by supply water to product water pressure differential

[0059] In one embodiment, the firing rate of the burner is reduced during idling in systems that use idling during no water demand.

[0060] In one embodiment, the battery capacity can be optimized to match the electrical power demand profile of the heating system as shown in FIG. 9.

[0061] In one embodiment, the TEG-Battery-controls integration can be optimized to reduce the electrical losses and match the heating system as shown in FIG. 10.

[0062] As an example, a prototype testing arrangement of six TEG modules around the burner within the combustion chamber of a water heater was run around the clock for three days while simulating three example 24-hour water load profiles. The TEG modules were equipped with copper blocks on their hot sides and water-cooled heat sinks on their cold sides (see FIG. 6). The TEGs were slanted towards the burner axis with the hot combustion gases impinging on the copper blocks. The power generated by the TEGs charged a rechargeable battery through a diode which prevented the battery from powering the TEGs in reverse as Peltier coolers. An inverter was connected to the battery to convert the battery's DC output to standard US AC output for powering the water heater. The power cord of the water heater, which normally connects to the grid, was connected to the inverter to power the water heater during start-up and to supply all parasitic electrical load when idling. All power for the water heater during the test was supplied from the power generated by the TEGs. FIGS. 11-13 are charts showing the water load and TEG power generation during three 24-hour test campaigns of the system, representing exemplary low, medium and high 24-hour water demand profiles. FIG. 14 shows output after a week of operation of the system.

[0063] While in the foregoing detailed description the subject development has been described in relation to certain preferred embodiments thereof, and many details have been set forth for purposes of illustration, it will be apparent to those skilled in the art that the subject development is susceptible to additional embodiments and that certain of the details described herein can be varied considerably without departing from the basic principles of the invention.

What is claimed is:

1. An apparatus for producing heat and electricity, the apparatus comprising:

- a burner adapted to produce at least one of radiant heat, flame and hot combustion gases;
- a liquid supply line; and
- a thermal-to-electric conversion device integrated with the burner and proximate to the burner, the conversion device having a first side disposed toward the at least one of radiant heat, flame and hot combustion gases and a second side disposed toward and in heat transfer contact with the liquid supply line.

2. The apparatus of claim 1, wherein a surface of the first side of the conversion device is disposed at an angle to a flame axis.

3. The apparatus of claim 1, further comprising an exhaust flue downstream of the burner, wherein the conversion

device is offset from the burner between the burner and the exhaust flue and a surface of the first side of the conversion device is tilted at an angle toward the burner and away from the exhaust flue.

4. The apparatus of claim 3, wherein the conversion device comprises a plurality of thermoelectric generators (TEGs) disposed around the burner.

5. The apparatus of claim 4, wherein one or more sections of the liquid supply line extend through the plurality of thermoelectric generators before connection to a heated water outlet.

6. The apparatus of claim 1, further comprising a heat sink on the second side of the conversion device.

7. The apparatus of claim 6, wherein the heat sink comprises a plurality of cooling channels connected to the liquid supply line.

8. The apparatus of claim 7, wherein the heat sink comprises an aluminum or copper body around the plurality of cooling channels.

9. The apparatus of claim 6, further comprising a thermally conductive plate on the first side of the conversion device.

10. The apparatus of claim 9, wherein the plate comprises a metal, an alloy, or a ceramic plate.

11. The apparatus of claim 1, further comprising a thermally conductive plate on the first side of the conversion device.

12. The apparatus of claim 1, comprising a water heater including a water storage tank, an inlet pipe for unheated water and an outlet pipe for heated water, wherein the liquid supply line is connected to the water inlet.

13. The apparatus of claim 12, wherein the liquid supply line connects to the outlet pipe and/or the storage tank downstream of the conversion device.

14. The apparatus of claim 13, further comprising a second storage tank downstream of the conversion device and in combination with the liquid supply line.

15. The apparatus of claim 13, wherein the conversion device comprises a plurality of thermoelectric generators disposed around the burner, wherein one or more sections of

the liquid supply line extends through at least adjacent pairs of the plurality of thermoelectric generator modules or heat sinks before connection back to the outlet pipe and/or the storage tank.

16. The apparatus of claim 1, further comprising a pressure boosting device in combination with the liquid supply line upstream of the conversion device.

17. A water heater including the apparatus of claim 1 for heating a supply of water from or within the liquid supply line.

18. The water heater of claim 17, further comprising:
a water storage tank in heat transfer combination with the burner;
an exhaust flue downstream of the burner and extending along the water storage tank;
an unheated water inlet pipe upstream of the water storage tank; and
a heated water outlet pipe downstream of the storage tank; wherein the liquid supply line is connected to the unheated water inlet pipe, the conversion device is offset from the burner between the burner and the exhaust flue and a surface of the first side of the conversion device is tilted at an angle toward the burner and away from the exhaust flue.

19. A method for providing heat and electricity to a machine, the method comprising the steps of:
introducing fuel and air to a burner;
producing radiant heat at least partially inside the flame housing;
converting thermal energy to electric energy with a thermal-to-electric conversion device integrated with the flame housing, wherein the thermal-to-electric conversion device includes a first side disposed at an angle toward and over the radiant heat; and
cooling a second side of the conversion device with a cooling flow of water.

20. The method according to claim 19, further comprising introducing heated water exiting the conversion device to a heated water outlet or storage tank of a water heater.

* * * * *