United States Patent [19]

Doerner

[11] **3,850,147**

[45] **Nov. 26, 1974**

[54] **ROTARY BOILERS AND COMBUSTORS**

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[73] Assignee: **E. I. du Pont de Nemours and Company**, Wilmington, Del.

[22] Filed: **Nov. 19, 1973**

[21] Appl. No.: **417,275**

[52] **U.S. Cl.** **122/11**, 60/108

[51] **Int. Cl.** **F22b 5/00**

[58] **Field of Search** 122/11; 60/39.18, 95, 108

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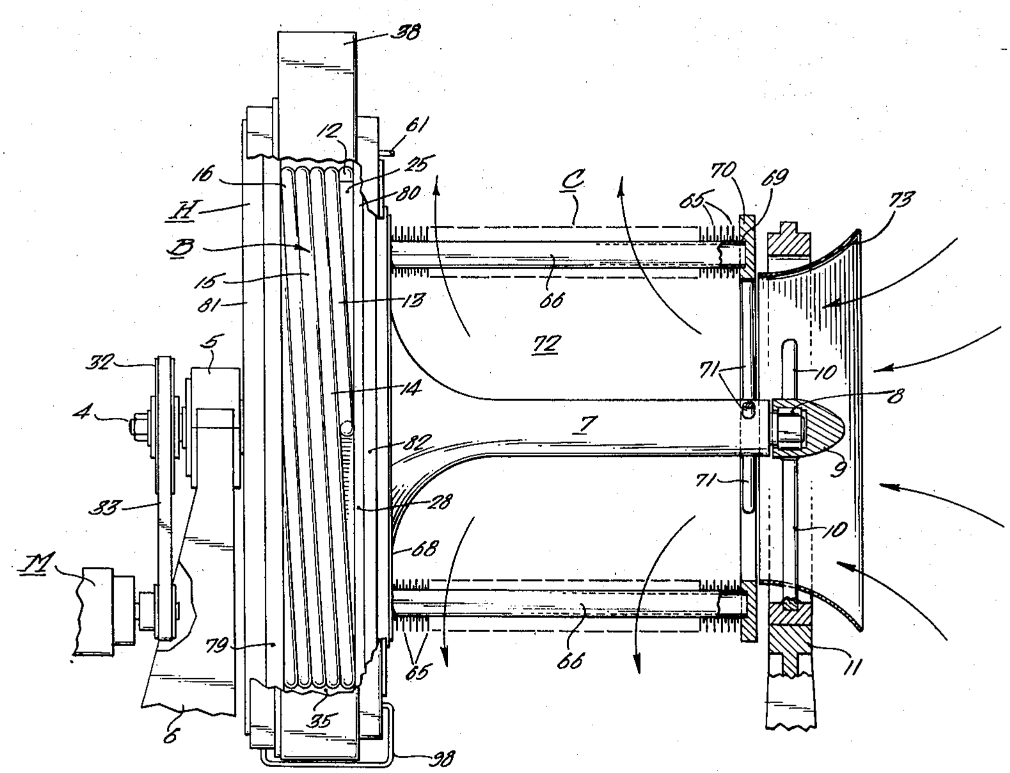
Primary Examiner—Kenneth W. Sprague
Attorney, Agent, or Firm—Howson and Howson

[57] **ABSTRACT**

A rotary boiler-combustor comprising a cylindrical housing rotatable about its axis and having a coaxial annular boiler extending circumferentially thereabout and rotatable with the housing as a unit. A stationary annular partition defines an annular combustion zone circumscribing the boiler, and a circumscribing stationary hood structure defines an exhaust chamber for combustion gases surrounding the stationary partition. Means are provided to rotationally drive the housing-boiler unit at a predetermined speed and provision is made for supplying combustion air and fuel to the combustion zone. A condenser for the pressure vapor generated in the boiler is mounted to rotate with said boiler, and a pre-heater for the boiler liquid condensate comprises a plurality of axially spaced coaxial annular fins having a plurality of heat exchange tubes extending therethrough and arranged circumferentially of the housing between the stationary partition and combustion gas exhaust chamber. The pre-heater rotates with the housing and operates to pump the combustion gases therethrough to the surrounding combustion gas exhaust chamber.

26 Claims, 14 Drawing Figures



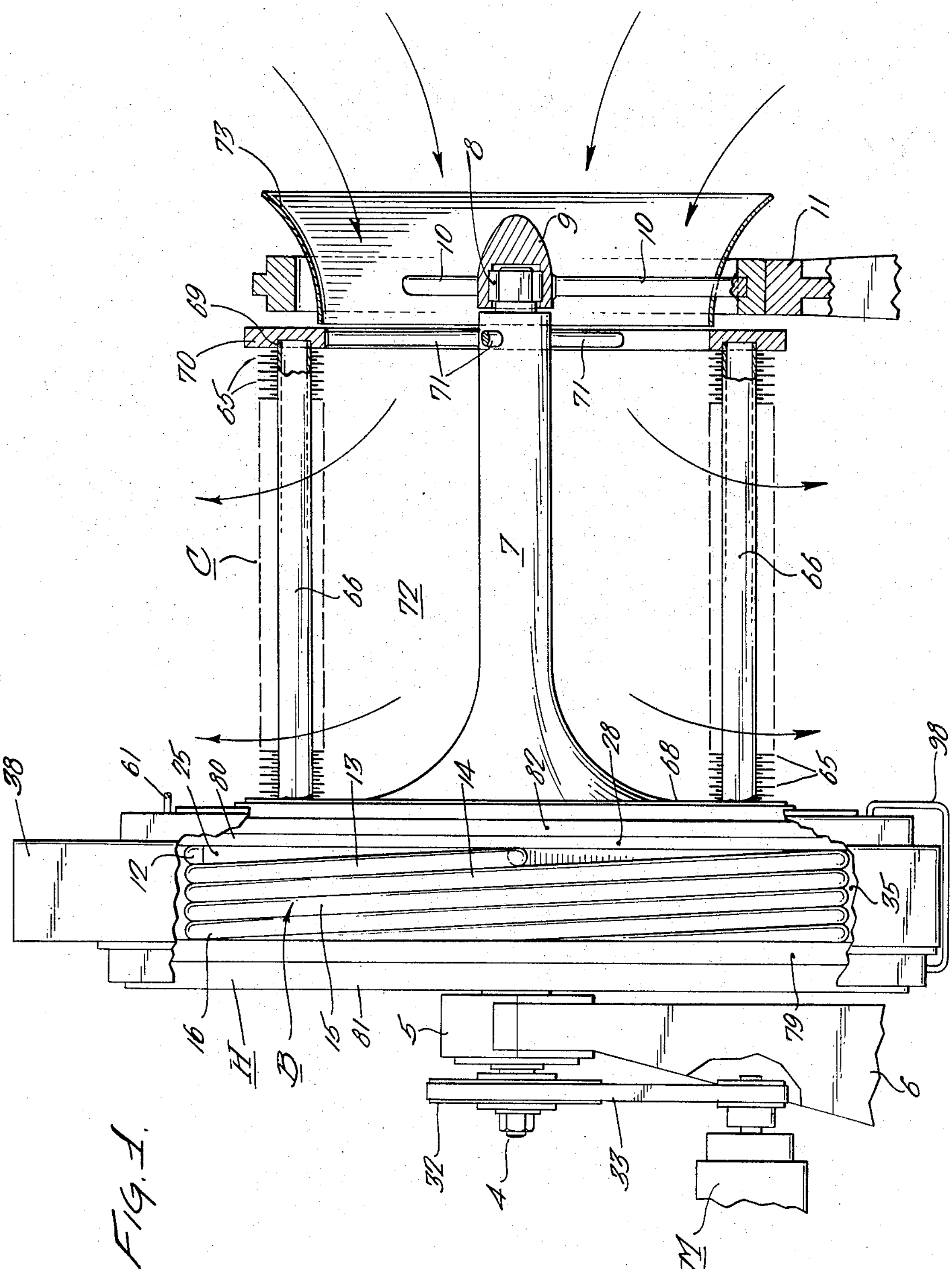


FIG. 1.

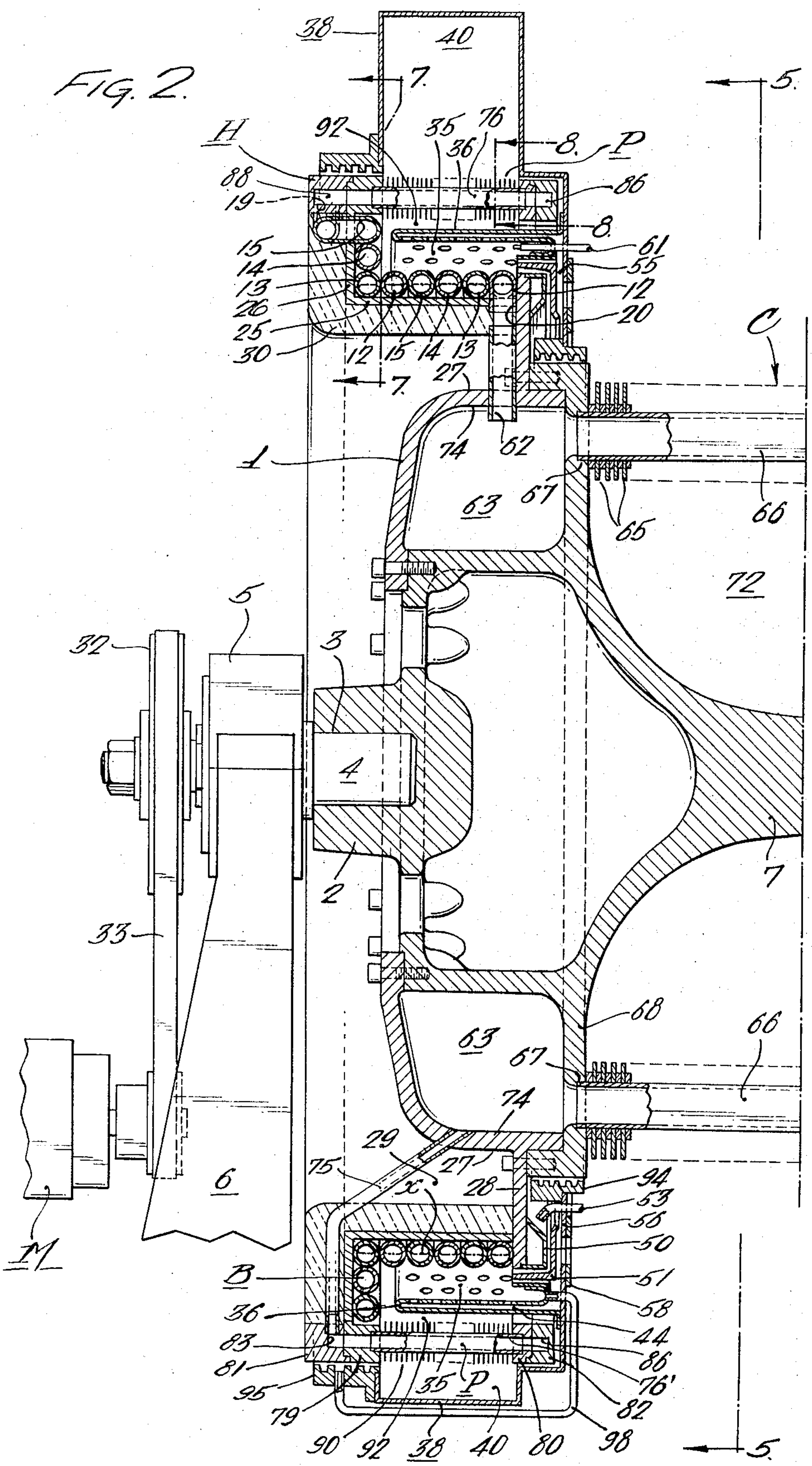

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FIG. 2.

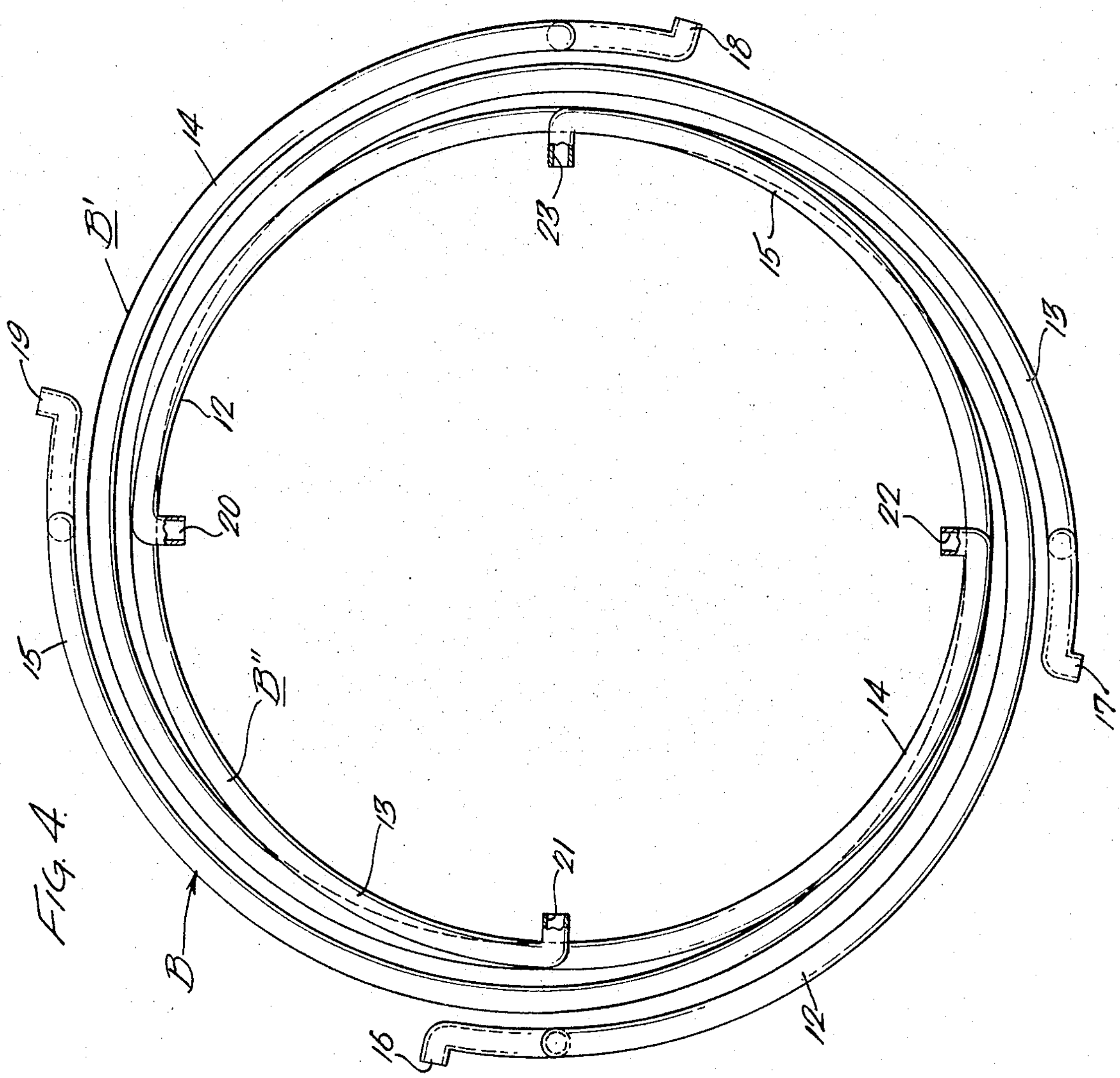
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FIG. 4.

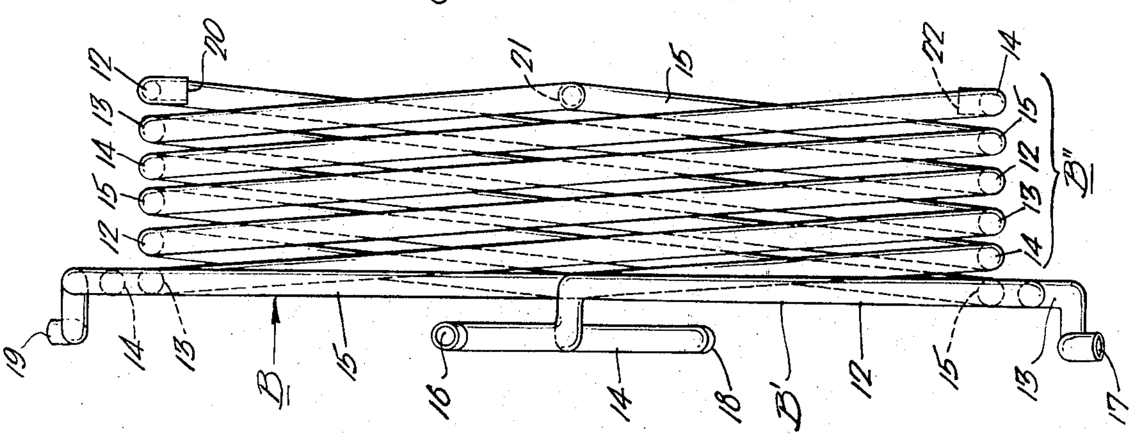
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FIG. 3.

FIG. 5.

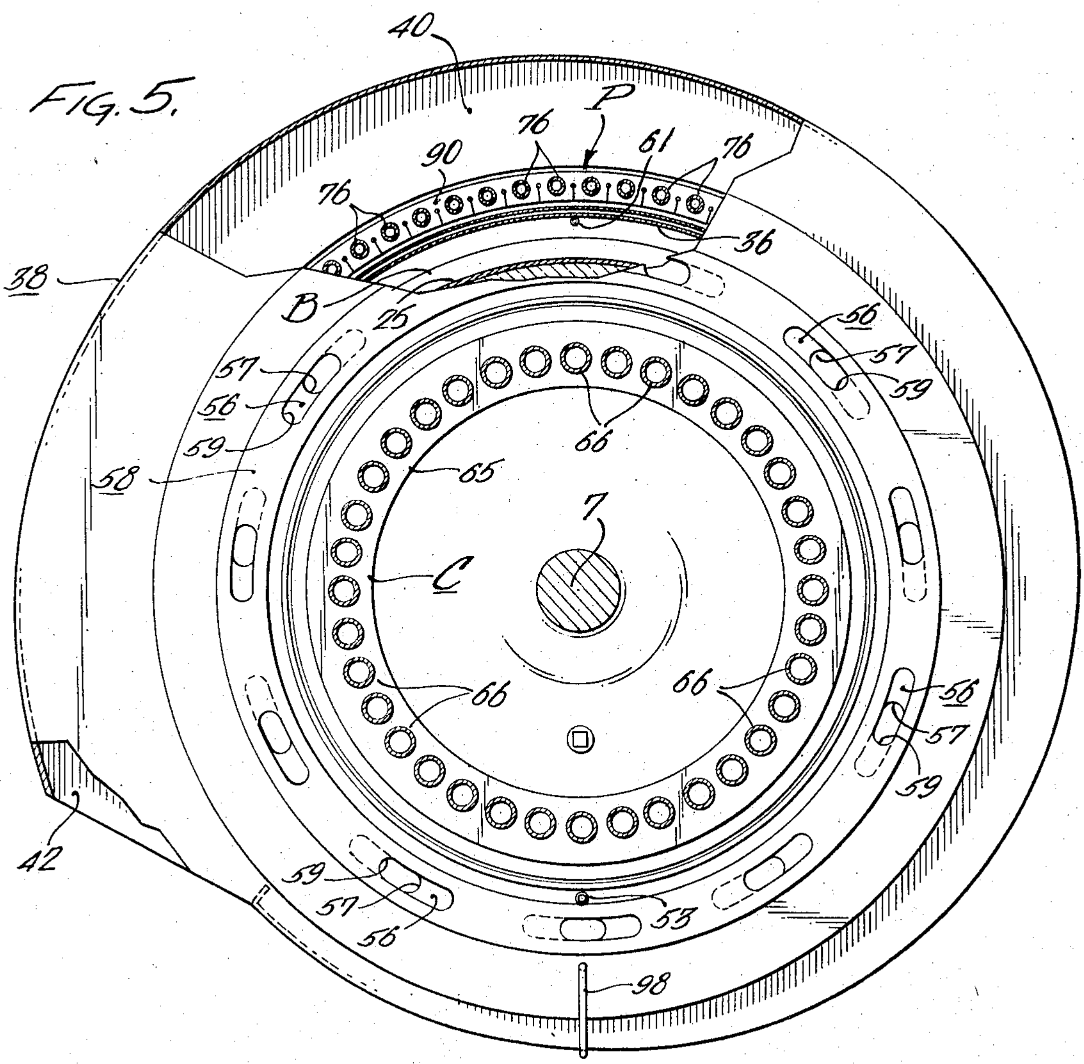
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FIG. 6.

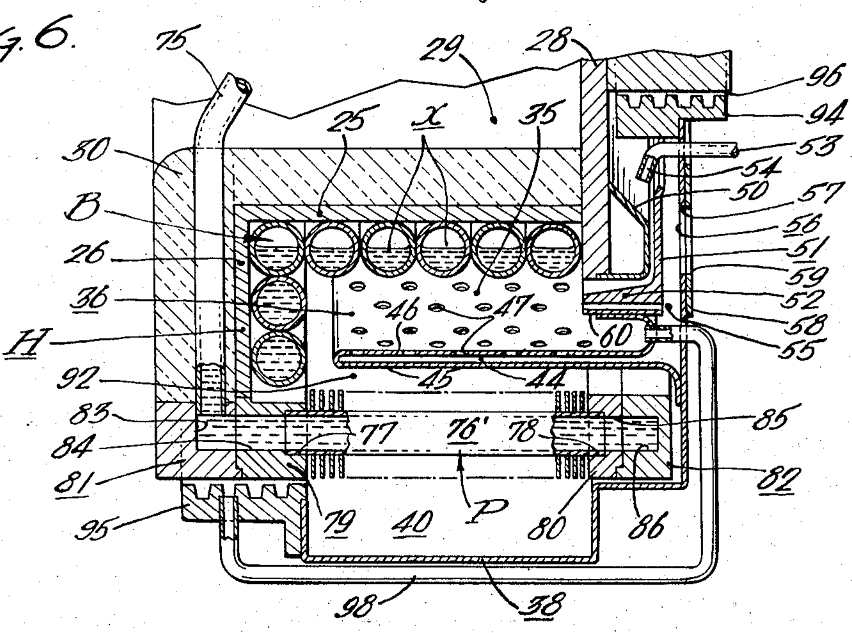
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FIG. 11.

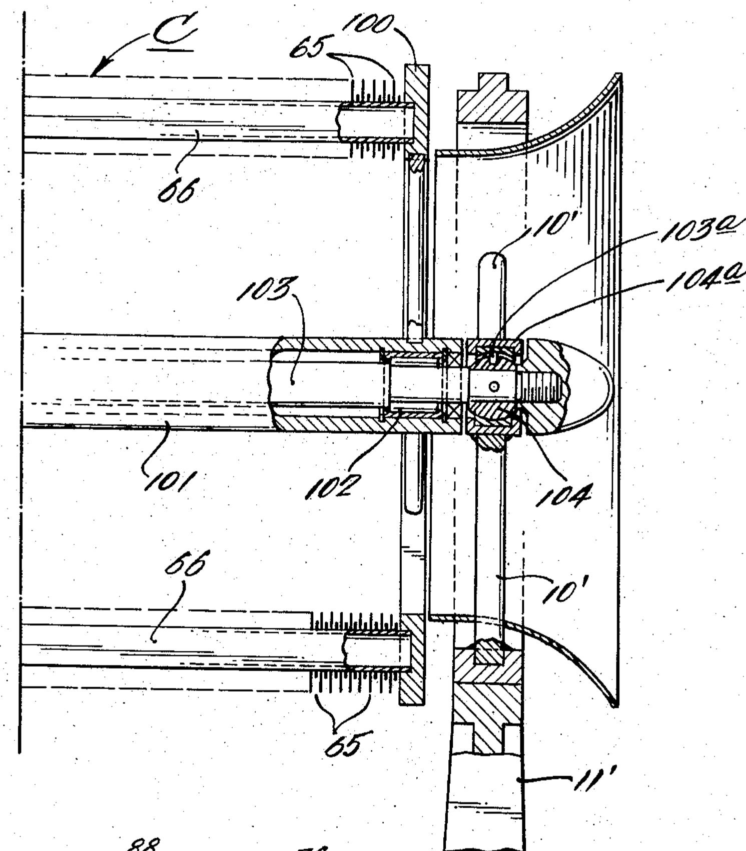


FIG. 7.

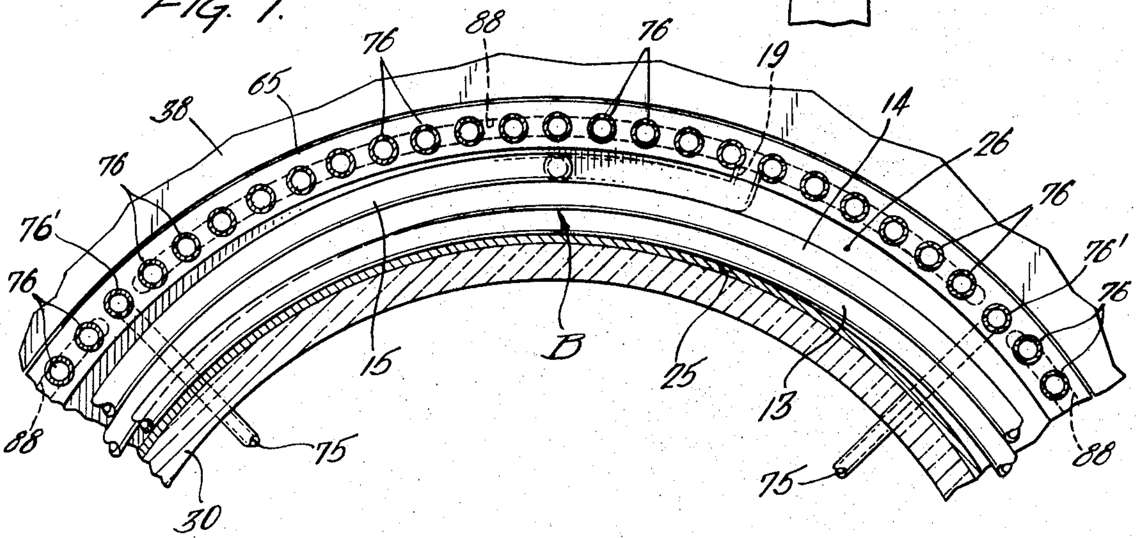
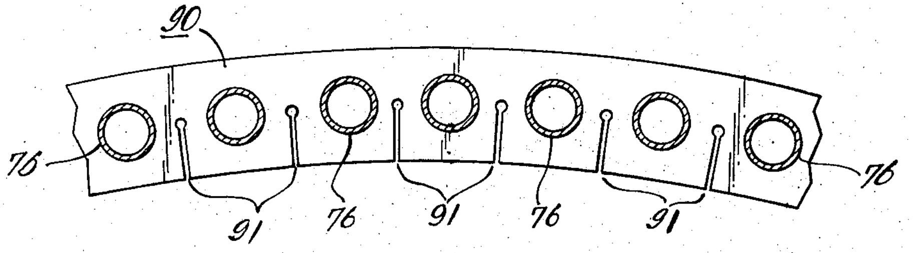


FIG. 8.



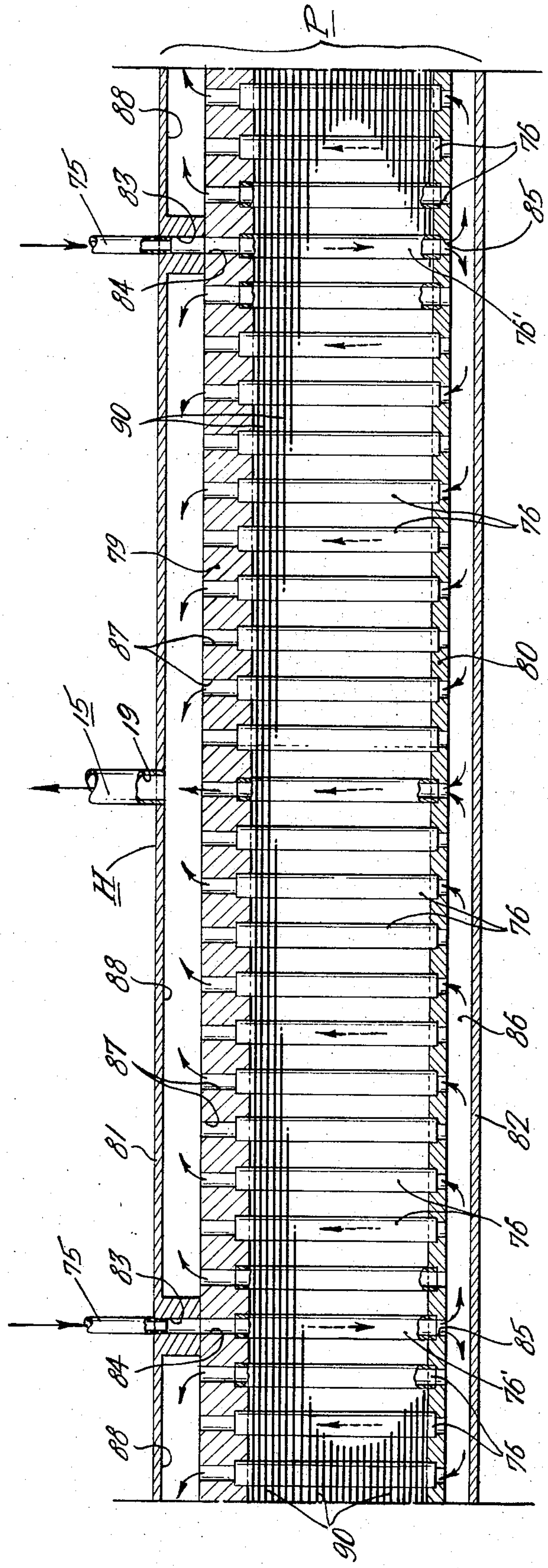


FIG. 9.

FIG. 12.

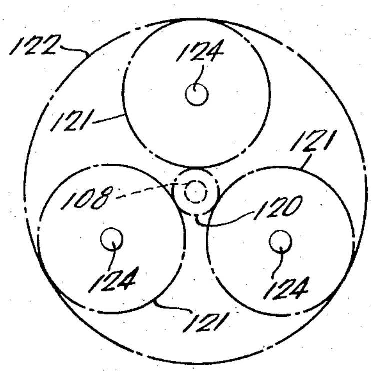

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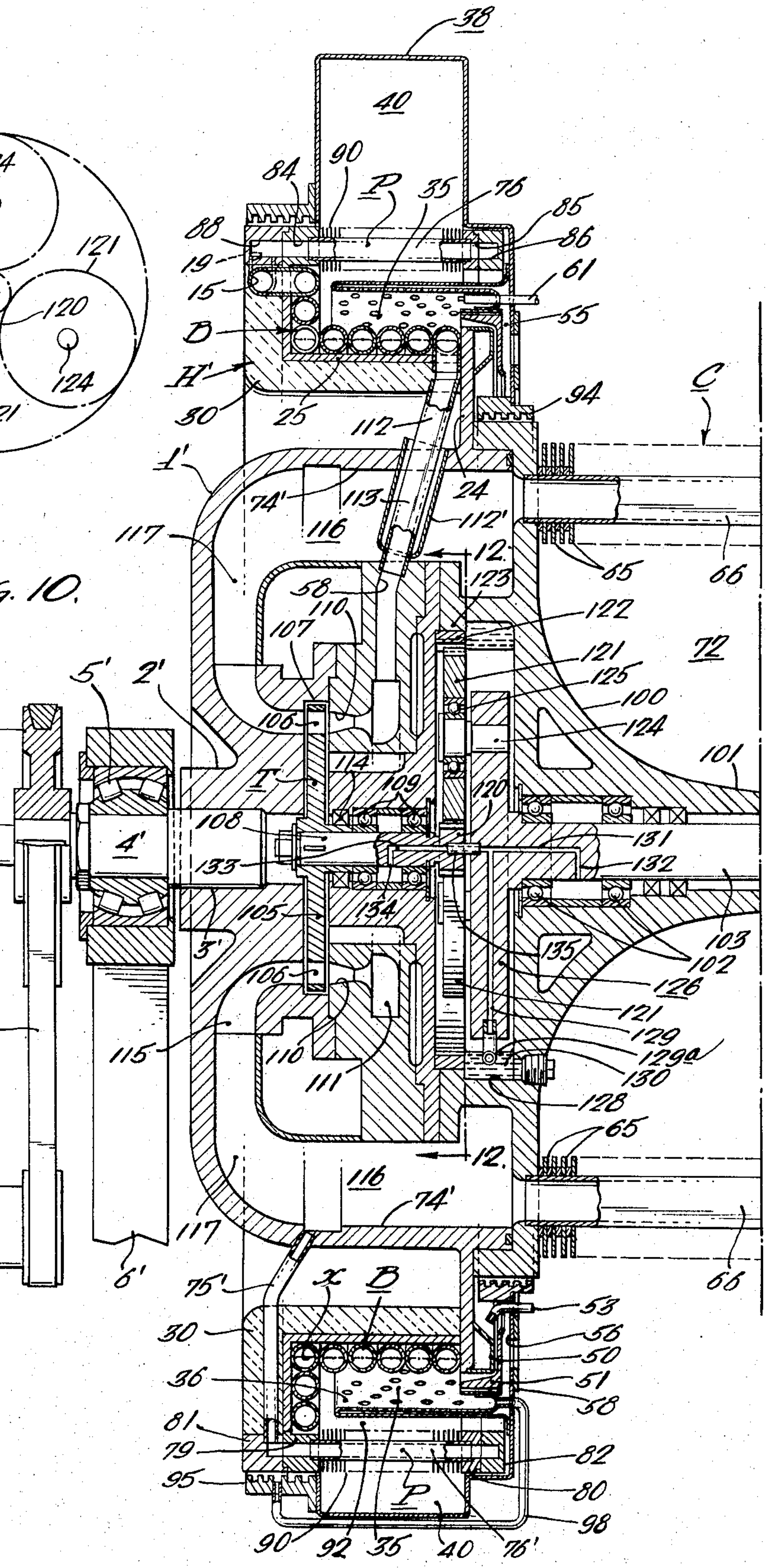
FIG. 10.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74'
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112'
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122
107
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72
125
5'
2'
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32'
106
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114
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133
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3'
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103
102
106
126
121
115
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129
129a
130
128
33'
M'
65
116
12
117
74'
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6'
75'
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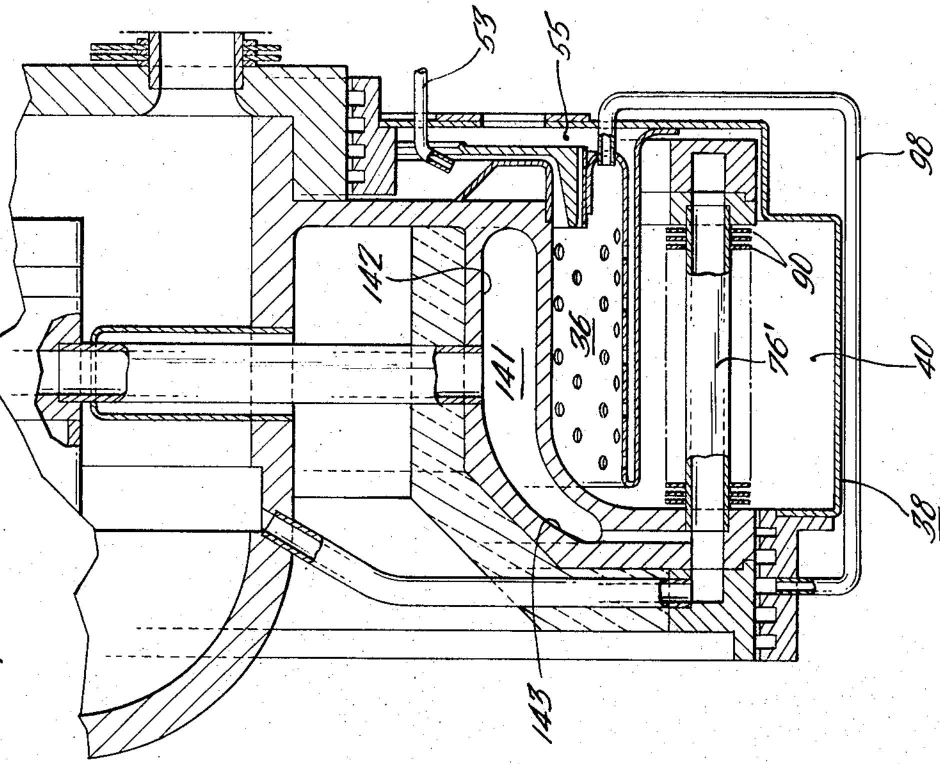
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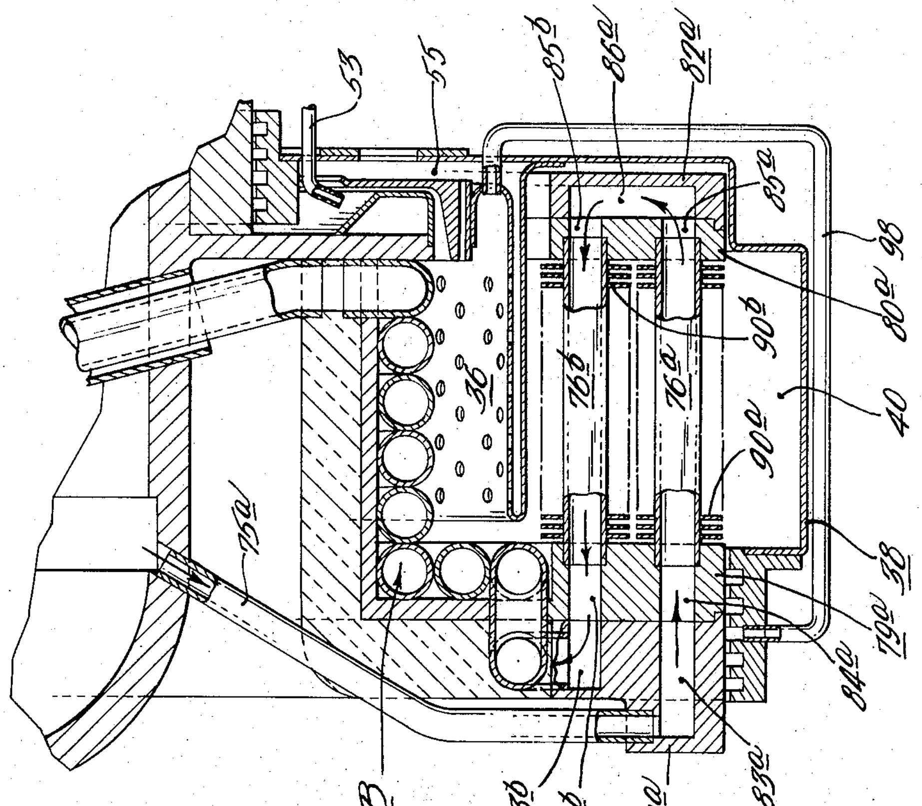
FIG. 14.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82a
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76b
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79a
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83b
84b
81a
83a

FIG. 13.

ROTARY BOILERS AND COMBUSTORS

This invention relates to new and useful improvements in rotary boiler and combustor devices. The invention is useful with any selected boiler fluid and particularly applicable to rotary boiler and combustor devices for use with organic high molecular weight power fluids. While useful for producing vapor for many purposes, the invention is especially adapted for use with rotary closed Rankine cycle engines such as, for example, shown and described in my U.S. Pats. No. 3,613,368 issued Oct. 19, 1971 and No. 3,744,246 issued July 10, 1973 and my pending application for U.S. Pat. filed Aug. 8, 1973, Ser. No. 386,630.

Rotary boilers are known in the art. Rotary boilers such as shown in my aforesaid patents and patent application provide many advantages that offset the disadvantages of prior rotary boilers. For example, such a rotary boiler can be operated at a much higher heat flux due to the high centrifugal forces on the liquid, and nucleate boiling is suppressed and replaced by a very stable quiescent convective type of boiling. Also, the rotary boiler has a low pressure drop and no hot spots. Most important, however, is the simplified liquid pumping that occurs in a rotary boiler, and if the rotary boiler is arranged so that there is a liquid leg between the condenser and the boiler, the centrifugal force developed by the rotation acting on this liquid leg is able to develop the necessary boiler pressure. Thus, simple radial tubes in a rotary boiler take the place of a complex boiler feed pump in a non-rotating system, and the liquid is automatically supplied to the boiler as required, thereby eliminating the necessity for a control system to match the boiler feed pump rate to the fuel rate as in a stationary boiler. Still another advantage of a rotary boiler is that the radial feed tubes supplying liquid to the boiler also act as relief valves that prevent overpressuring the boiler.

Nevertheless, there are several problems present in a rotary boiler. For example, it is difficult to provide a suitable seal between the rotary boiler and the surrounding fixed non-rotating combustion chamber to prevent hot gas or flame leakage. Insulation of the combustor is another problem. When the combustor wraps around the rotary boiler, the sides and periphery of the combustor must be insulated. This leads to large size and undesirable heat losses. Another problem is good heat transfer. Since the beam length for radiation is short, most of the heat transfer is by convection. Providing adequate convective heat transfer coefficients or sufficient boiler surface area can be difficult.

With the foregoing in mind, an object of the present invention is to provide a rotary boiler-combustor of the type described and embodying novel features of design and construction to produce high quality vapor with steady flow of both vapor and liquid independent of the earth's gravity field and orientation and capable of producing heat fluxes well above a peak boiling level for normal gravity.

Another object of the invention is to provide a rotary boiler-combustor wherein the seal points between the stationary and rotating parts are constructed and arranged so that the ambient air leakage is inward to the combustion chamber.

Another object of the invention is to provide a rotary boiler-combustor that is constructed and arranged to require a minimum amount of insulation.

Another object of the invention is to provide a rotary boiler-combustor construction having a combustion chamber that provides a high degree of mixing so as to obtain a high convective coefficient, quiet combustion, high volumetric heat release, and compactness.

Another object of the invention is to provide a rotary boiler-combustor device that is self-pumping and does not require a separate blower to provide combustion air.

Another object of the invention is to provide a rotary boiler-combustor device that operates with a low pressure fuel pump and a wide variety of liquid fuels without adjustment and does not require an atomizer fuel nozzle.

Another object of the invention is to provide a rotary boiler-combustor design and construction that provides for heat removal from the combustion flame between the introduction of primary and secondary air, thus keeping the combustion temperature down and minimizing formation of nitrogen oxides so that there is very low pollution.

Another object of the invention is to provide a rotary boiler-combustor construction characterized by high combustion efficiency obtained by providing for the combustion gas just prior to venting to the exhaust chamber a heat transfer section having a high surface area and a high convective heat transfer coefficient.

A further object of the invention is to provide a rotary boiler-combustor device of a construction having a low stress level providing maximum safety.

These and other objects of the invention and the various features and details of the construction and operation thereof are hereinafter set forth and described with reference to the accompanying drawings, in which:

FIG. 1 is a side elevational view partially in section of one embodiment of a rotary boiler-combustor constructed in accordance with the present invention;

FIG. 2 is an enlarged fragmentary vertical sectional view through **FIG. 1** showing certain details of construction and arrangement of the rotary boiler-combustor.

FIG. 3 is a side elevational view showing the construction and arrangement of the tubular boiler in the embodiment of the invention shown in **FIGS. 1** and **2**;

FIG. 4 is an end view of the boiler construction shown in **FIG. 3**;

FIG. 5 is a view partially in section on line **5—5, FIG. 2**;

FIG. 6 is an enlarged fragmentary sectional view of a portion of **FIG. 2** showing details of the construction of the rotary boiler-combustor;

FIG. 7 is an enlarged fragmentary view partially in section on line **7—7, FIG. 2**;

FIG. 8 is an enlarged fragmentary view partially in section on line **8—8, FIG. 2**;

FIG. 9 is a schematic diagram illustrating the flow of boiler liquid condensate through the heat exchange tubes of a rotary pre-heater prior to returning to the rotary boiler;

FIG. 10 is an enlarged fragmentary vertical sectional view showing certain details of construction and arrangement of another embodiment of the invention;

FIG. 11 is a side elevational view, partially in section, of the embodiment of the invention shown in **FIG. 10**;

FIG. 12 is a schematic view on line 12—12, FIG. 10;

FIG. 13 is a view similar to FIG. 6 showing still another embodiment of the invention; and

FIG. 14 is another view similar to FIG. 6 showing a further embodiment of the invention.

Referring now to the drawings, and more particularly to FIGS. 1 and 2 thereof, one embodiment of a rotary boiler-combustor mode according to the present invention is shown in the form of a closed Rankine cycle system comprising a rotary housing H and boiler B, an a rotary condenser C coupled to the housing and boiler for rotation therewith as a unit.

The housing H includes a coaxial central portion 1 having an axial hub 2 provided with a central bore 3 extending axially therein. Mounted in the bore 3 is a shaft 4 that is secured in the hub 2 for rotation therewith. The shaft 4 projects axially outward from the housing portion 1 and is journalled in a bearing 5 that is mounted in a fixed standard or support 6. At the opposite side from the shaft 4 the housing H includes a coaxial shaft 7 that is rotatably mounted by means of a bearing 8 housed in a hub structure 9 supported coaxially of the rotary housing by means of radial spokes 10 from a fixed support 11.

In the embodiment of the invention illustrated, the boiler B is of tubular construction comprising a plurality of successively coiled tubes 12, 13, 14 and 15, respectively. As shown in FIGS. 3 and 4 of the drawings, the boiler B comprises a radially disposed section B′ comprising a spirally coiled portion of each of the tubes 12, 13, 14 and 15, and an axially disposed section B″ comprising the helically coiled remaining portion of each of said tubes. Each of the boiler tubes 12, 13, 14 and 15 is of the same length and diameter and the respective tubes are coiled so that the inlet ends 16, 17, 18 and 19 thereof are equally spaced circumferentially about the eriphery of the radial section B′ of the boiler and with the outlet ends 20, 21, 22 and 23 of said tubes similarly spaced circumferentially about the opposite end of the axial section B″ of the boiler.

In FIGS. 3 and 4 of the drawings, the radially and axially coiled portions of the several boiler tubes 12, 13, 14 and 15 are shown in spaced relation to one another to better illustrate the arrangement of said tubes, and it is to be understood that in actual construction the adjacent coil portions of the tubes are disposed in contiguous abutting relation to one another. Also, the boiler B is not limited to the precise number of coiled tubes shown and described, and a more or less number of tubes may be employed as desired or required for a particular rotary boiler-combustor unit.

The tube coils in the axially extending section B″ of the boiler B are mounted on the outer surface of a cylindrical wall portion 25 of the rotary housing H and the radially disposed coils thereof are mounted on a radial wall portion 26 that projects outwardly from said axial wall portion 25. The cylindrical wall portion 25 is spaced radially outward from the outer surface 27 of the central portion 1 of the housing by means of a radial wall portion 28 to provide a thermal insulating air space 29 therebetween and the wall portions 25 and 26 are further thermally insulated by suitable insulation material 30.

The selected boiler liquid is supplied to the several tubes 12, 13, 14 and 15 of the rotary tubular boiler B through the inlet ends 16, 17, 18 and 19 of said tubes in the form of condensate from the condenser C as hereinafter described. The rotary housing H and boiler B are adapted to be driven about their axis at a predetermined speed of rotation calculated to create the centrifugal force necessary to maintain the coil portions of the tubes in the radial section B′ of the tubular boiler entirely filled with the selected boiler liquid and to maintain the boiler liquid in the coil portions of said tubes in the axial section B″ uniformly at the same depth circumferentially thereabout with a liquid-vapor interface, indicated at x, that is highly stable and essentially cylindrical and concentric with the axis of rotation with the boiler.

In the embodiment of the invention shown in FIGS. 1 and 2, the rotary boiler is rotationally driven at the desired predetermined speed by means of an electric motor M driving a pulley 32 fixed on the housing shaft 4 through a belt or chain 33, and the inventory of boiler liquid with which the boiler is charged is predetermined to insure that the coil portions of the tubes in the axially extending section B″ of the boiler B are about half full, as shown, at full power output of the boiler and at least partially filled at minimum power. Essentially, the liquid/vapor interface x is disposed at a predetermined radius from the rotation axis of the boiler to provide high boiling heat fluxes in excess of those obtainable at ambient gravity.

The liquid in the tubular boiler is heated to the required boiling temperature to vaporize the same by the combustion of a suitable fuel-air mixture in an annular combustion zone 35 that surrounds the rotary boiler B and is defined by a circumscribing cylindrical stationary wall or partition 36. The wall or partition 36 is fixedly mounted in a stationary scroll-shaped hood structure 38 that encloses the rotary boiler B and said partition 36 and defines an exhaust plenum chamber 40 for the combustion gases. The hood structure 38 has a discharge outlet at 42 as shown in FIG. 5 of the drawings.

Preferably, and in the illustrated embodiment of the invention, the wall or partition 36 is in the form of a secondary combustion air plenum chamber 44 comprising a pair of radially spaced substantially parallel concentric outer and inner cylindrical plate portions 45 and 46. Secondary combustion air is applied to the annular plenum chamber defined between the plate portions 45 and 46 as hereinafter described, and a plurality of openings 47 is provided in the inner plate 46 for discharging the secondary combustion air from the plenum chamber 44 into the annular combustion zone 35.

Mounted on the outer side of the radial wall portion 28 of the rotary housing H is an annular fuel distributor 50 that rotates with said housing and spaced axially outward from said distributor 50 and rotatable therewith is a fuel atomizing ring 51 having a peripheral discharge lip 52 extending axially inward toward the combustion zone 35. In the illustrated embodiment of the invention, the selected liquid fuel is supplied by a low pressure pump (not shown) to a fuel inlet tube 53 that has its discharge end 54 disposed in confronting relation to the rotation fuel distributor 50 so that fuel discharged from the tube 53 impinges on said distributor 50 and is distributed uniformly circumferentially thereabout. The circumferentially distributed liquid fuel is discharged by centrifugal force from lip 52 of the atomizing ring 51 axially into the combustion zone 35 in the form of a spray or mist of very fine droplets or particles.

A combustion air chamber **55** is provided adjacent the fuel distributor **50** and atomizing ring **51** and is partially enclosed by a stationary annular plate **56** of the stationary hood structure **38.** The annular plate **56** has a circular series of arcuate air inlet ports **57** formed therein, for example, as shown in FIG. **5** of the drawings and similar annular plate **58** having a corresponding series of arcuate openings **59** therein is mounted outwardly adjacent the stationary plate **56** and is rotatably adjustable relative thereto. By rotary adjustment of plate **58** relative to plate **56** the size or area of the air inlet ports **57** in said plate **56** may be increased or decreased as desired to regulate and control the amount of air admitted therethrough to the combustion air chamber **55** and maintain the proper air/fuel ratio at the desired power level.

From the chamber **55** primary combustion air passes between the rotating atomizing ring **51** and a stationary cylindrical ring **60** directly into the combustion zone **35** and secondary combustion air passes into the cylindrical plenum chamber **44** from which it is discharged into the combustion zone **35** through the openings **47** provided in the inner plate portion **46** thereof. The primary and secondary combustion air and the finely divided mist of fuel are thoroughly mixed in the combustion zone **35** by the relative rotation of the boiler B and associated parts with respect to the stationary well or partition **36.**

The air/fuel mixture in the combustion zone **35** is ignited by a plurality of igniter devices **61** mounted at circumferentially equally spaced intervals in the plate **36** of the stationary hood structure **38** so that combustion of the fuel/air mixture takes place substantially circumferentially throughout the annular combustion zone **35.**

Alternatively, gaseous fuel instead of liquid fuel may be used in the boiler-combustor. Instead of liquid fuel distribution ring **50** and liquid fuel atomizer ring **51** the combustor can be provided with a plurality of fuel gas nozzles located in the same radial position as igniters **61** but alternating with them around the side of the chamber.

High pressure vapor generated in the boiler B by combustion of the fuel/air mixture in the combustion zone **35** is discharged from the outlet ends **20, 21, 22** and **23** of the boiler tubes **12, 13, 14** and **15,** respectively, through a plurality of radial vapor tubes **62** to an annular pressure vapor chamber **63** as provided in the rotary housing H. The vapor tubes **62** are arranged circumferentially in equally spaced relation to insure rotational balance in the unit, and one vapor tube **62** is provided for each tube in the boiler B and connected to the outlet ends thereof.

Pressure vapor generated in the boiler B is discharged into the annular housing chamber **63** and enters a condenser C where it is condensed and the condensate returned to the boiler B as hereinafter described. While any suitable form of rotary condenser may be employed for condensing the boiler pressure vapor, in the illustrated embodiment of the invention the condenser C comprises a coaxial array of radially disposed annular fins **65** having a plurality of heat exchange tubes **66** extending longitudinally therethrough. The condenser C is mounted at one side of the housing H concentrically of the shaft **7** and its secured to said housing for rotation therewith as a unit. The fins **65** consist of separate or independent annular disk elements supported and secured in predetermined equally spaced parallel relation with respect to one another and the fins **65** and tubes **66** are fabricated of metal having high thermal conductivity such as, for example, copper or aluminum, said fins preferably being bonded to said heat exchange tubes by brazing, soldering or the like, to provide maximum thermal conductivity therebetween.

The tubes **66** are arranged in rotationally balanced spaced relation circumferentially of the fins **65** and are secured at their inner ends in corresponding openings **76** provided through the adjacent wall **68** of the housing H so that the interiors of the tubes **66** are in communication with the interior of the pressure vapor chamber **63** as shown in FIG. **2.** As shown in FIG. **1,** the outer ends of the tubes **66** are mounted and secured in recesses **69** provided in an annular end ring **70** that is disposed coaxially adjacent the outermost of the fins **65** and supported from the shaft **7** by circumferentially equally spaced radial spokes **71.** Thus, the condenser C, housing H and boiler B are rotatable as a unit about their common axis.

The inner peripheral edges of the fins **65** define internally thereof a coaxial inlet chamber **72** for the cooling fluid to the discharged outwardly by and between the plurality of rotating fins **65** as hereinafter set forth. The inner diameter of the ring **70** is substantially the same as the inner diamater of the adjacent group of fins **65** so as not to restrict the flow of fluid into the chamber **72,** and an outwardly flared or bell-shaped fluid intake member **73** is fixedly supported by the spokes **10** from the stationary support **11** in coaxial relation outwardly adjacent the end ring **70** as shown in FIG. **1.**

The axial spacing or distance between the adjacent fins **65** and the ratio of the inner to outer radii thereof is critical and the fin spacing must be determined with relation to both the rotational speed at which the unit is designed to be driven and the kinematic viscosity of the condenser cooling fluid to have a Taylor number that is operable at the fin radii ratio to utilize the viscous properties of the cooling fluid and the shear forces exerted thereon by the rotating fins **65** to convey and accelerate the fluid spirally outward between said fins by viscosity shear forces in accordance with the invention set forth and described in my copending application Ser. No. 307,612, filed Nov. 17, 1972.

The boiler pressure vapor discharged to the chamber **63** passes into the heat exchange tubes **66** where the vapor is condensed by heat exchange with a cooling fluid, such as ambient air, discharged outwardly between the array of fins **65** as previously described. The condensate thus formed in the tubes **66** flows from the inner ends thereof across the cylindrical wall surface **74** of the chamber **63** and enters a plurality of equally circumferentially spaced conduits **75** through which the condensate is discharged outwardly by centrifugal force generated by rotation of the housing-condenser unit and returned to the boiler B through a boiler liquid pre-heater arrangement generally designated P.

The boiler liquid pre-heater P comprises an annular series of a plurality of axially extending heat exchange tubes **76** arranged circumferentially in circumscribing relation about the combustion zone **35** outwardly adjacent the stationary partition **44** and within the stationary hood structure **38,** for example, as shown in FIGS.

5 and 7 of the drawings. Each of the tubes **76** has its opposite ends mounted in recesses **77** and **78** provided respectively in axially spaced circumferential mounting rings **79** and **80** of the rotary housing H. The rotary housing H also includes circumferential rings **81** and **82** disposed outwardly adjacent said mounting rings **79** and **80,** respectively.

In the illustrated embodiment of the invention there are provided, for example, four condensate return conduits **75** arranged circumferentially in equally spaced relation 90° apart within the rotary housing H. The outer end of each conduit **75** connects with a port **83** provided in the housing ring **81,** and each of the ports **83** in turn communicates with a registering port **84** in the adjacent housing ring **79.** Each of the ports **84** is in communication with the adjacent end of one of several of the tubes **76,** particularly designated **76'**. In the illustrated embodiment of the invention there are four such tubes **76'** disposed at equally spaced intervals circumferentially of the housing H in the annular series of tubes **76.** The opposite end of each of the several tubes **76'** communicates through a port **85** in the mounting ring **80** with a continuous annular manifold **86** that is provided in the housing ring **82** and is common to and in communication with the adjacent ends of all of the series of tubes **76** as illustrated in the schematic diagram shown in FIG. **9.**

The other ends of the tubes **76** opposite the common manifold **86** (except the tubes **76'**) communicate through passages **87** provided in the mounting ring **79** with one of four segmental arcuate manifold sections **88** formed in the housing ring **81.** Each of the manifold sections **88** is connected to the inlet end of one of the coiled tubes **12, 13, 14** or **15** of the boiler B, for example, the inlet end **19** of the tube **15** as shown in FIG. **9** of the drawings.

Thus in the pre-heater construction shown and described, the boiler liquid condensed in the condenser C will be discharged radially through the several conduits **75** and flow in one direction axially through the pre-heater tubes **76'** to the common manifold **86** and then in the reverse direction through the remaining tubes **76** to one of the manifold sections **88** from which the pre-heated boiler liquid is returned to the boiler B as described.

Each of the tubes **76** including the several tubes **76'** extends longitudinally through an array of a plurality of coaxial raidally disposed closely spaced annular fins **90.** The fins **90** and tubes **76** and **76'** are fabricated of metal having high thermal conductivity and said fins **90** preferably are bonded to the tubes **76** and **76'** to provide maximum thermal conductivity therebetween and optimum heat exchange between the combustion gases in the hood structure **38** and the boiler liquid condensate in the tubes **76** and **76'** of the pre-heater P. As shown in FIG. **8** of the drawings, intermediate each tube **76,** each of the fins **90** is slotted a predetermined distance radially from the inner edge thereof as indicated at **91** to accommodate differences in thermal expansion between the inner and outer peripheral edge portions of the fins due to differences in temperature of the combustion gases passing outwardly between the fins **90** of the pre-heater P.

As previously described in connection with the particular illustrated embodiment of the condenser C and its fins **65,** the axial spacing of the pre-heater fins **90** is determined with relation to the rotational speed at which the housing-boiler-condenser unit is driven and the kinematic viscosity of the combustion gases to have a Taylor number operable at the inner to outer radii ratio of said fins **90** to pump the combustion gases by viscosity shear forces spirally outward between the fins **90** into the exhaust plenum chamber **40** defined by the stationary hood structure **38.** Such shear force pumping is quiet, efficient and also provides a high convective heat transfer coefficient in the pre-heater P.

The combustion gases travel in a generally helical path through the combustion zone **35** and then pass about the lateral end of the stationary partition **44** to an annular transfer zone **92** between the said partition **44** and pre-heater P from which the gases are pumped by the rotating pre-heater fins **90** into the exhaust chamber **40.** The predominent velocity of the combustion gases is tangential due to the relatively high rotational velocity of the boiler tubes **12, 13, 14** and **15** with respect to the fixed cylindrical partition **44.** The very fine droplets of fuel discharged from the rotating fuel atomizing ring **51** into the combustion zone **35** are thoroughly mixed with the combustion air due to the high tangential velocity component of the combustion flame and the relatively long path of travel thereof through the cylindrical combustion zone **35** thereby providing a quiet, compact combustor characterized by a high volumetric heat release. Initially, the fuel from rotating atomizing ring **51** mixes with primary air entering through the annular space between rotating peripheral discharge lip **52** and stationary cylindrical ring **60.** While traveling in its helical path the fuel rich flame gives off heat to boiler tubes **12, 13, 14,** and **15.** Simultaneously, the flame is mixed with secondary air admitted to the combustion chamber through holes **47** in cylindrical plate **46** of the fixed cylindrical partition **44.** The loss of heat from the flame before the combustion is complete results in a lower combustion temperature which leads to a lower concentration of nitrogen oxides in the combustion products.

The opposite side portions of the stationary hood structure **38** surrounding the rotary boiler B are provided, respectively, with axially extending cylindrical sealing ring portions **94** and **95** that are disposed in circumscribing closely spaced relation with confronting cylindrical external surface portions of the rotary engine housing H. Thus, the sealing ring **94** is disposed in closely confronting relation with the cylindrical outer peripheral surface **96** of the engine housing H, and the sealing ring **95** is disposed in closely confronting relation with the cylindrical outer surfaces of the circumferential rings **81** and **69** of the rotary housing H. A plurality of circumferentially equally spaced tubes **98** are connected as shown in FIG. **6** between the sealing ring **95** and housing rings **81** and **79** and the combustion zone **35,** and since the latter is below atmospheric pressure, the tubes **98** will conduct air from the ambient atmosphere and exhaust gas leakage at seal **95** to the combustion zone **35** thereby not only preventing exhaust gas leakage from the stationary hood structure **38** to the ambient atmosphere but also providing exhaust gas recirculation to the combustion zone to substantially reduce the formation of pollutants, especially oxides of nitrogen.

In normal operation of the rotary boiler-combustor with the liquid in the rotary boiler B heated to the required temperature and pressure by combustion of the fuel/air mixture in the combustion zone **35,** the pressure vapor generated in the boiler is discharged inwardly through the tubes **62** to the chamber **63** and thence into the heat exchange tubes **66** of the condenser C where it is condensed by the cooling fluid discharged outwardly between the fins **65** as previously described. The boiler liquid condensate flows inwardly and out of the condenser tubes **66** and over the housing surface **74** into the conduits **75.** Condensate entering the conduits **75** is pumped by contrifugal force, through the heat exchange tubes **76** and **76'** of the preheater P and returned to the boiler B as previously described whereupon the cycle is repeated.

The cooling fluid, such as air, discharged outwardly between the fins **65** of the condenser is heated to a substantially high temperature by heat exchange with the high temperature boiler vapor condensed in the condenser tubes **66** and the hot air discharged through the condenser may be used for space heating, for example, by enclosing the condenser C to collect said hot air and ducting it to hot air outlets suitably disposed in the space to be heated. Alternatively, the hot air discharged from the condenser may be used for heating and/or drying purposes in industrial processes and the like.

A typical design of a rotary boiler-combustor embodying the construction shown and described has a boiler B comprising a plurality of coiled tubes **12, 13, 14** and **15** each having an outer diameter of 0.5 inch. The axial section B'' of the boiler has an axial length of 2.5 inches and the tube portions therein are coiled on 18.0 inch diameter centers so that the liquid/vapor interface x is spaced 9.0 inches from the rotation axis of the boiler. The inner cylindrical plate portion **45** of the stationary partition **36** has an inner diameter of 19.84 inches and the outer plate **46** has an outer diameter of 20.03 inches. The pre-heater P comprises ninety heat exchange tubes **76,** including the tubes **76',** each having an axial length of 2.5 inches and an outside diameter of three-eighths inch. The tubes are equally spaced circumferentially of the stationary partition **36** on 21.25 inch diameter centers. The array of annular fins **90** has an axial length of 2.5 inches and the fins each have a thickness of 1/32 inch and the spacing between adjacent fins is 1/16 inch. Each of the fins 90 has an inner diameter of 20.5 inches and an outer diameter of 22.0 inches. The design speed of rotation of the roller is 2,400 r.p.m.

Using as the boiler liquid a mixture of trichlorodifluorobenzene isomers as disclosed in patent application Ser. No. 172,513, filed Aug. 17, 1971 by Max F. Bechtold and Charles W. Tullock, now U.S. Pat. No. 3,774,393, issued Nov. 27, 1973, and using, for example, kerosene, as the combustion fuel, the specifications of a typical operation of the foregoing boiler-combustor are as follows:

Boiler feed liquid (°F.)	313.
Fuel rate (lbs/hr)	9.6
Air/fuel ratio	18.5
Boiler vapor (°F.)	620.
Boiler output (Btu/hr)	150,000.
Combustor efficiency (%)	88.

The invention is not limited to the embodiment shown in FIGS. **1** and **2** of the drawings, and the pressure vapor generated in the boiler B may be used advantageously, for example, to rotationally drive the rotary housing-boiler-condenser unit at the desired speed as well as to provide power for driving external equipment and machinery. One such embodiment is shown in FIGS. **10–12** of the drawings in which the same reference numerals are used to designate parts that are identical to parts shown in FIGS. **1** and **2.**

Referring to FIGS. **10–12** of the drawings, the housing H includes a coaxial central portion **1'** having an annular hub structure **2'** provided with a central bore **3'** extending axially therethrough. Mounted in the bore **3'** is a shaft **4'** that is secured in the hub **2'** for rotation therewith. The shaft **4'** projects axially outward from the housing portion **1** and is journalled in a bearing **5'** that is mounted in a fixed standard or support **6'** of the rotary engine. As shown in FIG. **11,** the opposite side from the shaft **4'** of the housing H' includes a radially extending coaxial circular plate **100** having an endwise extending coaxial tubular shaft **101** that is rotatably mounted by means of a bearing **102** upon a coaxially extending stationary shaft **103.** The outer end of the stationary shaft **103** is mounted in a bearing **104** housed in a hub structure **104*a*** supported coaxially of the rotary engine by means of radial spokes **10'** from a fixed support **11'.** The shaft **103** is secured against rotation by means of a radial pin **103*a*.**

An internal expander, such as a turbine T, is mounted coaxially within the rotary housing H'. The turbine T shown, is of the single stage type comprising a rotor **105** having a series of turbine blades **106** arranged peripherally thereabout. The turbine rotor **105** is received within an annular recess **107** provided in the housing portion **1'** and is mounted for coaxial rotation independently of the boiler B on a coaxial shaft **108** that is rotationally mounted in bearings **109.** An annular series of nozzles **110** is provided in the housing portion **1'** coaxially adjacent the turbine rotor **105** and in confronting relation to the blades **106** thereof. An annular high pressure vapor manifold **111** is provided in the housing portion **1'** and leads to the nozzles **106.**

High pressure vapor is supplied from the boiler B to the manifold **111** by a plurality of vapor tubes **112** and connecting passages **113** arranged in equally spaced relation circumferentially of the axis to insure rotational balance in the unit. The high pressure vapor is discharged from the manifold **111** through the nozzles **110** and impinges upon the blades **106** to drive the turbine rotor **105** and its shaft **108** at the desired speed of rotation. A seal **114** is provided on the shaft **108** inwardly adjacent the turbine rotor **105** to minimize migration of the pressure vapor from the turbine along said shaft **108.**

An annular diffuser **115** is provided in the housing portion **1'** to receive the exhaust vapor from the expander, such as turbine T, and the inlet opening thereto is disposed in confronting relation to the turbine blades **106** at the opposite ends thereof from the nozzles **110.** Exhaust vapor entering the diffuser **115** is discharged into an annular exhaust chamber **116** in the rotary housing from which it passes into the condenser C, and the portions of the vapor tubes **112** that span the annular exhaust chamber **116** are enclosed within concentric sleeves **112'** of larger diameter than said tubes **112** to thermally insulate the tubes **112** from the lower temperature of the exhaust vapor in the chamber **116.** A plurality of axially extending radial partitions or baffles **117** provided in the exhaust chamber **116** are arranged in equally spaced relation circumferentially about the engine axis function to maintain the angular velocity of the exhaust vapor at that of the rotating housing-boiler-condenser unit and to direct the vapor toward and into the condenser C.

In the illustrated embodiment of the invention, after start-up of the engine and with the liquid in the boiler B heated to the required temperature and pressure by combustion of the fuel-air mixture in the combustion chamber **35**, the housing-boiler-condenser unit is rotationally driven continuously by the primary power output generated by the engine by means of an internal occluded fixed-ratio gear train arranged coaxially of the engine axis within the housing H', for example, as shown and described in application for U.S. Pat. of Max. F. Bechtold, Ser. No. 206,779, filed Dec. **10, 1971**, now U.S. Pat. No. 3,769,796, issued Nov. 6, 1973.

As shown in FIGS. **10** and **12** of the drawings, the gear train is in the form of a planetary gear system comprising a sun gear **120** fixedly mounted on and driven by the turbine shaft **108.** Meshed with the sun gear **120** is a plurality of planetary gears **121** that are also meshed with a circumscribing annular ring gear **122.** The ring gear **122** is mounted on and carried by an annular flange **123** that is formed integral with and projects axially inward from the adjacent face of plate **100** of the rotary housing H'. In the present embodiment as shown in FIG. **12** of the drawings, three planetary gears **121** are provided and arranged in equally spaced relation circumferentially about the engine axis. Each of the planetary gears **121** is rotatably mounted on a stub shaft **124** by means of a bearing **125** and each stub shaft **124** is fixedly mounted in a stationary spider portion **126** provided at the inner end of the stationary shaft **103** whereby the axes of the planetary gears **121** are fixedly positioned so that they do not rotate or move circumferentially relative to or about the engine axis. Thus the full power output of the engine turbine T is transmitted from the driving sun gear **120** through the planetary gears **121** directly to the driven ring gear **122** and the rotary housing-boiler-condenser unit at the fixed-speed ratio of the particular gear train.

The turbine shaft bearings **109** and the bearings **102** of the stationary shaft **103** as well as the several gears in the gear train are lubricated by a force feed system utilizing a Pitot type pump as shown and described in my U.S. Pat. No. 3,744,246 issued July 10, 1973. In the embodiment shown, the ring gear **122** of the fixed-ratio gear train is disposed in an annular lubricant sump **128** formed in the rotary housing H' as shown in FIG. **10** of the drawings. The Pitot pump comprises a radial passage **129** formed in the stationary spider **126** and having at at its outer end an L-shaped tip **129*a*** the inlet end of which is immersed in an annular bath of lubricant **130** in the sump **128** with the inlet thereto facing opposite the direction of rotation of the engine. The inner end of the passage **129** is connected to a coaxial passage **131** formed in the spider portion **126** and extending into the adjacent end portion of the shaft **103** where it connects with a radial passage **132** that opens between the bearings **102.** A coaxial passage **133** extends through the sun hear **120** and adjacent portion of the turbine shaft **108** where it connects with a radial passage **134** that opens between the axially spaced turbine shaft bearings **109.** The connection between the non-rotating passage **131** and the passage **133** in the rotating sun gear **120** and turbine shaft **108** may be made by means of a connector tube **135** having one end fixed in the passage **133** and the other end mounted coaxially within the stationary passage **131** by means of a suitable seal, for example, as shown and described in my aforesaid patent.

In operation of the engine, it will be apparent at start-up that there will be no pressure vapor generated by the boiler to drive the internal expander and in turn the rotary housing-boiler-condenser unit. Consequently, at start-up it is necessary to independently drive the housing-boiler-condenser unit at the designed predetermined speed of rotation to establish and maintain the liquid/vapor interface x in the boiler B until the liquid in the boiler is heated to the temperature to produce the desired pressure vapor to drive the turbine T. This may be accomplished, for example, by means of a starter motor M' driving a pulley **32'** fixed on shaft **4'** through a belt or chain **33'**. Means such as a clutch (not shown), can be provided for breaking the drive between motor M' and pulley **32'** when the engine attains normal operation, or the motor can continue to be driven by the rotating housing-boiler-condenser unit and shaft **4'** and function as a generator operable, for example, for charging a battery that powers accessories such as the starter motor, lights and the like. A power take-off **136** or other suitable driving connection is provided at the outer end of the output shaft **4'** which may be used to drive any selected equipment or machinery such as, for example, a wheeled vehicle, boat, or otherwise, as desired.

In normal operation of the rotary engine, with the liquid in the rotary boiler B heated to the required temperature and pressure by combustion of the fuel-air mixture in the combustion one **35,** the pressure vapor generated in the boiler is discharged inwardly through the tubes **112** and passages **113** to the manifold **111** and thence through nozzles **110** into impinging contact against the turbine blades **106** thereby driving the turbine rotor **105** and shaft **108** at the desired speed of rotation. The shaft **108,** through the occluded fixed-ratio gear train previously described, drives the housing-boiler-condenser unit and the shaft **4'** at a predetermined speed of rotation relative to the speed of shaft **108** determined by the fixed-ratio of the gear train. In the embodiment of the invention shown, the direction of rotation of the housing-boiler-condenser unit and the shaft **4'** is opposite the direction of rotation of the turbine shaft **108.**

The exhaust vapor from the turbine enters the diffuser **115** and is discharged through the exhaust chamber **116** into the heat exchange tubes **66** of the condenser C where it is condensed by the cooling fluid discharged outwardly between the fins **65** as previously described. The boiler liquid condensate flows inwardly and out of the condenser tubes **66** and over the housing surface **74'** into the conduits **75'**. Condensate entering the conduits **75'** is conveyed therethrough by centrifugal force, through the heat exchange tubes **76** and **76'** of the pre-heater P and returned to the boiler B as previously described, whereupon the cycle is repeated.

The embodiment of the invention shown in FIGS. **10–12** is not limited to use of an internal gear train as previously described to rotationally drive the housing-boiler-condenser unit directly from the internal power fluid expander. Thus, in some installations, it may be desirable to rotationally rive the housing-boiler-condenser unit continuously by means of an external electric motor M as in the embodiment shown in FIGS.

1 and 2 of the drawings, and use the full power output of the tubine shaft **108** to drive other equipment. For example, the turbine shaft **108** may drive an electric generator or alternator mounted internally of the rotary housing coaxially thereof as shown and described in my copending U.S. Pat. application Ser. No. 316,851, filed Jan. 2, 1973. Such a generator or alternator may be used not only to supply electric current to the external drive motor but also to supply electric power for appliances, heating, lighting and other electrical equipment. Also, the turbine shaft **108** may be extended coaxially to the exterior of the engine and the full power output of the expander used to drive mechanical equipment either directly or through appropriate speed reduction gearing as required.

The invention is not limited to the particular construction and arrangement of the boiler B and preheater P previously described, and examples of modifications thereof are shown in FIGS. **13** and **14** of the drawings, respectively, in which the same reference numbers are used to designate parts that are essentially the same as parts previously described and shown.

Referring to FIG. **13,** as there shown, the pre-heater may consist of a plurality of radially spaced concentric sections, for example two sections, the outer section comprising a plurality of axially spaced radially disposed annular fins **90***a* having heat exchange tubes **76***a* extending longitudinally therethrough and the inner section comprising similarly arranged heat exchange tubes **76***b* and annular fins **90***b*. The outer end of each condensate return conduit **75***a* connects with a passage **83***a* in housing ring **81***a* and each of the passages **83***a* in turn communicate through passages **84***a* in the adjustment housing ring **79***a* with the adjacent ends of the tubes **76***a* of the outer pre-heater section. The opposite ends of the tubes **76***a* communicate through passages **85***a* in ring **80***a* with an annular manifold **86***a* in the ring **82***a* and the manifold **86***a* is also in communication, through passages **85***b*, with the adjacent ends of the tubes **76***b* of the inner pre-heater section. The other ends of the tubes **76***b* communicate through passages **84***b* in ring **79***a* with a manifold **83***b* in ring **81***a* to which are connected the inlet ends of several tubes of the boiler B. By this construction flow of condensate through the tubes **76***a* and **76***b* of the outer and inner sections of the pre-heater is in opposite directions to provide counterflow heat exchange with the combustion gases passing between the fins **90***b* and **90***a* of the pre-heater sections.

Referring to FIG. **14,** a composite single chamber boiler **141** is provided in lieu of the coiled tube boiler B previously described. As shown in FIG. **4,** the boiler **141** is of generally L-shape including a primary axially extending portion **142** and a radially extending smaller portion **143.** As in the case of the coiled tube boiler B, the radially disposed portion **143** of the single chamber boiler **141** provides adequate flame insulation and additional heat transfer to the liquid supplied to said boiler from the pre-heater.

From the foregoing, it will be apparent that the present invention provides a rotary boiler-combustion of novel design and construction capable of producing heat fluxes well above peak boiling level for normal gravity and characterized by a combustion chamber that provides a high degree of fuel-air mixing and produces a high convective coefficient, quiet combustion, high volumetric heat release and compactness. The invention also provides a boiler-combustor in which ambient air leakage is inwardly to the combustion chamber and which is self-pumping. The boiler-combustor of the present invention also keeps the combustion temperatures down and minimizes the formation of nitrogen oxide so that there is very low pollution.

While certain embodiments of the invention have been shown and described, it is not intended to limit the invention to such disclosures and changes and modifications may be made and incorporated as devised within the scope of the following claims.

I claim:

1. A rotary boiler-combustor comprising:

a cylindrical housing rotatable about its axis,

a coaxial annular boiler extending circumferentially of said housing and rotatable therewith, said housing and boiler adapted to be rotated at a predetermined speed to maintain in the boiler an annular body of boiler liquid having a liquid/vapor interface spaced a predetermined distance radially from said axis,

means operable to rotationally drive the housing-boiler unit at said predetermined speed,

means defining an annular combustion zone circumscribing said rotary boiler comprising a stationary annular partition spaced radially outward from the boiler,

means for supplying combustion fuel and air to the combustion zone,

rotation of said housing-boiler unit relative to the surrounding combustion zone being operable to mix said combustion fuel and air and provide the desired combustion fuel/air mixture in said zone,

means to ignite said fuel/air mixture in said combustion zone and cause combination thereof to heat the liquid in the boiler and generate pressure vapor therein,

a stationary hood structure circumscribing the rotatable housing-boiler unit defining a combustion gas exhaust chamber surrounding the stationary partition member in radially spaced relation thereto,

a pre-heater for liquid supplied to the boiler rotatable with said housing-boiler unit and comprising an array of a plurality of axially spaced coaxial annular fins having a plurality of parallel heat exchange tubes extending longitudinally therethrough, said pre-heater being disposed circumferentially of the housing in radially spaced circumscribing relating to said stationary partition member and operable at said predetermined speed of rotation to pump said combustion gases through the pre-heater to the surrounding combustion gas exhaust chamber,

and means for supplying boiler liquid through said pre-heater heat exchange tubes to the boiler at a predetermined rate correlated to the rate of vaporization of the liquid in the boiler to maintain the liquid/vapor interface in the boiler at said predetermined distance from the rotation axis of said housing-boiler unit.

2. A rotary boiler-combustor as in claim **1** wherein the boiler comprises an axially extending portion and a substantially radially extending portion disposed to provide flame insulation and additional heat transfer to the liquid supplied to the boiler.

3. A rotary boiler-combustor as claimed in claim **1** wherein the boiler is of tubular construction comprising a plurality of tubes of equal length coiled sequentially and arranged circumferentially relative to each other so that their respective inlet and outlet ends are disposed at equally spaced intervals circumferentially about said boiler.

4. A rotary boiler-combustor as claimed in claim **1** wherein the boiler is of tubular construction comprising a plurality of tubes of equal length coiled sequentially and arranged circumferentially relative to each other so that their respective inlet and outlet ends are disposed at equally spaced intervals circumferentially about said boiler, the inlet end portion of each of said tubes being disposed in the radial portion of the boiler and the remainder of each of said tubes and the outlet end thereof being disposed in the axial portion of said boiler.

5. A rotary boiler-combustor as claimed in claim **1** wherein the stationary annular partition defining the combustion zone comprises a plenum chamber for supplying secondary air to said combustion zone.

6. A rotary boiler-combustor as claimed in claim **5** wherein the secondary combustion air plenum chamber is defined by inner and outer radially spaced concentric plate portions and said inner plate portion is provided with apertures for discharging secondary air from the plenum chamber to the combustion zone.

7. A rotary boiler-combustor as claimed in claim **1** wherein the annular fins of the pre-heater have a predetermined inner and outer radii ratio and the axial spacing of said fins is correlated to the speed of rotation of the housing-boiler unit and viscous properties of the combustion gases to have a Taylor number operable at said fin radii ratio to convey and accelerate said combustion gases by viscosity shear forces spirally outward between said fins to the surrounding combustion gas exhaust chamber substantially at the velocity providing optimum heat exchange between said combustion gases and the boiler liquid in the heat exchange tubes of the pre-heater.

8. A rotary boiler-combustor as claimed in claim **1** having a condenser for the vapor generated in the boiler mounted coaxially adjacent the housing and rotatable with said housing-boiler unit, and means for delivering said vapor to the condenser and for returning condensate therefrom through the pre-heater to the boiler.

9. A rotary boiler-combustor as claimed in claim **8** wherein the housing includes means defining an annular coaxial chamber therein for receiving pressure vapor from the boiler, the condenser is connected to said chamber to receive pressure vapor therefrom and return boiler liquid condensate thereto, and means is provided for returning said condensate from the chamber to the pre-heater and boiler.

10. A rotary boiler-combustor as claimed in claim **8** wherein the condenser comprises a plurality of annular axially spaced radial fins having a plurality of heat exchange tubes extending longitudinally therethrough.

11. A rotary boiler-combustor as claimed in claim **10** wherein the condenser fins have a predetermined inner and outer radii ratio and the axial spacing between said fins is correlated to the speed of rotation of the housing-boiler unit and the viscous properties of the condenser cooling fluid to have a Taylor number operable at said fin radii ratio to convey and accelerate said cooling fluid by viscosity shear forces spirally outward between said fins to the velocity providing optimum heat exchange between the condenser cooling fluid and the vapor in the condenser heat exchange tubes.

12. A rotary boiler-combustor as claimed in claim **11** wherein the annular fins of the pre-heater have a predetermined inner and outer radii ratio and the axial spacing between said fins is correlated to the speed of rotation of the housing-boiler unit and the viscous properties of the combustion gases to have a Taylor number operable at said radii ratio to convey and accelerate said combustion gases by viscosity shear forces spirally outward between said fins to the surrounding combustion gas exhaust chamber substantially at the velocity providing optimum heat exchange between said combustion gases and the boiler liquid in the heat exchange tubes of the pre-heater.

13. A rotary boiler-combustor as claimed in claim **1** wherein the means for discharging a combustible fuel into the combustion zone comprises an annular liquid fuel distributor and an atomizing ring rotatable with the housing-boiler unit, and said atomizing ring is constructed and operable to discharge a mist of fine droplets of said fuel axially into said combustion zone circumferentially thereabout.

14. A rotary boiler-combustor as claimed in claim **1** wherein axially spaced opposite sides of the stationary hood structure are provided with inwardly facing cylindrical sealing ring portions disposed in spaced confronting cooperative relation to cylindrical peripheral surface portions of the rotary housing.

15. A rotary boiler-combustor as claimed in claim **14** wherein the operating pressure in the combustion zone is below atmospheric pressure and ambient air leakage is axially inward between the confronting sealing ring portions of the hood structure and housing respectively, wherein rotation of the housing-boiler unit relative to the combustor operates automatically to pump combustion air from the ambient atmosphere into the combustion chamber.

16. A rotary boiler-combustor as claimed in claim **15** wherein conduit means is provided connecting from at least one of the confronting sealing ring portions to the combustion zone for conducting to the latter inwardly leaking ambient air and outwardly leaking combustion gases thereby supplying air for combustion to said zone and recirculating thereto combustion exhaust gases to reduce formation of pollutants and prevent exhaust gas leakage.

17. A rotary boiler-combustor as claimed in claim **1** wherein the boiler liquid pre-heater comprises a plurality of radially spaced concentric sections each comprising a plurality of axially spaced annular fins having heat exchange tubes extending longitudinally therethrough, the connections are provided between said concentric sections so that flow of condensate through the tubes of adjacent sections is in opposite directions providing counterflow heat exchange with the combustion gases.

18. A rotary boiler-combustor as claimed in claim **1,** having an expander mounted coaxially with the housing for extracting work from the pressure vapor generated in the boiler and including a coaxial driving member rotatably driven thereby at a second predetermined speed, and means is provided for conducting pressure vapor from said boiler to said expander to drive said driving member.

19. A rotary boiler-combustor as claimed in claim **18,** having drive means connected between the driving member and the rotary housing-boiler unit operable to rotationally drive said unit at said one predetermined speed.

20. A rotary boiler-combustor as claimed in claim **19** wherein the drive means connected between the driving member and the housing-boiler unit comprises an occluded fixed-ratio gear train mounted coaxially within the housing, and there is means cooperable with said gear train opposing the reaction torque generated thereby so that the full power output of the expander is transmitted directly to the rotary housing-boiler unit.

21. A rotary boiler-combustor as claimed in claim **4** wherein the stationary annular partition defining the combustion zone comprises a plenum chamber for supplying secondary air to said combustion zone.

22. A rotary boiler-combustor as claimed in claim **21** wherein the secondary combustion air plenum chamber is defined by inner and outer radially spaced concentric plate portions and said inner plate portion is provided with apertures for discharging secondary air from the plenum chamber to the combustion zone.

23. A rotary boiler-combustor as claimed in claim **21** having a condenser for the vapor generated in the boiler mounted coaxially adjacent the housing and rotatable with said housing-boiler unit, and means for delivering said vapor to the condenser and for returning condensate therefrom through the preheater to the boiler.

24. A rotary boiler-combustor as claimed in claim **23** wherein the condenser comprises a plurality of annular axially spaced radial fins having a plurality of heat exchange tubes extending longitudinally therethrough.

25. A rotary boiler-combustor as claimed in claim **24** wherein the condenser fins have a predetermined inner and outer radii ratio and the axial spacing between the adjacent condenser fins is correlated to the speed of rotation of the housing-boiler unit and the viscous properties of the condenser cooling fluid to have a Taylor number operable at said radii ratio to convey and accelerate said cooling fluid by viscosity shear forces spirally outward between said fins to the velocity providing optimum heat exchange between the condenser cooling fluid and the vapor in the condenser heat exchange tubes.

26. A rotary boiler-combustor as claimed in claim **25** wherein pre-heater fins have a predetermined inner and outer radii ratio and the axial spacing of the annular fins of the pre-heater is correlated to the speed of rotation of the housing-boiler unit and the viscous properties of the combustion gases to have a Taylor number operable at said radii ratio to convey and accelerate said combustion gases by viscosity shear forces spirally outward between said fins to the surrounding combustion gas exhaust chamber substantially at the velocity providing optimum heat exchange between said combustion gases and the boiler liquid in the heat exchange tubes of the pre-heater.

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UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,850,147 Dated November 26, 1974

Inventor(s) William A. Doerner

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Col. 3, line 9 "mode" should be --made--.

line 11; "an" should be --and--.

line 38; "p" has been omitted in the word --periphery--.

Col. 4, line 63; "rotation" should be --rotating--.

Col. 6, line 27; "the" should read --be--, first occurrence.

line 30; "diamater" should be --diameter--.

Col. 8, line 16; "predominent" should be --predominant--.

line 51; "69" should be --79--.

Col. 9, line 11; "contrifugal" should be --centrifugal--.

line 46; "roller" should be --boiler--.

Col. 11, line 61; "hear" should be --gear--.

Col. 12, line 33; "one" should be --zone--.

FORM PO-1050 (10-69)

USCOMM-DC 60376-P69

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CERTIFICATE OF CORRECTION

Patent No. 3,850,147 Dated November 26, 1974

Inventor(s) William A. Doerner -Page 2-

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Col. 13, line 2; "tubine" should be --turbine--.

line 7; "316,851, filed Jan. 2, 1973" should be --386,630 filed August 8, 1973--.

line 34; "adjustment" should be --adjacent--.

line 52; "Fig. 4" should be --Fig. 14--.

Col. 14, line 36; "combination" should be --combustion--.

Col. 15, In claim 4, first line, "as claimed in claim 1" should be --as claimed in claim 2--.

Col. 16, line 36; "wherein" should be --whereby--.

Signed and sealed this 4th day of March 1975.

(SEAL)
Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents
and Trademarks