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Schuman

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[45] **Aug. 6, 1974**

[54] **OSCILLATING BELLOWS**

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[52] **U.S. Cl.**........................ **356/85,** 60/517, 60/520, 250/343, 356/51, 356/97, 417/207

[51] **Int. Cl.**.. **G01j 3/30**

[58] **Field of Search**........ 356/51, 85, 96, 97; 60/24, 60/25, 517, 520; 417/339, 340, 342, 328, 379, 209, 207; 250/343

[56] **References Cited**

UNITED STATES PATENTS

3,516,745	6/1970	Schuman	356/85

Primary Examiner—Vincent P. McGraw

Attorney, Agent, or Firm—Lowe, King and Price

[57] **ABSTRACT**

One or more bellows are driven in an oscillatory manner in response to a mass of compressible fluid that is cyclically heated and cooled. The fluid is heated in a thermal lag heating chamber in fluid flow relationship with the bellows which cools the fluid. Cooling of the bellows, and therefore the fluid within the bellows, is augmented by fans blowing cool air over the folds of the bellows. An optical chamber for analyzing gas being pumped by the bellows is provided.

91 Claims, 4 Drawing Figures

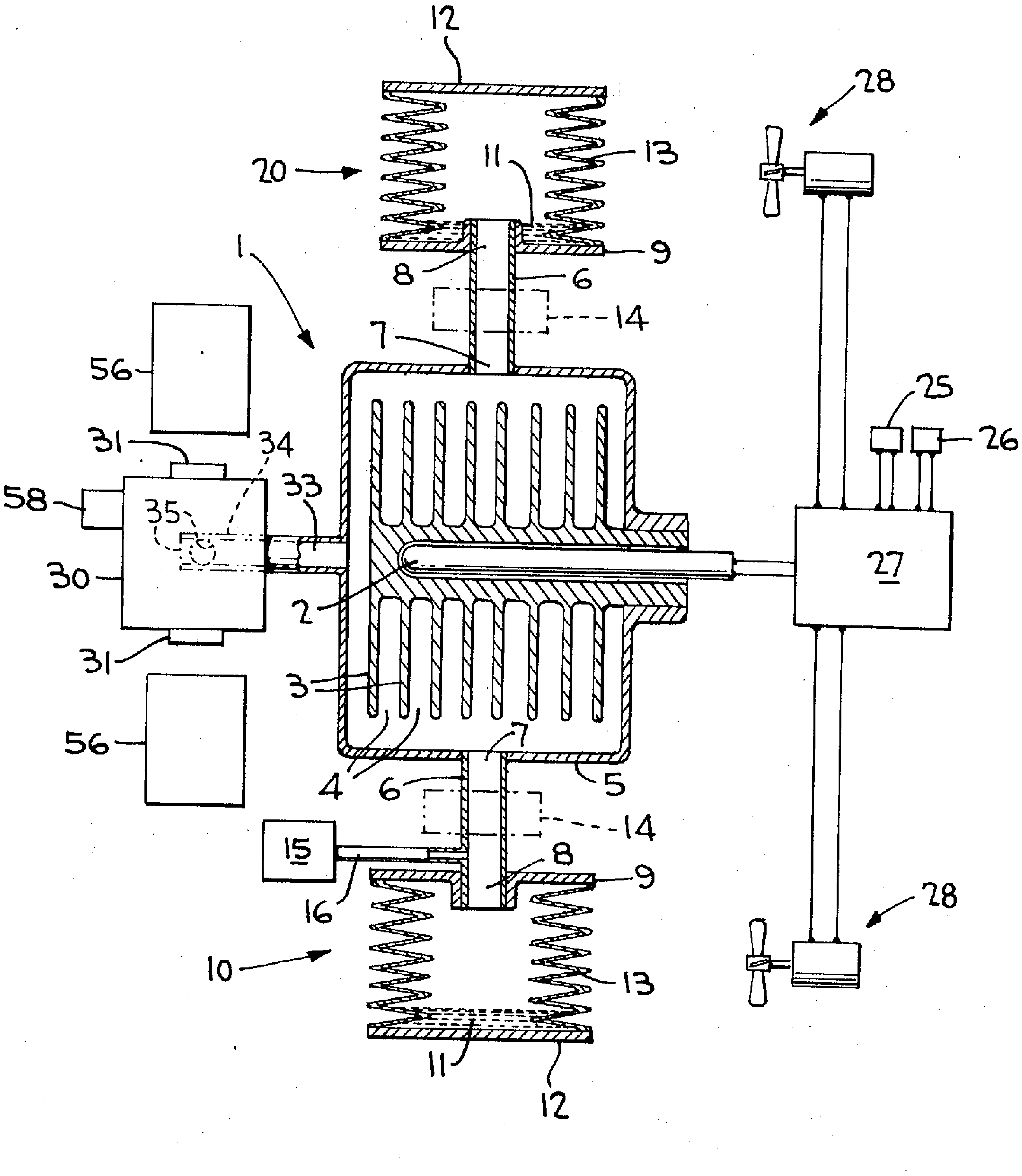

FIG. 1

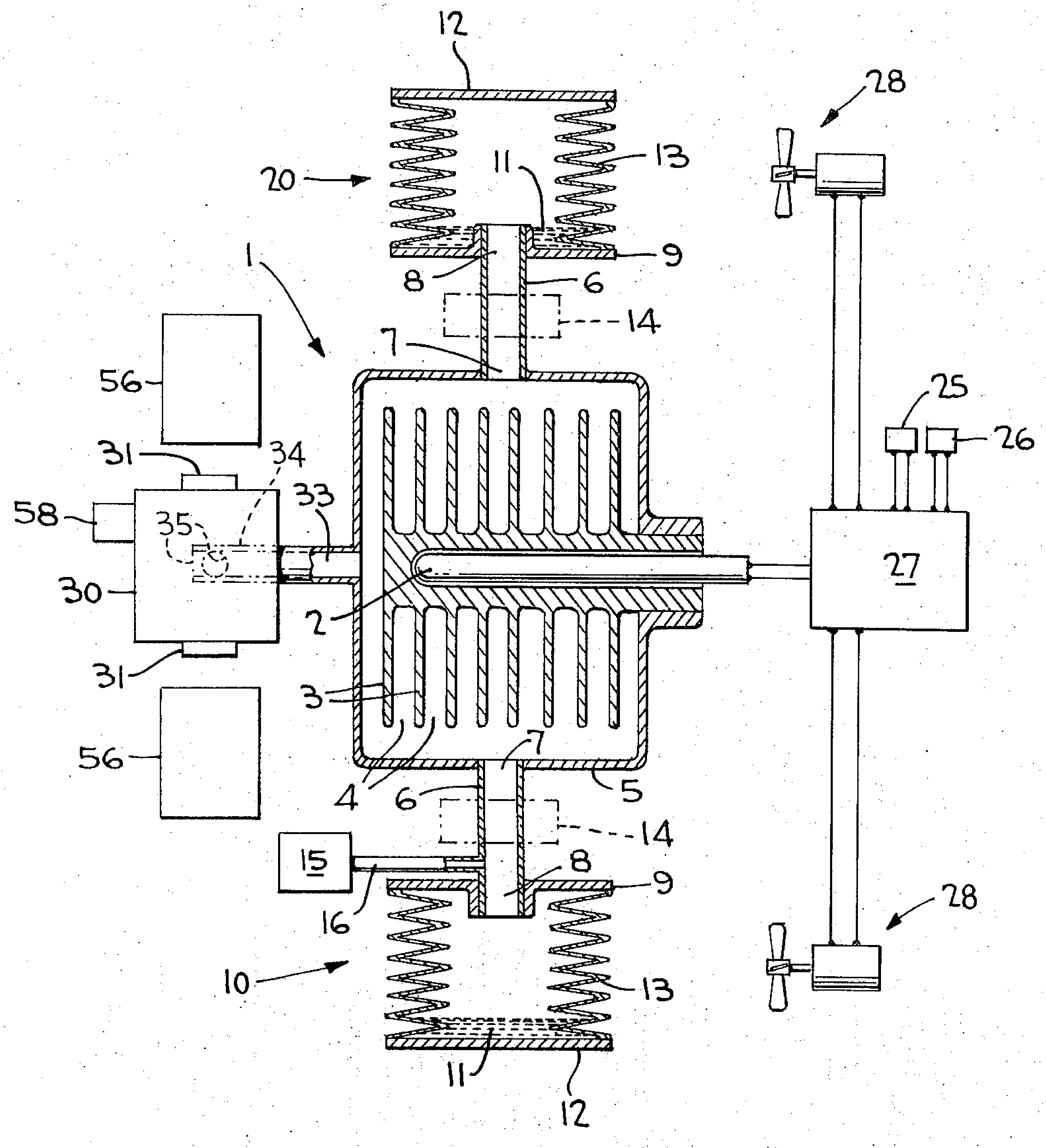
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FIG. 2

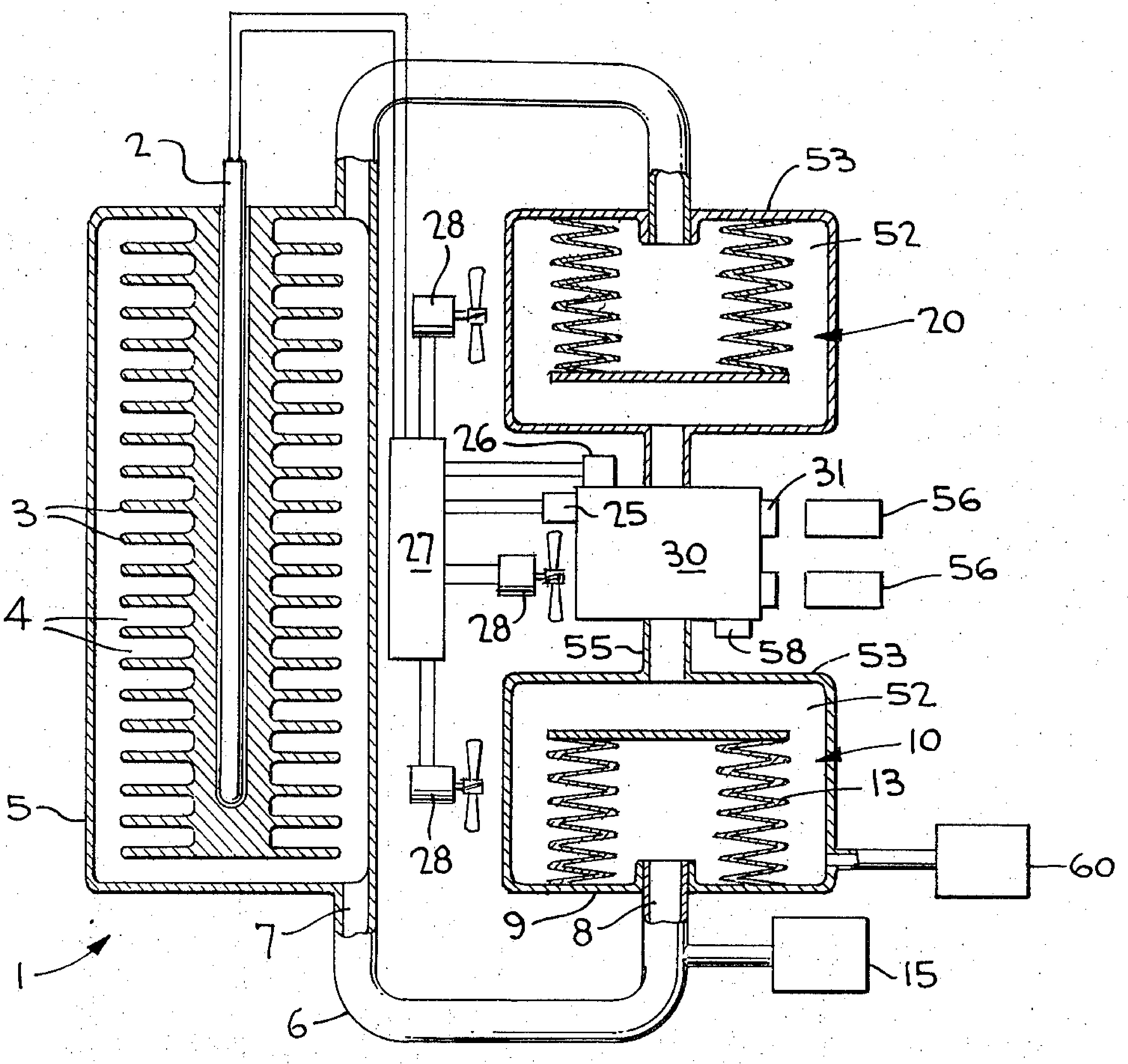
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FIG. 3

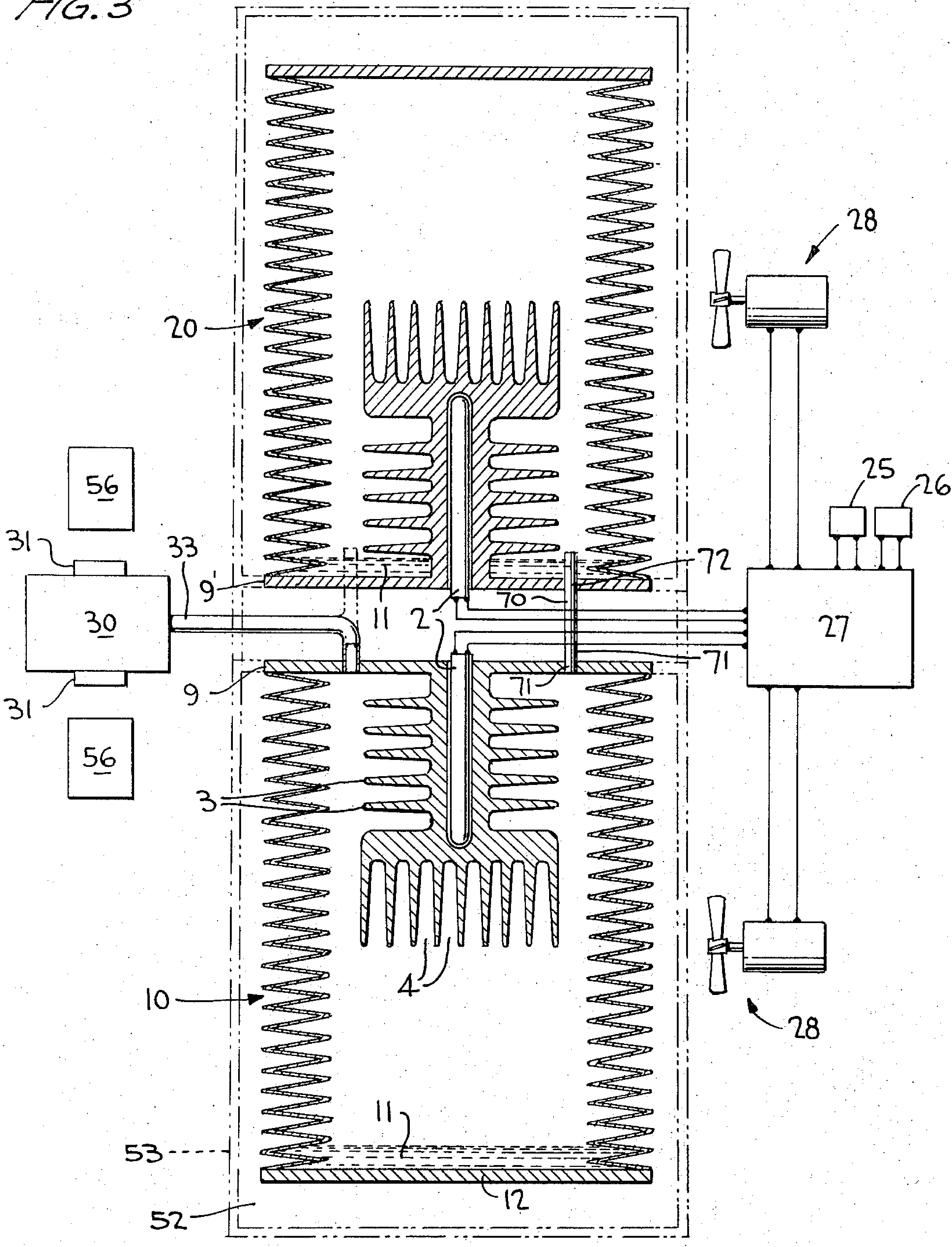
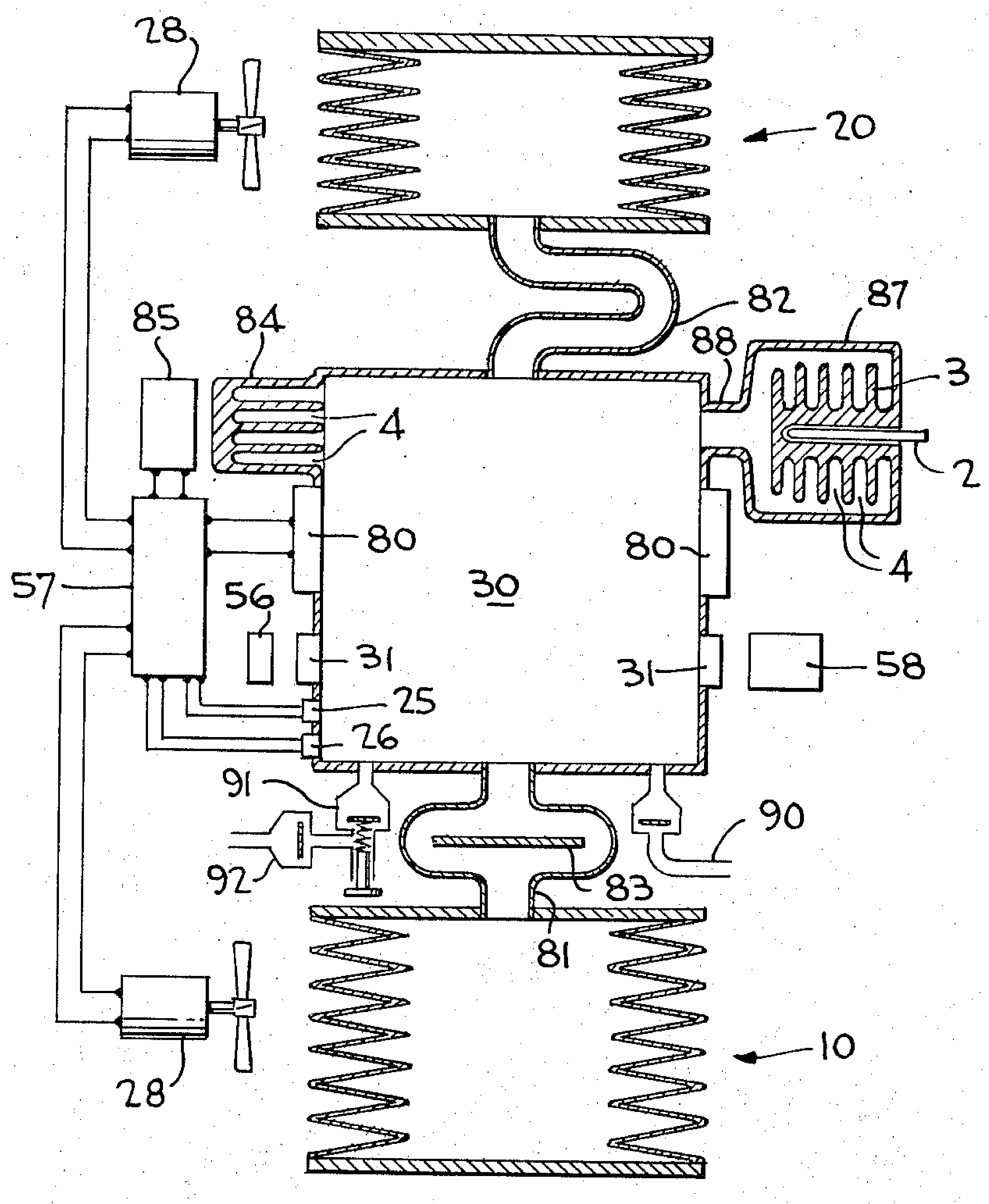


FIG. 4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OSCILLATING BELLOWS

FIELD OF INVENTION

The present invention relates generally to thermally operated oscillatory devices and, more particularly, to a thermally driven oscillating bellows.

BACKGROUND OF THE INVENTION

Presently available oscillating bellows are usually activated by a motor through a mechanical drive mechanism. The drive mechanism results in wear and vibration, as well as electrical and audible noises, all of which are generally undesirable and increase as a function of the bellows oscillation frequency. Further, the mechanical drive requires a number of moving parts, so that it is relatively complex and subject to failure. In addition, due to the fixed stroke of the drive mechanism, the bellows compression ratio is generally fixed which, in certain instances, is not desirable.

Oscillating bellows have found considerable use in pumping different types of compressible fluids. For example, they are widely employed for pumping fluids that cannot be contaminated by the pumping mechanism, since the fluid is in contact only with the bellows, valves and tubing and is not subject to possible contact with foreign matter such as lubricants and wear particles that are in other types of pumps.

BRIEF DESCRIPTION OF THE INVENTION

In accordance with the present invention, one or more bellows are driven in an oscillatory manner in response to a mass of compressible fluid that is cyclically heated and cooled. The fluid is preferably heated in a thermal lag heating chamber in fluid flow relationship with the bellows. The fluid is cooled while in the bellows, which function as variable volume, thermal lag cooling chambers. As described in my patent **3,489,335** and in my copending patent application entitled "Oscillating Piston Apparatus", Ser. No. 227,514, filed Feb. 18, 1972, a thermal lag chamber has one or more passageways having sufficient width and thermal time constant for relatively continuous heating or cooling of fluid forced into the passageways. Gas at one temperature enters the thermal lag chamber, resides therein, and escapes from the chamber at a significantly later time from its entry and at a different temperature. If the thermal lag chamber includes a heater, the escaping gas has a higher temperature than the inlet gas. If the thermal lag chamber includes a cooling means, such as cooling fins or cool folds of a bellows, the escaping gas has a lower temperature than the inlet gas.

In the present invention, compressible fluid is compressed into the thermal lag heating chamber by the oscillating bellows as the bellows is contracting. While the fluid is resident in the thermal lag heating chamber, it is heated by the thermal lag chamber passageways. Spring effects of the bellows folds and of the trapped compressed fluid combine with the increasing gas pressure due to gas heating to overcome the inertia of the contracting bellows and reverse its direction. The fluid reaches a maximum temperature and pressure after the oscillatory bellows has begun to expand due to continuous heating of the fluid in the chamber, and the fluid expands out of the thermal lag heating chamber into the bellows to assist expansion of the bellows. Expanding fluid moving into the expanding bellows is subsequently cooled by the opening bellows folds, which act as thermal lag cooling surfaces. To augment the cooling effect of the opened bellows folds, cool air may be blown across the folds. The fluid being cooled in the bellows assists in contraction of the bellows since the fluid reaches a minimum temperature and pressure after the oscillating bellows has begun to contract. The instantaneous compression ratio may be defined as the ratio of the maximum system volume to the instantaneous system volume. It has been found that the phase lags of the temperature and pressure variations with respect to the instantaneous compression ratio result in a higher average pressure while system volume is increasing than while system volume is decreasing, so that the thermal lag heating and cooling is more than sufficient to overcome spring and viscous losses, thereby enabling the device to perform useful work.

One particularly advantageous application of the invention is a pump for sampling a gaseous mixture and periodically compressing the mixture in a reflective optical chamber which includes means for detecting the periodic spectral radiant emission or absorption by the mixture, whereby the concentration of various constituents of the mixture can be monitored. Heat from the thermal lag heater vaporizes liquids in the mixture, to avoid condensation in the optical chamber, to improve sensitivity and accuracy of the monitoring device. For gases that emit infrared radiation, sensitivity is, in general, also increased as a result of the increase in periodic spectral infrared emission resulting from the heat absorbed by the gas.

While the device is particularly useful as a pump in combination with a spectrometric analyzer of a gas, it can be employed in many applications where it is desired to drive or pump a compressible or non-compressible fluid in a periodic manner, or for applications where a bellows may be employed as a mechanical vibrator, shaker, or as a means for driving another bellows. Except for valves which may be used for pumping or sampling, the device includes as its only moving parts, the oscillating bellows, and generally this facilitates a significant reduction in problems of the prior art, relating to wear, vibration, complexity and noise. A further feature of the invention is that the frequency and amplitude of bellows oscillation can be controlled in a facile manner merely by controlling a heater for the thermal lag heating chamber and/or the amount of cooling for the bellows. In some applications, such as infrared emission or radiant absorption gas analysis, the heat and/or radiance given off by the heating chamber are also useful. By arranging bellows in pairs, forces can be cancelled and vibration of the device substantially eliminated.

It is, accordingly, an object of the present invention to provide a new and improved drive system for an oscillating bellows.

Another object of the invention is to provide a new and improved thermally driven pump.

Another object of the invention is to provide a new and improved device for oscillating a bellows, wherein the need for a drive source having moving parts is obviated.

A further object of the invention is to provide a new and improved oscillating bellows having a drive mechanism that is simple, quiet, has very low wear and vibration, and does not produce electrical or audible noises.

A further object of the invention is to provide a new and improved drive mechanism for an oscillating bellows, wherein the frequency, amplitude and/or means position of the bellows can be controlled.

Yet another object of the invention is to provide a new and improved thermally driven oscillating pump particularly adapted for periodically driving hot or cool gaseous mixtures into a periodic emission or absorption spectrometric gas analyzing device.

Yet another object of the invention is to provide a new and improved simply constructed, sensitive, spectrometric gas analyzing device wherein a gas sample being analyzed is heated, cooled and pumped by the same device, to provide periodic or modulated spectral radiant emission and/or absorption by the gas, without causing condensation of the gas in an optical chamber.

The above and still further objects, features and advantages of the present invention will become apparent upon consideration of the following detailed description of several specific embodiments thereof, especially when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a schematic diagram of one embodiment of the present invention wherein a thermal lag heater is located between a pair of thermally driven bellows and is in direct communication with an optical chamber;

FIG. 2 is a modification of the system of FIG. 1, wherein the optical chamber is in direct communication with the outside of a pair of bellows;

FIG. 3 is a modification of the system of FIG. 1, wherein a thermal lag heater is positioned within each of a pair of oscillating bellows, and an optical chamber is responsive to gases within one of the bellows; and

FIG. 4 is a modification of the system of FIG. 1, wherein gases from thermally driven bellows and three alternative thermal lag heating chambers are all in fluid flow relationship with an optical chamber.

DETAILED DESCRIPTION OF THE DRAWING

Reference is now made to FIG. 1 of the drawings wherein there is illustrated a thermal lag heating chamber **1** providing heat for sustaining oscillation of thermally driven oscillating bellows **10.** Bellows **10** has a relatively high Q (greater than one) so that the energy which the bellows is capable of storing during each cycle is greater than the energy which it will dissipate during each cycle. Bellows **10** also preferably has good heat transfer properties and is capable of handling hot gases; one preferred material for bellows **10** is a metal, such as steel. Thermal lag heating chamber **1** comprises a housing **5**, which normally would be thermally insulated externally, and separated heating fins **3** forming thermal lag passageways **4** along the separations. An electrically activated, resistance heater plug **2** supplies heat to the heating fins **3**, independently of the instantaneous position of the bellows and is preferably continuously energized. Conduit **6** provides a fluid flow passageway between port **7** in thermal lag housing **5** and port **8** in fixedly mounted plate **9** that carries oscillating metal bellows **10.**

Except for ports leading to optical chamber **30** and optional bellows **20,** chambers **1** and **10** form a substantially closed chamber containing compressible fluid. The compressible fluid may be completely gaseous or it may be a mixture of gas and vaporizable liquid, illustrated in a rest condition on the bottom of bellows **10** by reference numeral **11.**

While bellows **10** is contracting it forces cool fluid at low pressure through conduit **6** into thermal lag heating chamber **1,** wherein the fluid is continuously heated and expands at higher pressure back into the bellows while the bellows is expanding. Bellows folds **13** provide thermal lag cooling passageways which open and cool the fluid drawn from chamber **1** into the exposed surface area of the bellows folds and lower the internal temperature and pressure of this fluid during subsequent contraction of bellows **10.** The variable exposure of the thermal lag passageways formed by the bellows folds is the primary means to reduce the pressure of the fluid in the chamber as the bellows volume is decreasing. Thus bellows **10** acts as a variable volume cooling chamber, as well as a chamber providing a variable exposure of a cool surface. Thereby, thermal lag heating and cooling provide sufficient energy during the cycle to sustain oscillation of bellows **10** and overcome losses due, inter alia, to spring losses of bellows folds **13,** frictional losses, and any work done by the device.

An optional thermal regenerator **14,** which may not be necessary, may be provided in conduit **6** between ports **7** and **8.** Regenerator **14** stores and releases thermal energy during the oscillating cycle of bellows **10.** The stored and released energy may be useful under certain conditions to increase the amplitude of pressure variations during the cycle. Regenerator **14,** which may be a mesh of thin wire segments establishing a positive temperature gradient in a direction from bellows **10** to thermal lag heater **1,** is not necessary but may be included to modify performance. To a certain extent the bellows folds function as regenerators.

Starter **15,** which may comprise a piston and cylinder, provides a pneumatic starting impulse to the device via conduit **16** which leads to conduit **6.** Starter **15** could be manually or solenoid operated. Other means, such as mechanical or magnetic means, for providing an impulse to plate **12** of bellows **10** can also be used to start the oscillation cycle.

Optional bellows **20** is similar to bellows **10** but is connected via a conduit in fluid flow relationship to the opposite side of housing **5.** Bellows **20** oscillates in synchronism with bellows **10** in response to the heated fluid escaping from chamber **1** so that both bellows are simultaneously moving away from and toward housing **5.** Bellows **20** can be used to cancel vibrational effects of bellows **10** and to do additional work. Any practical number of synchronized bellows can be thus connected to thermal lag heating chamber **1** or, alternatively, to a common conduit leading to chamber **1.** Thus, the remote end plates of all the bellows tend to move away from chamber **1** in phase, then stop and accelerate toward chamber **1** in phase. Also, separate thermally driven bellows devices, each with their own thermal lag heating chamber and bellows, may be synchronized by suitably connecting the thermal lag heating chambers together by conduits.

Any two of the following three bellows oscillation parameters, frequency, amplitude, and means position, can be controlled by monitoring the temperature and/or pressure variation within the bellows or at a load driven by the bellows and adjusting the rate of fluid heating and cooling. Cooling of bellows **10** and **20** in a controlled manner is performed with fans **28** that are positioned to circulate cool air at controlled flow rates into the folds of the bellows. Temperature and pressure probes **25** and **26** are respectively located outside of bellows **10** and **20** to sense temperature and pressure variations of a fluid pressurized by the oscillating bellows. In the alternative, probes **25** and **26** can be positioned within the substantially sealed confines of the device and sense temperature and pressure variations of the fluid resident therein. Signals derived from probe **25** or **26** are fed to control network **27** which, if desired, can be used to control the temperature of heater **2** and the speed of fans **28.** Cooling fans **28** augment the cooling normally resulting from the periodic flexing of the folds of oscillating bellows **10** and **20** and are useful for controlling the oscillation. As an example of control, by simultaneously increasing the heating and cooling effects of heater plug **2** and fans **28** the amplitude of bellows oscillation can be increased without major change in average fluid temperature or frequency. By varying the relative amount of heating and cooling, frequency can be varied without major change in amplitude.

The thermally driven bellows of FIG. **1** can be used to modulate the pressure of a substantially infinite gas volume in an enclosure surrounding the bellows, as well as to drive other types of loads. For example, end plate **12** of bellows **10** could abut against and oscillate one end plate of another bellows (not shown) of a bellows pump, which, in turn, samples a gaseous mixture and modulates the pressure of the mixture in a radiant emission or absorption optical chamber for analysis of the sample. Although the working fluid of such a device is isolated from the gas analyzer, heat transmitted through the abutting end plates of the two bellows is transferred to the analyzed mixture each cycle. By heating the mixture each cycle rather than heating the mixture before it enters the pump and optical chamber, peak gas temperature is reduced for a given gas analysis sensitivity. Thereby, the probabilities of thermal decomposition and chemical reaction of the sample are reduced. The material and design of the bellows plates can be chosen to provide the proper amount of heat to the sample being analyzed.

Another load that can be driven is a gas analyzer including fixed volume, reflective optical chamber **30** that is connected in fluid flow relation to heating chamber **1** by tube **33.** Operation of the bellows device produces a periodic concentration variation of hot gas within chamber **30,** thereby producing periodic spectral radiant emission and absorption by the gas sample, i.e., the pressure of gas in chamber **30** is modulated. If the gas in chamber **30** is a known gas, gas in chamber **30** can be used as a known periodic source of spectral emission and/or absorption, according to principles and techniques known to those skilled in the field of infrared and ultra-violet gas analysis. By adding valves **90, 91, 92,** as illustrated in FIG. **4,** an unknown sample can be drawn into chamber **30** and analyzed by virtue of the periodic spectral emission and/or absorption by the unknown sample induced by the periodic modulation of its pressure, concentration, and temperature.

The periodic emission and/or absorption of the gas in chamber **30** is monitored by providing the chamber with one or more windows **31** transparent to the wavelengths of interest. Radiation propagated through each

of windows **31** is directed to a separate spectrometric radiance analyzer **56** that enables correlations to be made between spectral energy at various wavelengths to qualitatively and quantitatively identify gases in the mixture.

If periodic radiant absorption of a gas is monitored, a radiant source **58** that emits either a substantially non-varying or modulated radiant beam into optical chamber **30** is generally required to augment the intensity of radiant energy in chamber **30,** and thus the sensitivity of the analyzer. In this instance, analyzer **56** responds to the energy passed through the periodically modulated gas and includes suitable processing devices for performing amplification, filtering and synchronous detection. The processing devices feed suitable output devices, e.g., recorders and/or displays; the processing devices are provided in radiance analyzer **56.** For qualitative and quantitative analyses of the gas mixture, it is usually necessary to monitor and control the periodic variation in temperature and/or pressure of the gas being analyzed. To this end, temperature and/or pressure probes may be located in optical chamber **30.** Signals from the probes would be coupled to analyzer **56,** to facilitate signal processing and thence to control device **27** so that heating and cooling of the gas can be controlled. If emission is monitored, there is no need for source **58,** as the varying concentration of hot gas in chamber **30** causes a variation in spectral radiant emission in chamber **30** characteristic of the gaseous constituent.

Oscillatory gas flow in chamber **30** may result in thermal cycling of the internal wall surface of chamber **30** and any coating of material on this surface. Thermal cycling of the surface results in periodic radiant emission, primarily in the infrared, by the surface material. Although the component of the wall emission signal which is 90° out of phase with the gas emission or absorption signals may be useful for calibration and for reducing output drift, as described in my U.S. Pat. No. 3,516,745, it is possible to reduce drift to some extent merely by reducing the thermal transfer between the gas and the wall surface, and thereby reduce the amplitude of thermal cycling and the amplitude of the resulting wall surface emission signal.

For this purpose, tube **33** is provided with an optional extension **34** having ports **35** near the center of optical chamber **30.** Gas flow parallel to the internal surfaces of chamber **30** is thereby reduced, as is the thermal transfer rate, and the gas flow into and out of chamber **30** via ports **35** is primarily radial. This reduces the periodic wall emission signal due to thermal cycling of the surface material. The decrease in thermal transfer also decreases the load on the oscillating bellows device, so that the amplitude of pressure variation in chamber **30,** and therefore sensitivity of the gas analyzer, are increased.

If desired, optical chamber **30** can be made nearly spherical to further reduce tangential gas flow so that the flow becomes substantially radial, thermal transfer is reduced further and made more uniform, and wall emission and thermal losses greatly reduced.

A near spherical shape, or other shape having a high volume to surface area ratio, is also desirable for a random path optical chamber since surface losses by radiant absorption are reduced and sensitivity of the gas analyzer thereby increased. A perfectly spherical shape may not be desirable, however, in the case of a random path optical chamber, since rays travelling in a plane passing through the center of the sphere will be in a stable mode of reflection and will seldom exit through an optical window **31** for measurement.

The devices illustrated in FIGS. **2–4** generally include heating and cooling control and gas monitoring devices, as well as a starter, similar to those of FIG. **1**, although these devices are not hereafter discussed unless they differ materially from the corresponding devices of FIG. **1**.

In FIG. **2**, there is disclosed a thermally driven bellows device that is generally similar to the device of FIG. **1**. In FIG. **2**, however, bellows **10** and **20** are enclosed in separate chambers **52** having sealed housings **53**. Housings **53** are positioned on opposite sides of a centrally located load that is to be periodically pressurized; such a load is an optical chamber **30**. The walls of housings **53** closest to chamber **30** include ports connected to conduits **55** that are connected to opposite walls of chamber **30**, whereby there are provided oppositely directed fluid flow paths from housings **53** to chamber **30**. Bellows **10** and **20** are positioned in housings **53** so that the free oscillating ends thereof are facing the chamber ports leading to conduits **55** and the other ends thereof are fixed to the walls of housings **53** opposite from the walls carrying the ports leading to conduits **55**. The volumes enclosed by the interiors of bellows **10** and **20** are connected in fluid flow relationship to opposite ends of thermal lag heater **1** by conduits **6**. Because gas in chamber **30** is sealed off from the thermal lag heater **1**, this gas never reaches a very high temperature, so that the heater can be operated at a higher temperature and greater efficiency, relative to the device of FIG. **1**, without thermally decomposing gas in chamber **30**. The natural cooling of the walls of chambers **30** and **52** augmented by cooling fans **28** further reduce the maximum temperature of gas in chamber **30** to avoid decomposition of unstable gases and to help sustain bellows oscillation.

In FIG. **2**, there is a thermal lag effect on the outside, as well as inside, of bellows **10** and **20**. Thus, when bellows **10** and **20** simultaneously expand, gas in chambers **52** is forced toward and within the opening folds of bellows **10** and **20**, which are warmer than the gas and act as variably exposed, variable volume, thermal lag heating surfaces. Maximum temperature and pressure of the gas in chambers **52** are not reached until after the bellows have begun to contract, thereby assisting mechanical and pneumatic spring forces in contracting the bellows. Heated gas leaving the contracting bellows folds is cooled by the walls of chambers **52** and **30** by virtue of natural external cooling of these walls augmented by fans **28**, tending to reduce the gas pressure by thermal lag cooling to assist subsequent expansion of the bellows. The flexing folds **13** of bellows **10** and **20** serve as variable volume, variably exposed surface area, heating chambers on their outside surfaces while the inside surfaces thereof simultaneously function as variable volume cooling chambers. Thus, the bellows **10** and **20** of FIG. **2** are driven from both ends rather than single-endedly as in FIG. **1**. Although the double ended effect is theoretically present in FIG. **1**, the large size of the outer enclosure generally makes the outside driving force insignificant.

In FIG. **2** an alternate or additional starter **60** is pneumatically connected to chamber **52**, as well as starter **15** that is connected to conduit **6**.

The embodiment of FIG. **3** is quite similar to those of FIGS. **1** and **2** but illustrates a compact design wherein the thermal lag heater is located within the bellows. Bellows **20** is pneumatically connected to bellows **10** by means of tube **70** for synchronized bellows oscillation. Tube **70** conducts fluid between port **71** in fixed plate **9** of bellows **10** near heating fins **3** through port **72** in fixed plate **9'** in a corresponding location of bellows **20**. If bellows **10** contains some liquid, as indicated by the dotted line **11**, tube **70** may extend to a point slightly above liquid layer **11** in bellows **20**, as shown. Alternatively, bellows **10** and **20** may be operated in a closed chamber **52** or in an essentially infinite enclosure.

Another embodiment is shown in FIG. **4** wherein heating elements **80** heat the walls of optical chamber **30** which is connected by conduits **81** and **82** to bellows **10** and **20**. Thereby, optical chamber **30** serves as thermal lag heating chamber for oscillating bellows **10** and **20**. Optical stop **83**, an opaque plate, in a widened portion of conduit **81** optically shields chamber **30** from the periodic radiance emitted and reflected by bellows **10** as a result of its changing geometry, temperature, pressure, and gas flow. An alternate optical stop is illustrated as a turn or bend in conduit **82**. Both optical stops attenuate the periodic radiance within the conduits by direct radiation absorption and by inducing multiple reflections.

Cool gas flowing into chamber **30** from bellows **10** and **20** is continuously heated while in the chamber by the chamber walls, and the resulting temperature increase of the gas in chamber **30** tends to increase the intensity of spectral emission monitored by detector **56** during this portion of the cycle. Detector **56** may also monitor radiant emission by the walls of chamber **30** as modulated by spectrally absorbing gas flowing into and out of chamber **30**.

One or more of alternative thermal lag heating chambers **84** or **87** can be provided around optical chamber **30**, i.e., instead of heating the optical chamber in which case primary means for periodically heating gas circulating through optical chamber **30** comprises heating chamber means external to the optical chamber. Chamber **84**, heated by heating element **85**, continuously heats cool gas flowing from chamber **30** into heated passageways **4** of chamber **84**. Heated gas flowing into bellows **10** and **20** from optical chamber **30** is cooled by the bellows folds, which thereby function as primary cooling means for the periodic cooling of gas circulating through the optical chamber. Thus the use of heating chamber **84** in conjunction with bellows **10** and/or **20** results in an alternate and periodic replacement of hot gas with cool gas and cool gas with hot gas in chamber **30**. Thus, there is an alternate recirculation of fluid between the optical chamber **30** and the cooling chamber formed by bellows **10** and/or **20**. Correspondingly, there is a periodic recirculation of fluid between optical chamber **30** and the external heating chamber means formed by at least one of chambers **84** or **87**. It is therefore evident that if the alternative thermal lag chamber means is employed, the alternate heating and cooling of fluid external to optical chamber **30** is the primary means for modulating the temperature and concentration of the fluid circulating through the optical chamber. Heating chamber **87** is quite similar to heating chamber **84** but has a neck **88** which shields optical chamber **30** from the radiant energy absorption by, and emission from, heated passageways **4**. However, heating chambers **87** and **84**, the heating elements **80**, and the walls of chamber **30** heated by the heating elements **80**, all serve to various degrees as sources of radiant emission, primarily in the infrared region of the spectrum. The varying concentration of gas in chamber **30** causes a periodic absorption of radiant emission from such sources as well as from optional radiant source **58** which, for example, may emit radiance in the ultra-violet and near infrared. This periodic absorption adds vectorially to the periodic gas emission, which depends primarily on the gas concentration and temperature (or the gas pressure and temperature) in chamber **30**, to produce a resultant periodic spectral radiant intensity variation in chamber **30.**

Valves **90, 91** and **92** provide flow of a gaseous sample through chamber **30.** Valve **90** is an intake check valve polarized to pass gas only into chamber **30.** Valve **91** is a check valve which is polarized similarly to valve **90** but is spring biased to allow a small, adjustable mass flow from chamber **30** to valve **92** at relatively low pressure differential. Pressure differential above a selected value automatically closes valve **91,** which thus acts as a flow limiter valve. Valve **92** is a check valve polarized to pass gas only from valve **91** to the outside or exhaust region.

Alternatively a known gas may be sealed into chamber **30** and bellows **10** and **20,** if the device is to be used as a periodic, known spectral source for gas analysis or other purposes.

Although the thermal lag heating chambers and bellows communicating with them in FIGS. **1** through **3** are illustrated as sealed with respect to the outside environment, they may communicate with the outside via a slow leakage port, filter, or valves. Thus the differential pressure between inside and outside may be established or controlled. This may be useful to vary or control performance. Such valves may also be useful for utilizing the internal pressure variations for sampling or pumping gases or other fluids.

While the source of heat is illustrated herein as electrical, any source of heat may be utilized. Correspondingly, the air cooling shown herein is only an illustrative example of cooling.

In the above embodiments, the width of the heated passageways **4** is generally chosen to be small enough for reasonable penetration by heat from the passageway walls of gas flowing into the passageways, but large enough to reduce fluid drag and to provide a reasonable thermal phase lag necessary for sustaining bellows oscillation at the operating frequency. Thus, the optimum passageway width for power or efficiency depends on the frequency of operation. The breadth and length of the passageways characteristically are each substantially greater than the passageway width in order to provide a compact and efficient heat transfer chamber providing adequate volume for admitting gas and adequate surface area for heating gas while keeping the average passageway length, and therefore fluid drag, to a minimum. The resulting heating chamber design is relatively compact and the passageway walls provide good paths for heat flow from the heat source to the passageway surfaces.

The thermal time constant of the thermal lag heating chamber, which is affected by the width, breadth, length, and smoothness of the passageways, is generally selected according to the desired frequency of bellows oscillation to provide a compromise between the degree of heating of gas flowing into and out of the passageways and the phase lag, or continuity, of heating of the flowing gas while within the passageways each cycle, both of which factors are important for providing adequate power and efficiency. An excessively large passageway width increases the phase lag but decreases the degree or amount of heating of a gas portion, while an excessively small passageway width increases the degree of heating while undesirably decreasing the thermal phase lag. Generally the width of a thermal lag passageway is substantially uniform throughout its length in order to produce a substantially uniform thermal time constant for heating or cooling gas in the passageway.

The bellows folds act as thermal lag cooling surfaces or passageways having a varying exposure to the hot gas, and a varying passageway width, volume, and, to a lesser extent, length. The bellows folds also have an average breadth and length, both of which are each substantially greater than the average width of the passageways which they form. Also, the portions of the bellows folds nearer to a particular chamber are more shielded from the external heating or cooling source than are the remote or most distant portions and thus act, to some extent as a regenerator for that particular chamber.

The heated walls of chamber **30** in FIG. **4** form a relatively wide heated passageway with very good thermal lag and very poor penetration into the gas in chamber **30** by the heat from the walls, and are thus an exception to the above principles. However, because chamber **30** simultaneously serves as a heating chamber and an optical chamber, or load, for the device, and because of the simplicity and different electrooptical characteristics of the device of FIG. **4,** it may have practical uses.

It should be understood that the concept of increasing radial flow and decreasing tangential flow of gas in a chamber which is nearly spherical or otherwise has a high volume to surface area ratio, as described in connection with chamber **30** of FIG. **1,** is applicable to all of the embodiments illustrated herein. This technique decreases thermal loss, wall surface radiant emission, and output drift, and increases gas analysis sensitivity.

While there have been described several specific embodiments of the invention, it will be clear that variations in the details of the embodiments specifically illustrated and described may be made without departing from the true spirit and scope of the invention as defined in the appended claims.

I claim:

1. An oscillating device comprising a chamber containing compressible fluid, an independent heat source for heating a portion of the chamber, a bellows, means for connecting the chamber and the bellows in a fluid flow relationship, and means, including the heating of fluid flowing into the chamber and the cooling of fluid flowing into the bellows, for sustaining oscillation of the bellows, wherein the variable exposure of thermal lag passageways formed by the bellows folds is the primary means for reducing the pressure of the fluid in the chamber as the bellows volume is decreasing.

2. The device of claim **1** wherein the means for cooling includes fan means for producing an external flow of cool fluid proximate to the bellows.

3. The device of claim **1** wherein the heated portion is shaped to form fluid passageway means.

4. The device of claim **3** wherein the heated passageway means includes at least one elongated passageway having an average length substantially greater than its average width.

5. The device of claim **3** wherein the heated passageway means includes at least one elongated passageway having an average breadth substantially greater than its average width.

6. The device of claim **3** wherein the heated passageway means includes at least one passageway having an average length and an average breadth which are each substantially greater than its average width.

7. The device of claim **3** wherein the heated passageway means includes at least one elongated passageway having a width which is substantially constant throughout its length.

8. The device of claim **1** further including regenerator means located between the heated portion and the bellows.

9. The device of claim **1** further including means for controlling the oscillation.

10. The device of claim **9** wherein the means for controlling includes means for varying the rate at which heat is supplied to the heated portion.

11. The device of claim **9** wherein the means for controlling includes means including a fan for varying the average temperature of the bellows.

12. The device of claim **9** wherein the means for controlling includes means for monitoring pressure variations resulting from oscillation of the bellows.

13. The device of claim **1** further including a second chamber connected in fluid flow relationship with the fluid containing chamber, whereby heated fluid flows into and out of the second chamber.

14. The device of claim **13** wherein the second chamber is an optical chamber containing one or more optical windows for transmitting spectral radiance variations derived at least in part from the heated fluid.

15. The device of claim **1** further including a second bellows connected in a fluid flow relationship with the chamber, whereby synchronous oscillation of the first and second bellows is obtained.

16. The device of claim **1** further including a starter pump for initiating the oscillation.

17. The device of claim **1** wherein the bellows is within a second chamber containing cool fluid, whereby the means for sustaining further includes the exposure of the cool fluid to the bellows folds when the bellows is expanded, wherein the bellows folds are heated on one side by fluid flowing from the heated portion and are cooled on the other side by cool fluid in the second chamber.

18. The device of claim **17** wherein a portion of the second chamber is shaped to form an optical chamber including means for enabling variations in spectral radiance, resulting at least in part from fluid flowing in and out of the optical chamber, to be monitored.

19. The device of claim **1** wherein the heated portion is within the bellows.

20. The device of claim **19** further including an oscillator comprising another chamber containing the compressible fluid, a heat source for heating a portion of the another chamber, another bellows, means for connecting the another chamber and the another bellows in a fluid flow relationship, and means, including the heating of fluid flowing into the another chamber and the cooling of fluid flowing into the another bellows, for sustaining oscillation of the another bellows, wherein the variable exposure of thermal lag passageways formed by the another bellows folds is the primary means for reducing the pressure of the fluid in the another chamber as the another bellows volume is decreasing, and means for connecting the device and oscillator in a fluid flow relationship for synchronized operation thereof.

21. The device of claim **1** further including a second chamber connected in fluid flow relationship with said device, whereby pressure variations are supplied to the second chamber.

22. The device of claim **21** wherein the second chamber is an optical chamber designed for monitoring variations of spectral radiance produced by the pressure variations.

23. The device of claim **1** further including valve means responsive to pressure variations in the bellows for pumping fluid.

24. The device of claim **1** wherein the chamber is shaped to form an optical chamber suitable for monitoring variations in spectral radiance resulting at least in part from pressure variations of fluid within the optical chamber.

25. The device of claim **1** further including an optical chamber located between the heated portion and the bellows, said optical chamber being suitable for monitoring variations in spectral radiance resulting at least in part from the oscillatory gas flow therein.

26. The device of claim **24** wherein the means for connecting includes optical stop means for attenuating radiation traversing the connecting means.

27. The device of claim **25** wherein the means for connecting includes optical stop means for attenuating radiation traversing the connecting means.

28. The device of claim **1** wherein the chamber is shaped to form an optical chamber suitable for monitoring variations in spectral radiance resulting at least in part from temperature variations of fluid within the optical chamber.

29. The device of claim **1** wherein the chamber is shaped to form an optical chamber suitable for monitoring variations in spectral radiance resulting at least in part from pressure and temperature variations of fluid within the optical chamber.

30. A spectrometric analyzer for enabling the presence of a constituent of a compressible fluid to be determined comprising a substantially fixed volume optical chamber, means for repeatedly forcing a hot mass of said fluid into the optical chamber and for withdrawing a hot mass of said fluid therefrom so that in response to the hot fluids being repeatedly forced into and withdrawn from the chamber there is derived a repeated variation in spectral radiance in the chamber, and means for detecting said variation.

31. The device of claim **30** wherein the means for repeatedly forcing includes a thermally driven oscillatory device.

32. The device of claim **30** wherein the means for repeatedly forcing includes a thermally driven oscillating bellows.

33. A spectrometric fluid analyzer for enabling the presence of a constituent of a fluid to be determined comprising an optical chamber, means for repeatedly forcing a cool mass of the fluid into the optical chamber, means for heating at least a portion of the cool fluid within the optical chamber, means for withdrawing a mass of the fluid from the optical chamber, whereby there is derived a variation in spectral radiance in the chamber in response to the fluid masses being forced into and withdrawn from the chamber and the cool fluid being heated within the chamber, and means for detecting said variation.

34. The device of claim **33** wherein the means for repeatedly forcing cool fluid includes a thermally driven oscillatory device.

35. The device of claim **33** wherein the means for repeatedly forcing cool fluid includes a thermally driven oscillating bellows.

36. The device of claim **33** wherein the chamber has a substantially fixed volume.

37. An oscillating device comprising a chamber maintained in a substantially closed condition during at least a portion of the oscillatory cycle, a compressible fluid in the chamber, a bellows forming a portion of the chamber and arranged so that expansion of the bellows tends to decrease the volume of the chamber, means for sustaining oscillation of the bellows, said sustaining means including means for heating the bellows to a temperature greater than chamber wall portions adjoining the bellows whereby: fluid is expelled from within folds of the bellows into the chamber while the bellows is contracting, and the expelled fluid is cooled by the adjoining chamber wall while the bellows is contracted and continues to be cooled as the bellows begins to expand, and fluid flows from the chamber into the folds of the bellows while the bellows is expanding, and the fluid in proximity with the bellows is heated by the bellows folds while the bellows is expanded and continues to be heated as the bellows begins to contract.

38. An oscillating apparatus comprising a chamber device having walls, a bellows device having walls in fluid flow relationship with the chamber device, means for sustaining oscillation of the bellows device, a compressible fluid within the chamber, said means for sustaining including means for heating walls of one of said devices and for cooling walls of the other device, whereby fluid flows from within folds of the bellows device to the chamber device while the bellows and folds are moving to a contracted state and fluid flows from the chamber device into the folds of the bellows device while the bellows folds are moving to an expanded state, the bellows folds and chamber device being thermal lag devices responsive to the means for heating and cooling and providing sufficient energy to maintain the bellows in oscillation so that the fluid flowing from the one device to the other device is cooled by the other device while the bellows folds are in one of said states and as the bellows folds begin to move toward the other state, and the fluid flowing from the other device to the one device is heated by the one device while the bellows folds are in the other state and as the bellows folds begin to move toward said one state.

39. A spectrometric fluid analyzer for monitoring the concentration of a constituent of a compressible fluid comprising an optical chamber, fluid recirculation means for alternately and substantially periodically replacing a substantial amount of cool fluid in the chamber with hot fluid and a substantial amount of the hot fluid in the chamber with cool fluid, whereby there are derived a substantially periodic spectral radiant emission by the fluid in the chamber and a substantially periodic spectral absorption of radiant energy in the chamber by the fluid in the chamber in response to its changing temperature and concentration, said periodic emission and said periodic absorption being substantially out of phase with each other and adding vectorially to produce a resultant, substantially periodic, spectral radiant intensity variation in the chamber, and means for monitoring said variation.

40. The analyzer of claim **39** wherein the optical chamber has a substantially constant volume.

41. The analyzer of claim **39** further including a radiant source emitting radiant energy into the chamber for augmenting the intensity of radiant energy in the chamber, whereby energy from the source is substantially periodically absorbed in response to the alternate and substantially periodic replacement of the cool and hot fluids.

42. The analyzer of claim **39** wherein the means for replacing includes a cooling chamber and a heating chamber each connected in fluid flow relationship with the optical chamber.

43. The analyzer of claim **39** wherein the means for replacing hot fluid with cool fluid includes a cooling chamber connected in fluid flow relationship with the optical chamber.

44. The analyzer of claim **43** further including fan means for cooling the cooling chamber.

45. The analyzer of claim **39** wherein the optical chamber is an internally reflective, substantially random path, optical chamber.

46. An electro-optical type fluid analyzer for analyzing a compressible fluid comprising an optical chamber having a highly reflective internal surface, means for alternately and substantially cyclically circulating cool and hot samples of the fluid through the chamber such that a substantial amount of the hot fluid in the chamber is swept from the chamber by cold fluid which replaces it and a substantial amount of the cold fluid in the chamber is swept from the chamber by hot fluid which replaces it, whereby there is derived a substantially cyclical variation in spectral radiance in the chamber in response to the alternate circulation, and means for detecting said variation.

47. The analyzer of claim **46** wherein the volume of the optical chamber is substantially constant.

48. The analyzer of claim **46** wherein the means for circulating includes a heating chamber connected in fluid flow relationship with the optical chamber.

49. The analyzer of claim **46** further including a radiant source for augmenting the intensity of radiance within the optical chamber to thereby augment the irradiation of the sample in the optical chamber.

50. The analyzer of claim **46** wherein the means for circulating includes a cooling chamber connected in fluid flow relationship with the optical chamber.

51. The analyzer of claim **46** wherein the means for detecting includes synchronous detection means.

52. The analyzer of claim **48** further including a radiant source emitting radiant energy into the optical chamber to increase the cyclical variation in spectral radiance.

53. The analyzer of claim **48** wherein fluid circulated through the optical chamber is alternately recirculated between the optical chamber and the heating chamber and between the optical chamber and a cooling chamber external to the optical chamber.

54. The analyzer of claim **46** wherein the optical chamber is a substantially random path optical chamber.

55. An electro-optical type analyzer of a compressible fluid comprising an optical chamber, a cooling chamber external to the optical chamber, means for connecting the cooling chamber and the optical chamber in a fluid flow relationship, means for alternately recirculating fluid between the optical chamber and the cooling chamber, whereby recirculating fluid flowing into the cooling chamber is cooled in the cooling chamber, means including alternate cooling of fluid circulating through the optical chamber for substantially cyclically modulating the temperature and concentration of the fluid circulating through the optical chamber, wherein the cooling of the fluid in the cooling chamber is the primary cooling means for the alternate cooling of fluid circulating through the optical chamber; whereby there is derived a substantially cyclical variation in apectral radiance in the optical chamber in response to the modulation of the fluid, and means for monitoring said variation.

56. The analyzer of claim **55** wherein the optical chamber is a substantially random path optical chamber.

57. The analyzer of claim **55** wherein the means for modulating the temperature and concentration of the fluid circulating through the optical chamber further includes means for alternately circulating hot fluid through the optical chamber.

58. The analyzer of claim **55** wherein the means for modulating the temperature of the fluid circulating through the optical chamber includes means for heating fluid.

59. The analyzer of claim **55** wherein the means for modulating includes a heating chamber external to the optical chamber, and means for connecting the heating chamber and the optical chamber in a fluid flow relationship.

60. The analyzer of claim **59** wherein the volume of the optical chamber is substantially constant during the cycle.

61. The analyzer of claim **55** wherein the internal surface area of the optical chamber is substantially constant.

62. The analyzer of claim **59** wherein the means for modulating further includes means for alternately recirculating fluid between the optical chamber and the heating chamber, whereby recirculating fluid flowing into the heating chamber is heated therein.

63. The analyzer of claim **62** wherein the heating and cooling of fluid in the heating and cooling chambers, respectively, constitute the primary heating and cooling means for the modulation of the fluid.

64. The analyzer of claim **55** further including a radiant source emitting electromagnetic energy into the optical chamber, said electromagnetic energy being absorbed by the fluid to augment the variation in apectral radiance.

65. The analyzer of claim **55** further including means for connecting the cooling chamber in fluid flow relation with the optical chamber throughout at least most of the cycle.

66. The analyzer of claim **55** further including means for connecting the cooling chamber in fluid flow relation with the optical chamber throughout substantially all of the cycle.

67. The analyzer of claim **55** wherein the alternate recirculation of hot and cool fluid through the optical chamber is the primary means for modulating the temperature and concentration of the fluid circulating through the optical chamber.

68. The analyzer of claim **55** including fan means for cooling the cooling chamber.

69. The analyzer of claim **59** wherein the cooling and heating chambers each communicate with the optical chamber throughout most of the cycle.

70. The analyzer of claim **62** wherein the cooling and heating chambers each communicate with the optical chamber throughout substantially all of the cycle.

71. The analyzer of claim **55** wherein the variation in spectral radiance is substantially periodic, and wherein the means for detecting said variation includes synchronous detection and filtering.

72. An electro-optical instrument for monitoring the concentration of a constituent of a compressible fluid comprising a substantially fixed volume optical chamber, a cooling chamber external to the optical chamber, means for connecting the cooling chamber and the optical chamber in a fluid flow relationship, means for alternately recirculating fluid between the optical chamber and the cooling chamber, whereby recirculating fluid circulating through the optical chamber and alternately into the cooling chamber is cooled in the cooling chamber, means including the alternate cooling of fluid circulating through the optical chamber for substantially cyclically modulating the temperature and concentration of the fluid circulating through the optical chamber; whereby there is derived a variation in spectral radiance in the optical chamber in response to the modulation of the fluid, and means for monitoring said variation.

73. The instrument of claim **72** wherein the means for modulating includes a heating chamber external to the optical chamber, and means for alternately recirculating fluid between the optical chamber and the heating chamber.

74. The instrument of claim **72** wherein the means for modulating includes a heating chamber and means for alternately circulating hot and cool fluid from the heating and cooling chambers into the optical chamber.

75. The instrument of claim **74** further including a radiant source emitting electromagnetic energy into the optical chamber.

76. The instrument of claim **73** wherein the heating chamber is in fluid flow communication with the optical chamber during at least most of the cycle.

77. The instrument of claim **74** further including means for connecting the heating and cooling chambers in fluid flow communication with the optical chamber during at least most of the cycle.

78. The instrument of claim **74** further including means for connecting the heating and cooling chambers in fluid flow communication with the optical chamber during substantially all of the cycle.

79. The instrument of claim **72** wherein the means for monitoring includes means for synchronously detecting the variation.

80. The instrument of claim **72** wherein the optical chamber is a substantially random path optical chamber.

81. The analyzer of claim **62** wherein the heating of fluid in the heating chamber constitutes the primary heating means for the modulation of the fluid.

82. The analyzer of claim **55** wherein the volume of the optical chamber is substantially constant.

83. An electro-optical type fluid analyzer for analyzing a compressible fluid comprising a substantially constant volume optical chamber, means for repeatedly: (1) during a first time interval, forcing a cool mass of the fluid into the chamber while withdrawing a mass of the fluid from the chamber, and (2) thereafter, during a second time interval, forcing a heated mass of the fluid into the chamber and withdrawing a mass of the fluid from the chamber, whereby there is derived a substantially cyclical variation in spectral radiance in the chamber in response to the repeated forcing of the fluid into and withdrawal of fluid from the chamber, said variation being characteristic of the fluid, and means for monitoring said variation.

84. The analyzer of claim **83** further including a radiant source emitting radiant energy into the chamber to be absorbed by the fluid, whereby said radiance variation is augmented.

85. The analyzer of claim **83** wherein the means for forcing heated fluid includes transfer of heat from a radiant source to the fluid.

86. The analyzer of claim **85** wherein the radiant source emits radiant energy into the chamber to be absorbed by the fluid.

87. The analyzer of claim **83** wherein the chamber has a substantially constant geometry.

88. The analyzer of claim **83** wherein the monitoring means includes means for synchronously detecting said variation.

89. The analyzer of claim **83** wherein the chamber is a reflective, random path chamber.

90. The device of claim **83** wherein the means for repeatedly forcing and withdrawing includes a thermally driven oscillatory device.

91. The device of claim **83** wherein the means for repeatedly forcing and withdrawing includes a thermally driven oscillating bellows.

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