United States Patent

[11] 3,589,184

[72] Inventor George E. Moore
Scotia, N.Y.

[21] Appl. No. 854,420
[22] Filed Sept. 2, 1969
[45] Patented June 29, 1971
[73] Assignee General Electric Company

[54] CONTINUOUS-FLOW GAS CALORIMETER
9 Claims, 2 Drawing Figs.

[52] U.S. Cl. 73/190R
[51] Int. Cl. G01k 17/00
[50] Field of Search 73/190

[56] References Cited

UNITED STATES PATENTS

1,779,371	10/1931	Parr	73/190
2,743,609	5/1956	Schuller	73/190

FOREIGN PATENTS

171,246	11/1921	Great Britain	73/190

Primary Examiner—Charles A. Ruehl
Assistant Examiner—Herbert Goldstein
Attorneys—Richard R. Brainard, Paul A. Frank, Charles T. Watts, Leo I. MaLossi, Frank L. Neuhauser, Oscar B. Waddell and Joseph B. Forman

ABSTRACT: A compact, precise gas calorimeter is described comprising a sintered metal walled enclosure, a plenum in flow communication with one wall of the enclosure for receiving a metered gaseous fuel/air mixture, an igniter located adjacent the inside of the one wall, means embedded within each wall of said enclosure to provide for passage of a metered coolant flow through the interior of each of said walls and means located in the inlet to and outlet from said coolant passage means for determining the differential in temperature between the incoming and outgoing coolant flow. During operation the one wall functions as a plug burner, while the rest of the wall surface of the enclosure serves as condenser area.

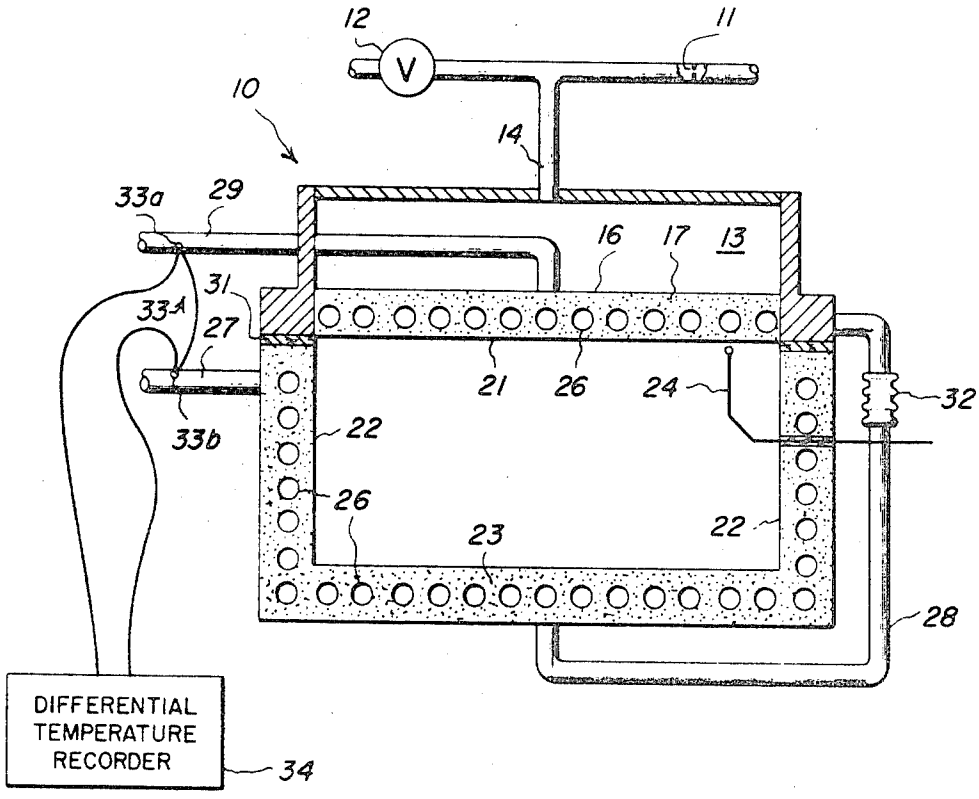


FIG. 1

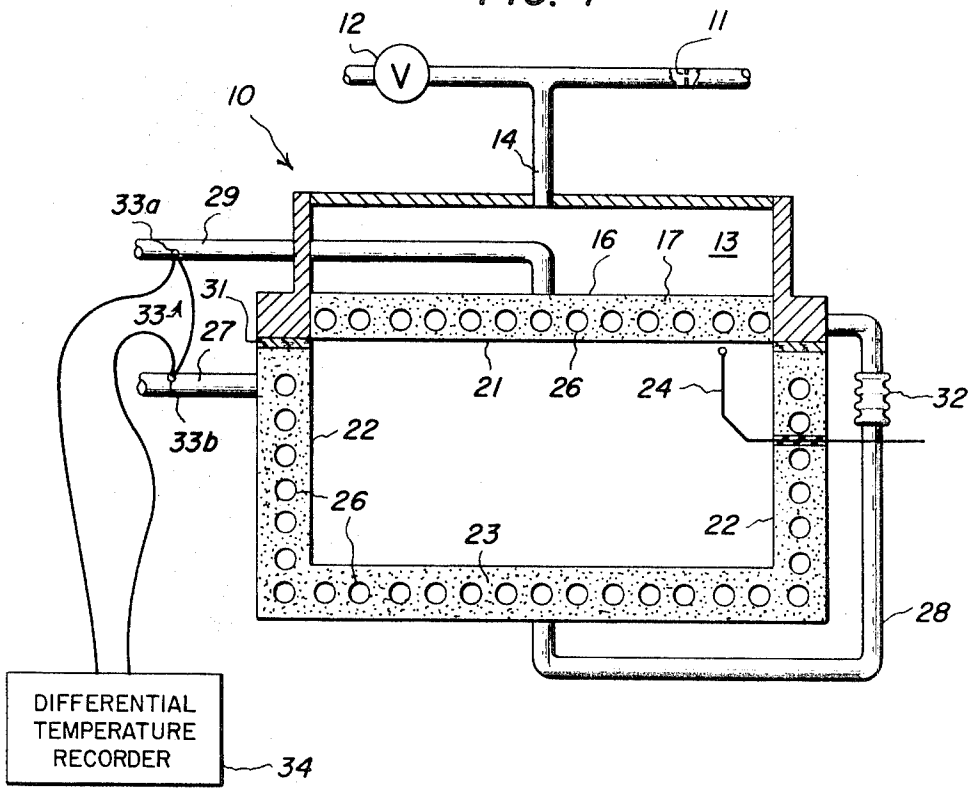
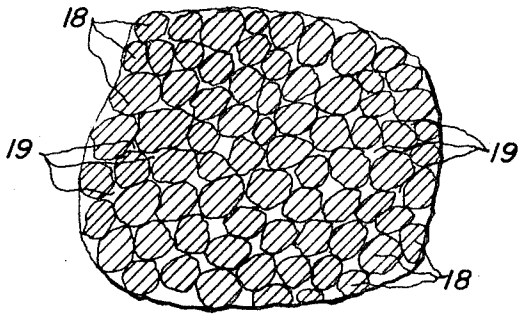


FIG. 2



INVENTOR:
GEORGE E. MOORE,
by Leon L. Mantoni
HIS ATTORNEY

CONTINUOUS-FLOW GAS CALORIMETER

BACKGROUND OF THE INVENTION

The heating (calorific) value of any fuel gas measured in British Thermal Units (B.t.u.) is an important factor in the purchase and sale thereof, because the heat content of a gaseous fuel is the principal measure of its ability to perform a heating service, with the exception of the type of application in which flame intensity is the principal criterion. In accordance with the principle that the sale of fuel gas is actually the sale of calorific value, in many locations gas is purchased and sold on a therm (100,000 B.t.u.'s) basis. This basis of sale requires suitable equipment for accurately determining the calorific value of gas passing from the seller to the consumer.

Two widely recognized types of equipment for this purpose are commonly known as "Junkers Calorimeters" and "Cutler-Hammer Recording Calorimeters" (both employ water flow calorimetry). Measurement of the calorific value of gas to the consumer is seldom accomplished at standard conditions (see definitions below) and conditions of temperature, pressure and water vapor content for the contracted calorific value must be agreed upon by the contracting parties. The manner in which such conversion is accomplished is set forth in the Gas Engineers Handbook in Chapter 8 thereof entitled "Gas Calorimetry" by Donald L. White (The Industrial Press, 1st Edition [1966], pages 6/42—6/46) incorporated herein by reference.

The following definitions from the aforementioned source are of particular use in water flow calorimetry:

British Thermal Unit (B.t.u.): quantity of heat that must be added to 1 avoirdupois pound of pure water to raise its temperature from 58.5° F. to 59.5° F. under standard pressure.

Combustion Air: air passing into combustion space of calorimeter (theoretical air plus excess air).

Excess Air: quantity of air passing through combustion space in excess of theoretical air.

Flue Gases: products of combustion remaining in gaseous state together with excess air.

Net (Lower) Calorific Value: number of B.t.u. evolved by the complete combustion at constant pressure of 1 standard cubic foot of gas with air; temperature of gas, air, and products of combustion being 60° F., all water formed by combustion reaction remaining in the vapor state; this term is arrived at by subtracting from the total (higher) calorific Value the latent heat of vaporization at standard temperature of water formed by the combustion reaction.

Total (Higher) Calorific Value: number of B.t.u. evolved by the complete combustion at constant pressure of 1 standard cubic foot of gas with air; temperature of gas, air, and products of combustion being 60° F., all water formed by combustion reaction being condensed to liquid state.

Products of Combustion: sum of all substances resulting from burning of gas with its theoretical air, including inert constituents of gas and theoretical air, but excluding excess air.

Standard Cubic Foot of Gas (SCF): quantity of any gas that at standard temperature (60° F.) and pressure will fill a space of 1 cubic foot when in equilibrium with liquid water.

Standard Pressure: absolute pressure of a column of pure mercury 30 in. high, at 32° F., under standard gravity (32.174 ft. per sec.^{2}).

Standard Temperature: 60° F., based on the international temperature scale.

Theoretical Air: volume of air that contains the quantity of oxygen, in addition to that in gas itself, which is consumed in complete combustion of a given quantity of gas.

The waterflow calorimeter has been accepted as a standard for calorific value measurement by many utility companies and utility regulating agencies. The essential parts of such commercial devices are meters for the gas, for the combustion air and for the ambient air used for heat absorption, a motor gear reduction unit, a water pump for the coolant water, temperature sensing means for the entering and leaving water and for the heated air, heat exchange means with which to cause air to absorb the heat of combustion and recording means to measure the temperature differences occurring in the temperature sensing devices.

SUMMARY OF THE INVENTION

The instant invention constitutes an improved waterflow calorimeter considerably simplified in that the necessity of employing a second coolant fluid (ambient air) has been obviated (as have the sensing means for determining the volume of coolant air employed and the sensing means for determining the temperature rise brought about therein). The accuracy of this improved device is comparable to the accuracy of the prior art device, while occupying much less volume.

In essence, the instant invention comprises a sintered metal walled enclosure, a plenum in flow communication with one wall of the enclosure for receiving and containing a metered gaseous fuel/air mixture, means for metering (measuring the mass flow rate of) the gaseous fuel and means for metering (measuring the mass flow rate of) the combustion air, the output side of each of said metering means being in flow communication with said plenum, means embedded within each wall of the enclosure to provide passage of a metered coolant flow through the interior of each of said walls, and means located in the inlet to and outlet from said coolant passage means for determining and recording the temperature differential between incoming and outgoing coolant flow. The one wall functions as a plug burner to accomplish combustion of the metered gaseous fuel/air mixture, while the rest of the enclosure, which may or may not be separable from the first wall, serves as the cooler/condenser, which may be maintained within 2—3° C. of the ambient temperature.

BRIEF DESCRIPTION OF THE DRAWING

The exact nature of this invention as well as other objects and advantages thereof will be readily apparent from consideration of the following specification relating to the annexed drawing in which:

FIG. **1** is a section through a cylindrical configuration of the instant invention, and

FIG. **2** is an enlargement of a portion of any of the sintered porous metal walls of the enclosure of FIG. 1.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The fuel gas for which the calorific value is being determined enters the calorimeter device **10** through a pressure-reducing orifice **11** (as for example, a critical-flow orifice meter) and simultaneously air enters through metering valve **12** preferably in an amount slightly in excess of the quantity required to completely burn the entering fuel gas. It is necessary that the fuel be metered with an accuracy at least as great as the accuracy desired in the calorific value, while the air need not be as accurately metered and may be determined to an accuracy of about 5 to 10 percent. The conditions of pressure and temperature under which the quantities of gas or air is measured must, of course, be known to enable correction of the measured quantity to the particular standard to which reference is desired (e.g. 25° C. and 1 atmosphere). Thus, determining the quantity of a gas and the pressure and temperature thereof actually amounts to measuring the mass flow rate the gas. The fuel gas and combustion air enter closed plenum **13** via conduit **14** at ambient temperature mixing in transit such that a stoichiometric air/fuel mixture (or one with a slight excess of air) is presented to face **16** of the porous sintered metal burner plate **17**, the velocity of the unburned mixture being less than the normal burning velocity of the particular air/fuel combination.

By way of example, the porous plug burner **17** is made of sintered copper particles in the size range of from about 1 to about 200 microns. The illustration in Fig. **2** shows the general relationship of the sintered copper particles **18** and interconnecting voids **19** permitting continuous passage of the gas mixture through the sintered body **17** from face **16** to face **21** with a pressure drop of less than 1 p.s.i. for a burner body having a thickness of about five-eights of an inch. The pressure drop will vary as a function of the velocity of the unburned gas flow introduced thereto. For plug burners one-half inch thick, the pressure drop is about 0.03 p.s.i./cm./sec. of gas flowing under pressure of about 1 atmosphere.

For this application, other metals may be employed in place of copper, for example, bronze shot, nickel shot or any structurally sound metallic shot material having a thermal conductivity at least 30 percent of the value of thermal conductivity for sintered copper shot may be used both for the construction of burner plate **17**, and also for the condenser portion of the device **10** comprising cylindrical wall **22** and bottom **23**.

When the unburned gas mixture reaches face **21** (there having previously been ignition at face **21** by means of spark igniter **24**), it burns as a flat flame spread over face **21**. The heat generated by the burning mixture is rejected in part to the burner body **17** with the burned gas eventually passing through the wall surfaces **22** and **23** leaving the device substantially at ambient (within 2—3° C. of the initial air/gas temperature) for release as flue gas.

Cooling of the combustion products to ambient temperatures is accomplished by passing a cooling fluid through the continuous single copper cooling conduit **26**, most of which is embedded in the sintered metal walls **22**, **23** and in burner plate **17** for the circulation of metered cooling water therethrough. In the construction shown in FIG. **1**, the cooling water (at or below room temperature, 23° C.) enters end **27** of conduit **26**, proceeds through the length of the coiled conduit configuration embedded in wall **22**, traverses the spiral configuration embedded in base **23**, passes along external leg **28** (normally insulated) to reach the flat spiral configuration embedded in burner plate **17**, and exits from the cooling system via end **29** of the continuous cooling tube **26**.

In this manner, the total of the heat generated during the combustion of the metered fuel input at surface **21** is absorbed with the exception of the heat in the water vapor content of the existing gases. Heat rejected to burner plate **17** is efficiently removed therefrom by the coolant circulated therein, while at the same time the gaseous products of combustion plus any excess air pass through walls **22** and **23** and are cooled by the metered cooling water traversing coolant conduit **26** whereby the balance of the combustion-generated heat is absorbed. All water vapor from the combustion process (with the exception of the saturation water vapor content in the existing gases) is condensed during during passage of the gases through walls **22** and **23** and is forced through these porous walls to drip from the exterior thereof. The pressure drop from downstream of the metering means for the fuel and air to the exterior of condenser walls **22** and **23** is about 2 p.s.i. or less. The pressure necessary to overcome this drop may either be supplied at the inlet to calorimeter **10** or, if desired, by applying suction by means not shown to the exterior surfaces of the condenser.

The exit temperature of the burned products is within a few degrees of the water temperature, so all of the heat of combustion is recovered or accountable by a simple correction. Any excess air that accompanies the product also leaves at the water temperature and there is no correction necessary for that heat carried with it nor is there any need to meter it with extreme accuracy.

All exterior surfaces are at, or very close to, ambient temperature, therefore, virtually no heat leak corrections are required and the heating value of the fuel is directly determinable from (a) the flow rate and the temperature rise of the coolant and (b) the fuel flow. Any gaseous fuel (representing wide variations in B.t.u. per cubic foot of gas) can be used with only minor adjustments, if any, in fuel/air flows and without changes in the inlet gas orifice or burner.

The burner plate **17** is separate from the cup-shaped condenser (walls **22** and **23**) and is assembled thereto in sealed engagement by interposing a sealant layer **31** (e.g. a silicone rubber gasket) therebetween. Removal of plate **17** to expose the cavity is facilitated by the inclusion of flexible coupling **32** in external leg **28**. Shapes for the condenser other than the cuplike shape indicated may be employed. Thus, for example, the condenser may be in the form of a cone, a pyramid, a prism, etc., so long as the cooling conduit may be conveniently introduced therein during manufacture. If desired, to minimize the coolant pressure drop, the continuous cooling conduit **26** shown may be separated into a cooling circuit for the condenser unit and a cooling circuit for the burner plate **17**, however, such a construction would require separate temperature sensing means for each of these two coolant paths.

In manufacture, the cooling conduit and surrounding copper particles are placed in an appropriate graphite mold. The assembly is then sintered, while applying a small pressure (less than about 2 p.s.i.) thereto. The extent of pressure application determines the void content and, therefore, the strength of the sintered porous body. However, the most important aspect of void content control is the maintaining of low flow resistance and introducing reasonably high thermal conductivity both within the sintered particle mass and between the sintered particle mass and the cooling conduit.

For the preferred embodiment shown (e.g. 6.3 cm. diameter × 3.5 cm. height cavity) the unburned mixture velocity at the burner surface may be set at roughly 10 cm./sec., though the magnitude of this parameter is unimportant. If the fuel is natural gas (mostly CH_4), with the mixture composition adjusted to about 8 volume percent fuel, about 200 cal./sec. of heat would be released. A substantial amount of this heat is received by the burner **17**, but most of the heat is absorbed by the cooler condenser walls **22**, **23**. This transfer of heat corresponds to an average heat flux to the porous metal of about 1.6 cal./cm.^{2}-sec. By fixing the water flow at about 10 cc./sec., the temperature rise of the water will be about 20° C., a quantity easily measurable with sufficient accuracy with a simple differential thermocouple structure **33** shown connected to the input of the differential temperature recorder **34**. To detect smaller rises in temperature a more sophisticated differential thermocouple, a resistance thermometer bridge or a thermoistor bridge arrangement may be used.

Circuitry in recorder **34** receiving signal inputs from thermocouples **33***a* and **33***b* transforms this information into displays of temperature difference, if desired. By providing additional information (rate of flow of coolant and rate of air/fuel flow) input to the recorder (properly instrumented), the lower calorific value in B.t.u./ft^3 (at 60° F., 1 atmosphere) of the gas being monitored can be monitored and displayed on a continuous basis, thereby forming (together with separate information on total gas flow) the basis for billing for gas consumed.

Following in Table I are examples of several tests made with different flows of pure methane (representing a range of about a 15 percent change in fuel flow) using a 6.3 cm. diameter burner of the construction shown in the drawing:

TABLE I

Air flow, 25° C., 1 atm. (cc./sec.)	CH_4 flow, 25° C., 1 atm. (cc./sec.)	Percent CH_4 (by vol.)	Cooling water		Total heat corrected for water vapor loss at 30° C. (cal./sec.)	Gross heat of combustion (cal./cc.)
			Flow (g./sec.)	Δ time (° C.)		
233	22.4	8.77	9.70	19.6	194	8.65
233	20.6	8.13	9.70	18.1	180	8.75
233	18.9	7.5	9.70	16.6	165	8.73

The average of the gross heat of combustion values obtained for the three tests displayed in Table I is 8.71 cal./cc. (25° C., 1 atm.), which is equivalent to 1011 B.t.u./ft.^{3} (60° F., 1 atm.). This value for higher (total) calorific value compares very favorably with the accepted higher calorific value of 1012 B.t.u./ft.^{3} (60° F., 1 atm.) for the pure methane gas employed. The lower (net) calorific value is calculated by subtracting from the measured 1011 B.t.u./ft.hu **3** higher calorific value the value of the latent heat of vaporization at standard temperature for the water contained in the exiting gas flow (assumed to be saturated with water vapor). This value obtained from the test results was 910 B.t.u./ft.^{3} (60°F., F, 1 atm.), which value compares very well with the accepted lower calorific value of 911 B.t.u./ft.^{3} (60° F., 1 atm.) for the pure methane employed.

Thus, a compact, precise continuous-flow monitoring gas calorimeter has been disclosed herein, providing a significant improvement over prior art waterflow calorimeters in that the need for a second coolant medium (usually air) has been obviated along with the necessity of metering and sensing the temperature of this second coolant medium.

What I claim as new and desire to secure by Letters Patent of the united States is:

1. A gas calorimeter comprising in combination,

a. a completely enclosed walled container having a plurality of sintered metal porous walls,

b. a plenum in flow communication with one porous wall of said container,

c. first means in flow communication with said plenum for metering gas fuel input thereto,

d. second means in flow communication with said plenum for metering air input thereto,

e. means located within said container adjacent said one wall for igniting a combustible mixture of air and fuel passing through said one wall from said plenum,

f. means embedded within each porous wall of said container for circulating a liquid coolant at a known rate of flow therethrough to controllably cool said each porous wall and

g. means interconnected with inlet and outlet ends of said coolant circulating means for determining temperature differentials between incoming and outgoing coolant flows.

2. The gas calorimeter as recited in claim **1** wherein the one wall may be removed from the container.

3. The gas calorimeter as recited in claim **1** wherein the sintered metal is copper.

4. The gas calorimeter as recited in claim **1** wherein said coolant circulating means is one continuous conduit.

5. The gas calorimeter as recited in claim **1** wherein the plurality of container walls consist of a flat wall as the one wall together with wall area generated as a surface of revolution.

6. The gas calorimeter as recited in claim **1** wherein that wall area other than the one wall is in the form of a flat-bottomed cylinder.

7. The gas calorimeter as recited in claim **6** wherein the cylinder is a right circular cylinder.

8. The gas calorimeter as recited in claim **1** wherein the means for determining temperature differentials includes a differential thermocouple.

9. The gas calorimeter as recited in claim **1** wherein the sintered metal is metallic shot material having a thermal conductivity at least 30 percent of the value of the thermal conductivity of sintered copper shot.