March 29, 1960 D. B. SPALDING 2,930,226

APPARATUS FOR THE SIMULATION OF COMBUSTION

Filed May 23. 1955 3 Sheets-Sheet 1

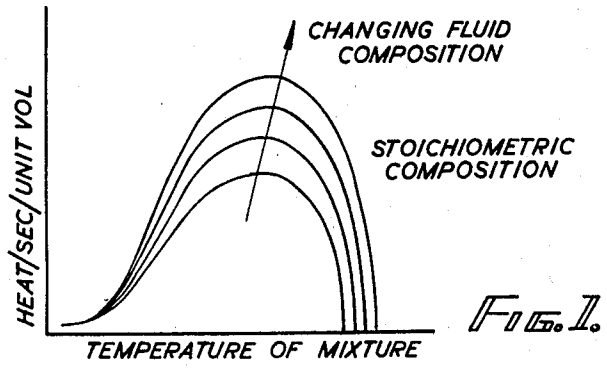


FIG. 1.

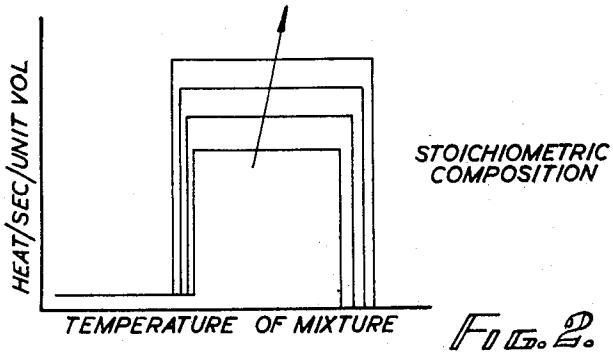


FIG. 2.

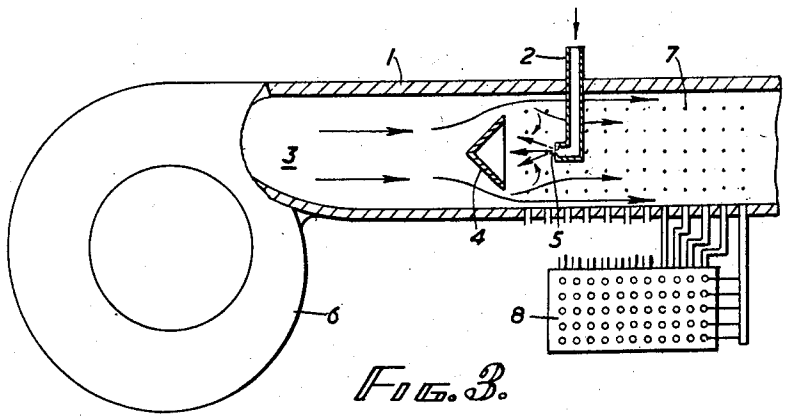


FIG. 3.

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APPARATUS FOR THE SIMULATION OF COMBUSTION

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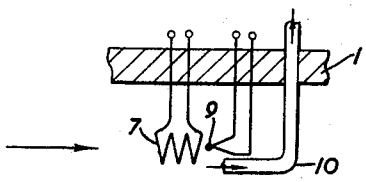


FIG. 4.

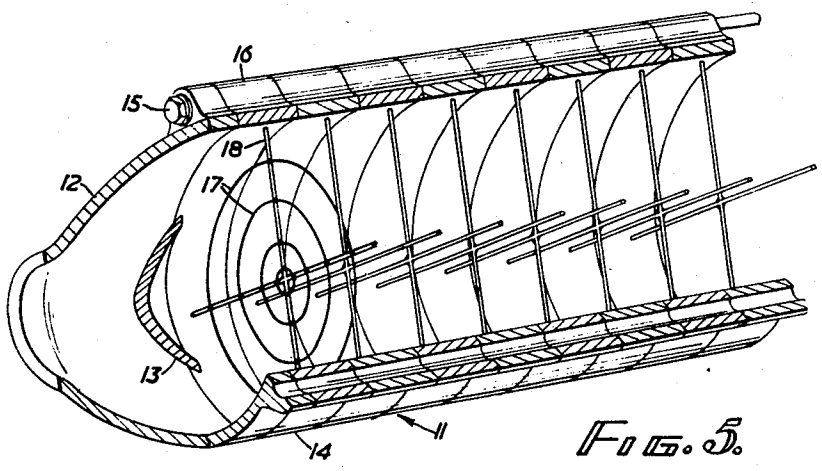


FIG. 5.

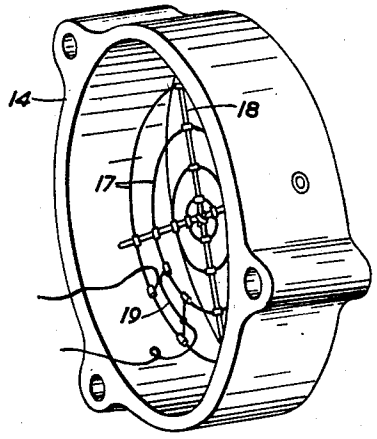


FIG. 6.

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APPARATUS FOR THE SIMULATION OF COMBUSTION

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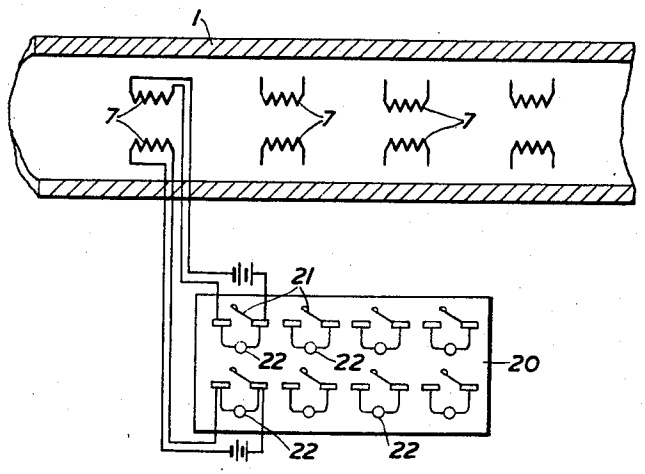


FIG. 7.

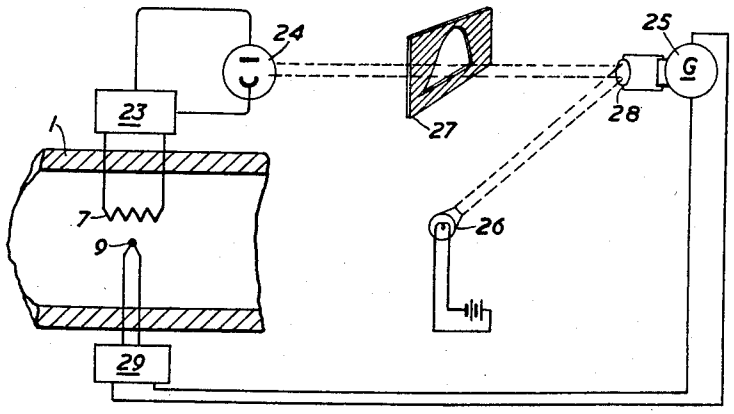


FIG. 8.

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United States Patent Office 2,930,226
Patented Mar. 29, 1960

2,930,226

APPARATUS FOR THE SIMULATION OF COMBUSTION

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Application May 23, 1955, Serial No. 510,329
Claims priority, application Great Britain May 26, 1954
12 Claims. (Cl. 73—116)

The invention relates to apparatus for simulating combustion and is particularly but not exclusively concerned with the simulation of combustion occurring in combustion chambers of the kind used in gas turbine engines, ram-jets, rockets or like devices.

A comprehensive investigation of the performance of combustion systems by direct comparison involves the construction of prototypes and the provision of facilities for testing the prototypes under actual operating conditions of temperature, pressure and mass flow of air or other combustion-supporting gas. Direct comparison would be costly therefore due to the considerable time that would be required for the manufacture of the prototypes and the necessary ancillary or auxiliary equipment. An object of the present invention is to provide apparatus whereby the behaviour of combustion systems may be investigated comparatively easily, quickly and economically.

According to the invention apparatus for simulating combustion in a combustion chamber comprises a model of the combustion chamber or the combustion chamber itself, means whereby fluid representing combustion-supporting gas in the combustion chamber may be passed through the model, means capable of changing a property of the fluid, the said property-changing means being spaced apart within the model in a region thereof representing a combustion region of the combustion chamber, means capable of detecting a change of property of the fluid in the locality of the said property-changing means and control means whereby the said property-changing means may be selectively operated to simulate the combustion process. The term property changing means is intended to mean herein a device or apparatus which is capable of changing a property of a fluid which is conserved in adiabatic steady flow mixing.

Preferably the property-changing means are heating means and the detecting means are temperature-responsive devices, the heating means being selectively operated by the control means to simulate the combustion process but at temperatures substantially lower than combustion temperatures. The heating means may be electrical heater elements which may be coils or wires arranged in rings or arcuate portions spaced apart both transversely and longitudinally of the model. The temperature-responsive devices may actuate automatically the control means for the heater elements.

Means may be provided whereby a second fluid representing fuel may be introduced into the main fluid stream in a manner similar to fuel introduction into the combustion-supporting gas stream, in which case fluid composition determining means would be provided to detect the distribution of the second fluid in the main fluid stream. Preferably the fluid composition determining means or a sampling means therefor is positioned adjacent each of the heating means.

Instead of employing heating means as the aforesaid property-changing means, means may be provided for introducing a tracer fluid into the stream of fluid representing combustion-supporting gas, the detecting means would then be required to detect the quantity of tracer fluid in the locality of the tracer introduction means.

The invention also consists in a method of simulating combustion in a combustion chamber by introducing heat at a multiplicity of heating means spaced apart in a model of the combustion chamber or the combustion chamber itself in accordance with a predetermined rate of heat input per unit volume and temperature relationship but at temperatures substantially lower than combustion temperatures, the model receiving a fluid or fluids to represent the combustion-supporting gas and/or fuel respectively.

The term "combustion chamber" has been used herein in a broad sense to mean a container or vessel supplied with air or other combustion-supporting gas and a fuel and in which combustion is intended to occur. The term is primarily intended to mean a combustion chamber of the gas turbine type or a combustion duct such as that employed for afterburning in a gas turbine jet engine or for combustion in a propulsive duct such as a ram-jet; but it is envisaged that the simulating apparatus of this invention has other applications and could be used for example for furnace combustion chambers. The term "combustion chamber" as used herein also includes the combustion chamber together with any flame-tube or baffle contained therein, or even a flame-tube alone.

By way of example the invention will now be described with reference to the drawings in which:

Figure 1 is a diagram showing graphically the relationship between the rate of heat input per unit volume and the temperature for various mixture strengths in a combustion chamber or model thereof;

Figure 2 is a modification of Figure 1;

Figure 3 is a diagrammatic longitudinal sectional view of one embodiment of the invention;

Figure 4 is a portion of Figure 3 drawn to a larger scale;

Figure 5 is a diagrammatic perspective longitudinal sectional view of another embodiment of the invention;

Figure 6 is a view of a portion of Figure 5 drawn to a larger scale;

Figure 7 is a diagram showing a switching arrangement for controlling the apparatus shown in Figures 3 and 4,

Figure 8 shows diagrammatically an automatic control device for the apparatus shown in Figures 3 and 4 or 5 and 6, and

Figure 9 is a diagrammatic longitudinal section view of a further embodiment of the invention.

In order to simulate a combustion process at temperatures lower than combustion values, that is to say without combustion occurring, it is necessary to comply with certain conditions. For complete similarity between a model of a combustion chamber and the actual combustion chamber the following conditions should be satisfied:

(*a*) the model should be geometrically similar to the actual combustion chamber including flame tubes and baffles if any,

(*b*) the Reynolds' numbers for the model and actual combustion chamber should be equal,

(*c*) a geometrically similar relation between the rate of heat input per unit volume and the temperature should be followed in each case,

(*d*) there should be equal values in each case for the dimensionless group $c\rho V(T_b-T_u)/\dot{q}'''d$ where

c=air (or fluid representing air in the model) specific heat at constant pressure

ρ=air (or representative fluid) density at inlet

V=air (or representative fluid) velocity at inlet

d=a typical dimension of the chamber or model

T_b=adiabatic combustion temperature
T_u=initial temperature
$\dot{q}'''$=maximum heat input per unit time per unit volume of combustion chamber (i.e. the value of the peak of the curve giving the relation referred to in (*c*) and to be described hereinafter)

(*e*) there should be equal values of T_b/T_u,

(*f*) the $\frac{\text{fuel flow}}{\text{air flow}}$ and $\frac{\text{fuel momentum}}{\text{air momentum}}$ ratios for the combustion process should be equal to the corresponding ratios for fluids representing fuel and air respectively in the model, and

(*g*) the quantity $(T_b-T_u)/\dot{q}'''$, should be related to the local

$$\frac{\text{fuel}}{\text{air}}$$

ratio in the model in the same way as in the combustion system.

When the Reynolds' number for a combustion process is high (e.g. in a gas turbine combustion chamber) the condition (*b*) above can be disregarded. Conditions (*d*) and (*f*) should be complied with, but conditions (*c*) and (*g*) need be only partially satisfied. If no fluid simulating fuel is admitted to the simulated combustion chamber, then it is clearly impossible and moreover unnecessary to adhere to condition (*f*). There is no simple way of fulfilling condition (*e*) but this is not expected to be very important in practice. Therefore, a combustion simulator for use in the design and development of combustion chambers for gas turbines, ram-jets, rockets or like apparatus should be designed so that conditions (*d*) and (*f*) are complied with and conditions (*c*) and (*g*) are at least partially satisfied.

In the above conditions mention has been made of the rate of heat input per unit volume and temperature relationship. Figure 1 illustrates graphically this relationship for several fuel/air mixtures, but at equal pressures and initial temperatures. In order to satisfy condition (*c*) the curve appropriate for the particular local fuel mixture should be followed in the model; but as has been stated above the condition (*c*) need only be partially followed. Hence Figure 2 shows a series of curves of a similar nature to those in Figure 1 which can be followed in the model. These curves may be obtained by a simple on-off operation of heaters spaced apart in the model. However, curves such as those in Figure 1 could be produced by the use of control devices such as photo-electric cells or other electronic devices operating electrical heating elements. A suitable control device will be described herein with reference to Figure 8.

The following numerical example will give the heat input required in a model of a combustion chamber burning a uniform mixture ratio. In the combustion chamber itself the pressure of a stoichiometric hydrocarbon/air mixture is 0.1 atmosphere and the average heat input in the flame per unit time per unit volume i.e. $\dot{q}'''\simeq 10$ cals./cm.^{3} sec., and $(T_b-T_u)\simeq 2000°$ C. In the model the heat input/temperature curve of Figure 1 is to be simulated by a step function as in Figure 2, having zero ordinate from T_u to a temperature T_i and a constant ordinate from T_i to T_b and (T_i-T_u) may be taken as 0.6 (T_b-T_u). Velocities in the model are to be one tenth of those in the combustion chamber and the dimensional ratio is to be unity. The model is to operate at atmospheric pressure. Incidentally this combination of values gives equal Reynolds' numbers for the combustion chamber and the model.

For the condition (*d*) the dimensionless group

$$c\rho V(T_b-T_u)/\dot{q}'''d$$

must be equal for both combustion chamber and model. Let the model be denoted by suffix M and the combustion chamber by suffix C. Then,

$$\frac{V_M(T_b-T_u)_M}{p_M\dot{q}'''_M d_M}=\frac{V_c(T_b-T_u)_c}{p_c\dot{q}'''_c d_c} \text{ since } p\alpha\frac{1}{\rho}$$

$$\therefore \frac{\dot{q}'''_M}{(T_b-T_u)_M}=\frac{\dot{q}'''_c}{(T_b-T_u)_c}\cdot\frac{V_M}{V_c}\cdot\frac{d_c}{d_M}\cdot\frac{p_c}{p_M}$$

$$=\frac{10}{2000}\cdot\frac{1}{10}\cdot\frac{1}{1}\cdot\frac{10}{1}$$

$$\therefore \frac{\dot{q}'''_M}{(T_i-T_u)_M}=\frac{10}{2000}\cdot\frac{1}{10}\cdot\frac{1}{1}\cdot\frac{10}{1}\cdot\frac{1}{0.6}$$

$$=0.00833 \text{ cal./cm.}^3 \text{ sec. } ° C.$$

If

$$(T_i-T_u)_M=20° \text{ C. } \dot{q}'''_M=0.167 \text{ cal./cm.}^3 \text{ sec.}$$

$$=0.7 \text{ watts/cm.}^3$$

Thus in the model only a 20° C. rise and heat energy input of 0.7 watts/cm.^{3} are required. This can be suitably produced by electrical heating elements as in the embodiments of the invention described below with reference to Figures 3–4 and Figures 5 and 6.

The theory discussed above provides a basis on which various degrees of accuracy of results can be achieved and it is evident that the closer the simulator structure conforms to the structural conditions set out and the closer the simulator is operated to the operational conditions, the more accurate would be the result. Conversely, many of the theoretical conditions may be neglected if only certain aspects of combustion are to be investigated, for example, the investigation of temperature distributions can be made without the addition of a fuel simulating fluid.

In Figure 3 there is illustrated a model of a simple combustion chamber. The model comprises a duct **1** of circular cross-section containing a baffle **4**. Both the duct **1** and the baffle **4** are geometrically similar to the combustion chamber under investigation. At one end **3** of the duct **1** there is an air compressor or blower **6** supplying a stream of air to the duct to represent the air or other combustion-supporting gas supplied to the combustion chamber. A tracer, e.g. carbon dioxide, is introduced into the air stream through a supply pipe **2** from a reservoir **40** or other source and an injector **5** to represent the fuel supply in the actual combustion chamber. The tracer mixes with the air downstream of the baffle to form a composite fluid which is re-circulated by the baffle in a manner similar to the recirculation which would occur in the combustion chamber. Downstream of the baffle there is a multiplicity of electrical heaters **7** arranged as separated coils distributed uniformly throughout the domain of flow of the fluids and having dimensions considerably smaller than the corresponding dimensions of the model. The heaters are spaced apart from one another both transversely and longitudinally of the duct. Each heater is connected to an electrical supply and switching arrangements are provided for each heater separately or in groups. Control and switching means are shown in outline at **8** and will be described hereinafter with reference to Fig. 7 or Fig. 8. The number of heaters determines the degree of similitude between conditions prevailing in the model and those which would occur in the combustion chamber itself. The greater the number of resistors the greater will be the similarity; but even a relatively sparse distribution of heaters can give valuable results. Adjacent each heater there is a temperature-responsive element **9** such as a thermo-couple (see Figure 4 which is an enlargement of part of Figure 3). The elements **9** indicate the temperature in the vicinity of the associated heater and may be employed to control the current supplied to the heater automatically or to give an indication to an operator who can then switch on or off or adjust the heater supply circuit accordingly. The temperature indicated by each element is recorded. Adjacent each heater or at each of a multiplicity of other positions spaced apart in

the duct there is a composition-determining device to ascertain the distribution of the tracer representing the fuel. As shown in Figure 4 this is a sampling-tube **10** through which a sample of the composite fluid is extracted and led to an analysis apparatus to determine the concentration of tracer fluid in the air at that point. For example, if the tracer employed is carbon dioxide, the quantity of carbon dioxide present in the air at a sampling point can easily be determined by exhaust gas analysis apparatus e.g. the Orsat apparatus. Of course, an estimation of the quantity of carbon dioxide present in the air entering the duct **1** would have to be made to determine the initial quantity of carbon dioxide present in the air. Thus knowing the "fuel/air" ratio and the local temperature at or near each heater, the heaters can be controlled to follow the curves of Figure 1 or Figure 2.

To commence the operation of the simulator apparatus, the fluids representing the air and fuel respectively i.e. the air from the blower **6** and the tracer e.g. carbon dioxide, are introduced to the model. The "fuel/air" ratio is then measured and estimated for each heating position by extracting a sample of the air/tracer mixture through the sampling tubes **10**. Now that the fuel distribution has been determined the tracer supply can be discontinued; but it may be necessary to continue to introduce a stream of tracer or other fluid to simulate the momentum of the fuel. All the heaters **7** are then switched on to give their predetermined maximum heat input. This state of affairs corresponds to ignition. Then the heaters are adjusted separately or in groups in accordance with the prescribed relation for the appropriate gas analyses already determined. The curves followed are either those of Figure 1 or Figure 2 according to the nature of the switching and control means **8** available. Since the alteration of heat input at one point may affect the temperature at a point at which adjustment has already been made, an iterative procedure is necessary before the relation can be satisfied at all points. When all the adjustments to the heating circuits have been made the temperature distribution throughout the model will correspond to that which would exist in the actual combustion chamber. The temperature distribution can be determined by reading or recording the temperatures indicated by the thermocouples or by an indicator associated with the switching means for the heaters. Such an indicator will be described more fully hereinafter with reference to Figure 7.

When the rate of flow of air from the blower **6** is increased above a certain value it will be found that for any particular model and prescribed heat input law the only steady condition is that at which the temperature at any point in the duct is substantially the same as the temperature at that point before heating in the model commenced. This condition corresponds to the extinction of the flame and is therefore of great practical importance. The apparatus can thus be used to reveal the flow velocity at which extinction of the flame will occur for a given combustible mixture. In this way the stability of various flow patterns can be compared.

In the calculated example given above, suppose that extinction of "combustion" is found to occur in the model when the dimensionless group

$$\frac{c\rho V(T_i - T_u)}{0.6\dot{q}'''d} = N$$

Then the blow-out or extinction velocity for a mixture of air/fuel ratio and pressure such that $(T_b - T_u)/\dot{q}''' = x$ is given by the equation:

$$V_{\text{Blow-out}} = \frac{N}{x}\frac{d_c}{c\rho_c}$$

Thus the expected blow-out velocity can be calculated evaluating N from the conditions prevailing in the model and by evaluating the value of X from the heat input law (i.e. Figure 1 or 2) for the appropriate mixture strength.

Although no pressure measuring devices have been shown, the pressures prevailing at various points through the model during operation could be simultaneously measured. Such readings could provide information on the resistance of the combustion chamber to flow and would therefore be of value in the design of a combustion chamber.

In the simulator apparatus described hereinbefore the tracer representing fuel is carbon dioxide which can be detected chemically in the air and thus the distribution of fuel in the air stream of the combustion chamber can be predicted. It is within the scope of the invention to inject instead of a chemically different tracer, a stream of heated air. The spread of the stream can then be detected by the thermocouples or other temperature-responsive devices associated with the heaters **7**. One of the heaters **7** could be used to heat the stream of air representing the fuel. This heater would have conveniently a higher voltage supply than the other heaters. The use of heated air to represent fuel has the advantage that composition determining devices are not required and the only measurements to be made are the temperatures in the vicinity of each heater.

The apparatus described with reference to Figures 3 and 4 employed heating coils. Another apparatus that falls within the scope of this invention employs heaters in the form of concentric rings as is shown in Figures 5 and 6.

Figure 5 shows a model **11** constituting a duct of the combustion chamber constructed from an upstream end portion **12** containing a baffle **13** and a multiplicity of short cylindrical portions **14** fitting together. The portions **12** and **14** are held together by bolts **15** passing through holes in lugs **16**. A model can quickly and easily be assembled to represent a combustion chamber by selecting the required portions. Each portion **14** contains heating-wire rings **17** arranged in concentric circles and mounted upon a cross-shaped wire carrier **18** held within the portion. The wires in each portion are connected to switches and an electrical supply in such a manner that the rings in each portion are heated separately or together. Thus the model can be heated at a multiplicity of positions both radially and longitudinally. Thermocouples **19** extending over part of an arc adjacent a heating wire are provided to determine the temperature in the vicinity of each heater. (See Figure 6.) The heating wire rings **17** are so arranged that the heat input per unit volume of the cylindrical part of the model is uniform. This will be satisfied with wires of uniform thickness, and therefore resistance, and having the same supply voltage, if the wires are spaced apart so that they divide into equal areas annular areas of inner and outer radii r_j, r_k which obey the equation

$$(r_k^2 - r_j^2)^2(r_j^2 + r_k^2) = \text{constant}.$$

For large radii, the radial spacing is approximately inversely proportional to the square of the radius. In this construction no tracer is employed to represent fuel. Instead, one of the wires is connected to a supply of greater voltage and therefore heats part of the air stream by a greater amount than the other heaters. The wire chosen for this purpose could be the innermost ring of the first (i.e. the left-hand as viewed in Figure 5) portion **14**.

The model **11** may represent a flame-tube of a gas-turbine combustion chamber. The portions **12** and **14** would then be apertured similarly to the flame-tube itself and the whole model would be contained in an outer casing.

Although Figures 5 and 6 show heating wires arranged in circles, they may be divided into individual arcuate portions isolated from one another but arranged in concentric circles. There will then be a thermocouple for each portion.

Figure 7 shows a switching arrangement for the apparatus shown in Figures 3 and 4 and also suitable for the apparatus shown in Figures 5 and 6. A switchboard 20 has switches 21 arranged on it in a lay-out corresponding to the spacing of the heaters in the model. That is to say the switchboard represents a section of the model. In the figure the switchboard is a vertical longitudinal section through the centre-line of the duct. Each switch controls a group of heaters positioned horizontally and in the same vertical plane as the heater illustrated. Adjacent each switch is a lamp 22 which is automatically illuminated when the switch completes the circuit to the appropriate heaters. The switches are of a simple-off-on type and therefore the heat input relation of Figure 2 is followed. When the switching operation has been completed the lamps illuminated give a visual indication of the temperature distribution in the model; that is to say, of the state of the "flame." The lamps 22 may be omitted, of course, and the distribution of temperature indicated simply by the position of the switches. In the case of the apparatus shown in Figures 5 and 6 the switches and lamps would control and indicate respectively the wire rings "cut" by a vertical longitudinal section through the model. Buzzers or other indicators could be employed instead of lamp 22.

The switching arrangement shown in Figure 7 is, as has been stated, for the Figure 2 heat input relation. If the Figure 1 relationship is to be followed automatically a device such as shown in Figure 8 must be employed. In this device the heating circuit for a heater or group of heaters contains a photoelectric cell 24 and an amplifier 23. The photo-electric cell 24 receives light reflected by the mirror 28 of a mirror galvanometer 25 from a pilot lamp 26. The galvanometer 25 is connected in series with the thermocouple 9 through an amplifier 29. The movement of the mirror is dependent upon the current flowing in, and therefore the temperature of, the thermocouple 9 associated with the heater 7. Between the photo-electric cell and the mirror there is a screen 27 shaped in accordance with the heat input per unit volume—temperature relation to be followed i.e. the curve of Figure 1 appropriate for the mixture strength. The screen is aligned with its temperature or abscissae axis aligned with the direction of travel of the mirror. As the temperature changes, the current passing through the coil of the galvanometer changes and the mirror reflects light from the lamp in a beam moving in a direction aligned with the temperature axis of the screen. Thus the light received by the photoelectric cell and therefore the heating current passing through the heater varies in accordance with the prescribed relationship, light being admitted to the photo-electric cell through a region bounded by the temperature axis and the curve representing the prescribed relationship between the local heat input per unit volume and temperature.

High speed electromagnetic or electronic devices may be employed to perform automatically corrections for changing fuel/air composition whether detected by gas analysis as in the apparatus of Figures 3 and 4 or simply by temperature difference as in the apparatus of Figures 5 and 6. Thus with the assistance of such devices it is believed that it will be possible to study non-steady states of flow, for example the rapid spreading of a flame from an ignition point or the stages in the process of flame extinction. In the embodiment illustrated in Figure 9, the duct 1 representing a combustion chamber and the blower 6 are arranged in substantially the same manner as in the embodiment of Figures 3 and 4. The heating coils 7 of the latter embodiment are replaced in this embodiment by a multiplicity of tubes 30 (only a few are shown for the sake of clarity) which are adapted to introduce streams of tracer fluid, e.g. carbon dioxide, instead of heat as introduced by the heater coils. A supply of tracer fluid is stored in a reservoir 33. The spread of tracer fluid is detected by sampling tubes 31 connected

to a mixture analyzer denoted by 32. The amount of tracer fluid introduced at the various positions is controlled in accordance with a prescribed relationship of heat input and local temperature represented by tracer input and local air/tracer composition.

In conclusion it should be emphasised that as the temperature variations in a model are only relative to those occurring in the combustion system represented thereby, the temperatures occurring in the model will normally be considerably lower than those which would occur in the combustion system itself and therefore the construction of a model is easier and will usually be cheaper than the construction of an actual combustion chamber.

It should also be emphasised that although the foregoing description refers to a "model" of the actual combustion chamber, it is within the scope of the invention to simulate combustion in the combustion chamber itself. This would be the case if it should not be desired to subject an existing combustion chamber to high temperatures until the combustion process likely to take place in the chamber has been investigated.

What we claim is:

1. Apparatus for simulating combustion in a combustion chamber, including a model geometrically similar to said combustion chamber, a fluid inlet in said model, a multiplicity of means capable of changing a property of a fluid, individual control means capable of controlling the effect of each of said property-changing means, a multiplicity of detectors and a number of indicating means corresponding to the multiplicity of detectors, said inlet being arranged to feed fluid representing combustion-supporting gas through the model, said property-changing means being spaced apart longitudinally and transversely within the region of the model corresponding to the combustion zone of the combustion chamber in order to change locally the relevant property of the fluid, said property changing means being distributed uniformly throughout the domain of flow of the fluid, said detectors being positioned to detect locally the change in property of the fluid effected by said property-changing means and each of said indicating means being operatively connected to one of the detectors, the number and spacing of said property changing means being such that the apparatus will simulate combustion.

2. Apparatus for simulating combustion in a combustion chamber, including a model geometrically similar to said combustion chamber, a fluid inlet in said model, a multiplicity of heating means, a multiplicity of temperature-responsive devices, individual control means capable of controlling the effect of each of said heating means, and indicating means, said inlet being arranged to feed fluid representing combustion-supporting gas through the model, said heating means being spaced apart longitudinally and transversely within the region of the model corresponding to the combustion zone of the combustion chamber in order to change locally the temperature of the fluid, said heating means being distributed uniformly throughout the domain of the flow of the fluid, each of said temperature-responsive devices being positioned within the model in the vicinity of one of said heating means, said control means being selectively operable to simulate the combustion process at temperatures substantially lower than combustion temperatures, and said indicating means being in operative connection with said temperature-responsive devices, the number and spacing of said heating means being such that the apparatus will simulate combustion.

3. Apparatus as claimed in claim 2, in which the heating means are constituted by wire coils, each coil having dimensions considerably smaller than the corresponding dimensions of the model.

4. Apparatus as claimed in claim 2, in which each of said control means is operatively connected to one of said indicating means.

5. Apparatus as claimed in claim 1, in which said model is constructed from tubular portions assembled end-to-end.

6. Apparatus as claimed in claim 5, in which each tubular portion has at least two lugs each having an aperture through which a bolt can pass to secure a plurality of tubular portions together.

7. Apparatus as claimed in claim 2, in which the heating means are constituted by concentric electric resistor rings spaced apart radially of each other, transversely of the model and spaced apart in groups longitudinally of the model.

8. Apparatus as claimed in claim 2, in which the heating means are constituted by arcuate lengths of electric resistance wire arranged in concentric rings spaced apart radially of each other, transversely of the model, and spaced apart in groups longitudinally of the model.

9. Apparatus as claimed in claim 7, in which the radial spacing of adjacent rings is such that the heat input per unit volume of the model in the region of the heater rings is uniform.

10. Apparatus as claimed in claim 2, in which said temperature-responsive devices are constituted by thermocouples, the hot-junctions of which are positioned in the vicinity of the heating means.

11. Apparatus for simulating combustion in a combustion chamber, including a model of said combustion chamber, a first fluid inlet in said model, a plurality of heating means, a plurality of temperature-responsive devices, control means capable of controlling the effect of said property-changing means, a second fluid inlet within the model, a plurality of fluid-sampling means and indicating means, said first inlet being arranged to feed fluid representing combustion-supporting gas through the model, said second inlet being arranged to introduce a second fluid representing fuel into the stream of fluid representing combustion-supporting gas in such a manner as to simulate introduction of fuel into a combustion-supporting gas, said plurality of fluid-sampling means being disposed within the model downstream of the second fluid inlet means to detect the distribution of said second fluid in the first fluid, said heating means being spaced apart longitudinally and transversely within the region of the model corresponding to the combustion zone of the combustion chamber in order to change locally the temperature of the fluid, each of said temperature-responsive devices being positioned within the model in the vicinity of the heating means, said control means

being selectively operable to simulate the combustion process at temperatures substantially lower than combustion temperatures, and said indicating means being in operative connection with said temperature-responsive devices.

12. Apparatus for simulating combustion in a combustion chamber, including a model of said combustion chamber, a first fluid inlet in said model, a plurality of heating means, a plurality of temperature-responsive devices, control means capable of controlling the effect of said property-changing means, a second fluid inlet within the model, a plurality of fluid-sampling means and indicating means, said first inlet being arranged to feed fluid representing combustion-supporting gas through the model, said second inlet being arranged to introduce a second fluid representing fuel into the stream of fluid representing combustion-supporting gas in such a manner as to simulate introduction of fuel into a combustion-supporting gas, said plurality of fluid-sampling means being disposed within the model downstream of the second fluid inlet means to detect the distribution of said second fluid in the first fluid, said heating means being spaced apart longitudinally and transversely within the region of the model corresponding to the combustion zone of the combustion chamber in order to change locally the temperature of the fluid, each of said temperature-responsive devices being positioned within the model in the vicinity of the heating means, each of the fluid-sampling means being disposed adjacent one of said heating means, said control means being selectively operable to simulate the combustion process at temperatures substantially lower than combustion temperatures, and said indicating means being in operative connection with said temperature-responsive devices.

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