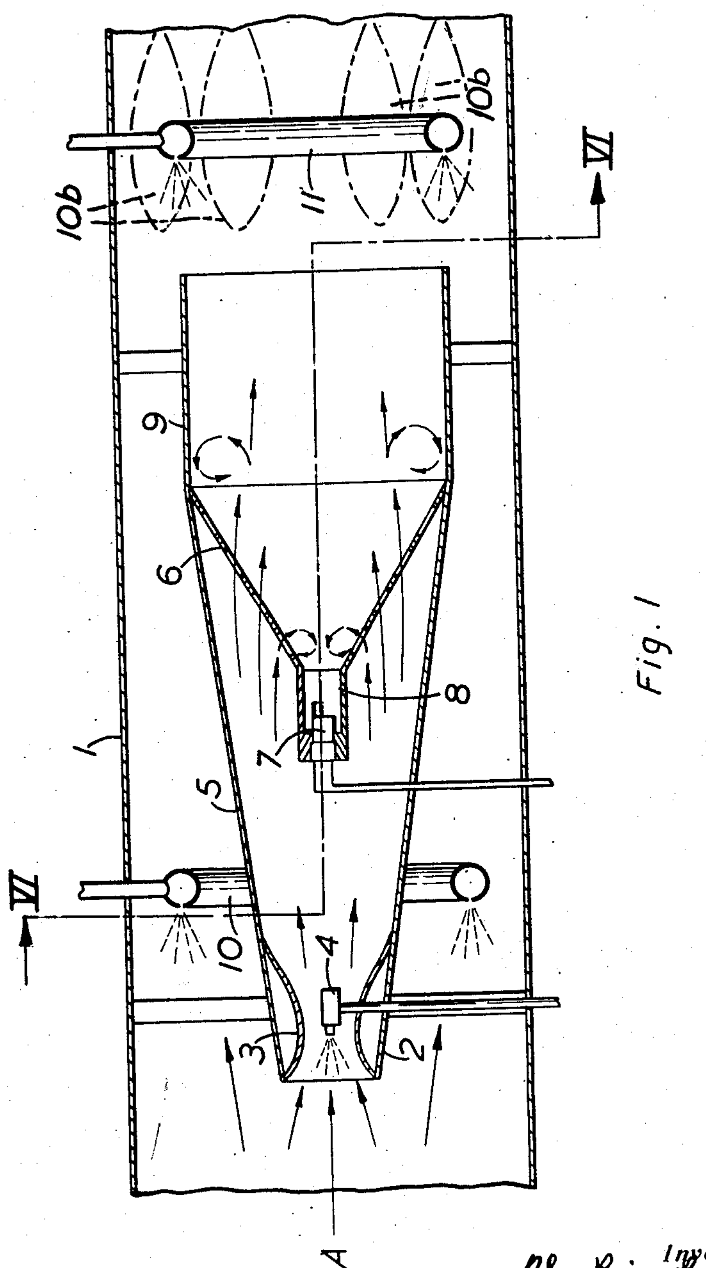
May 25, 1954 R. P. PROBERT 2,679,137

APPARATUS FOR BURNING FUEL IN A FAST MOVING GAS STREAM

Filed Oct. 14, 1948 5 Sheets-Sheet 1



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Filed Oct. 14, 1948 5 Sheets-Sheet 2

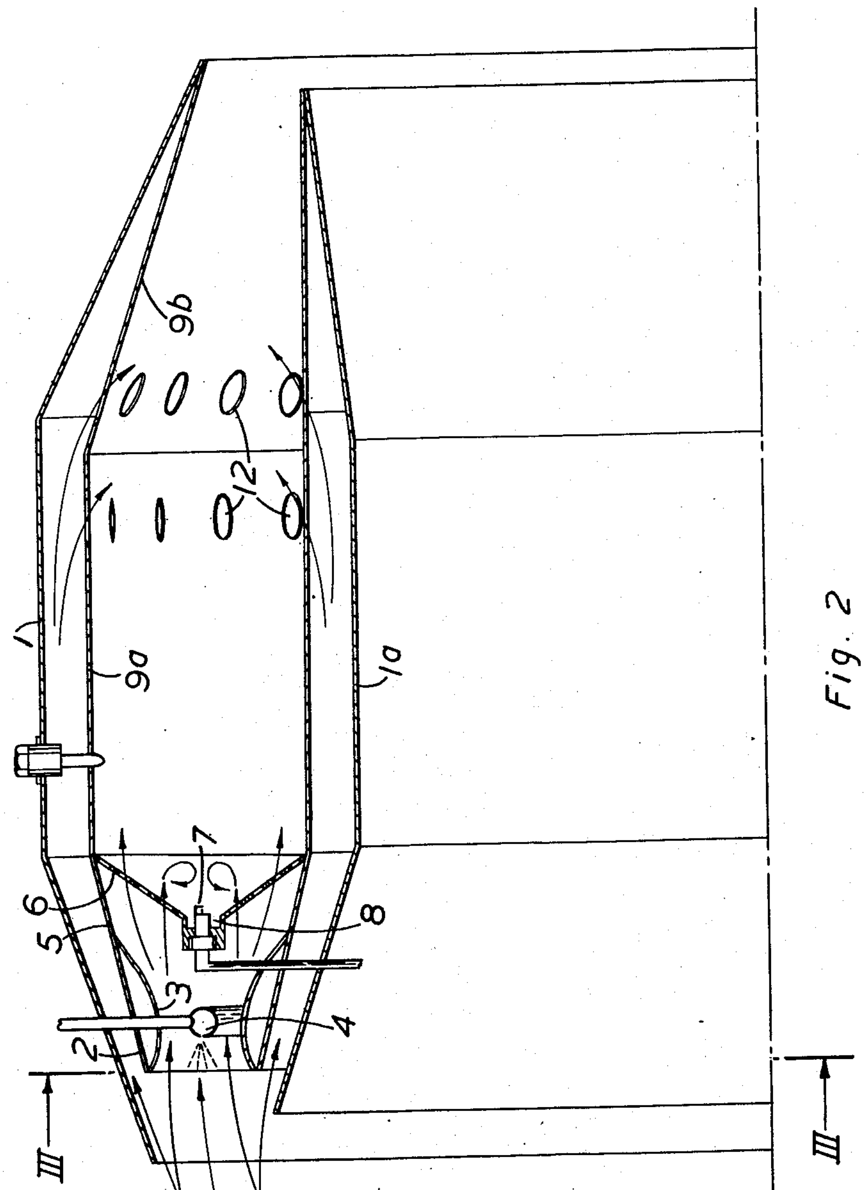

Fig. 2

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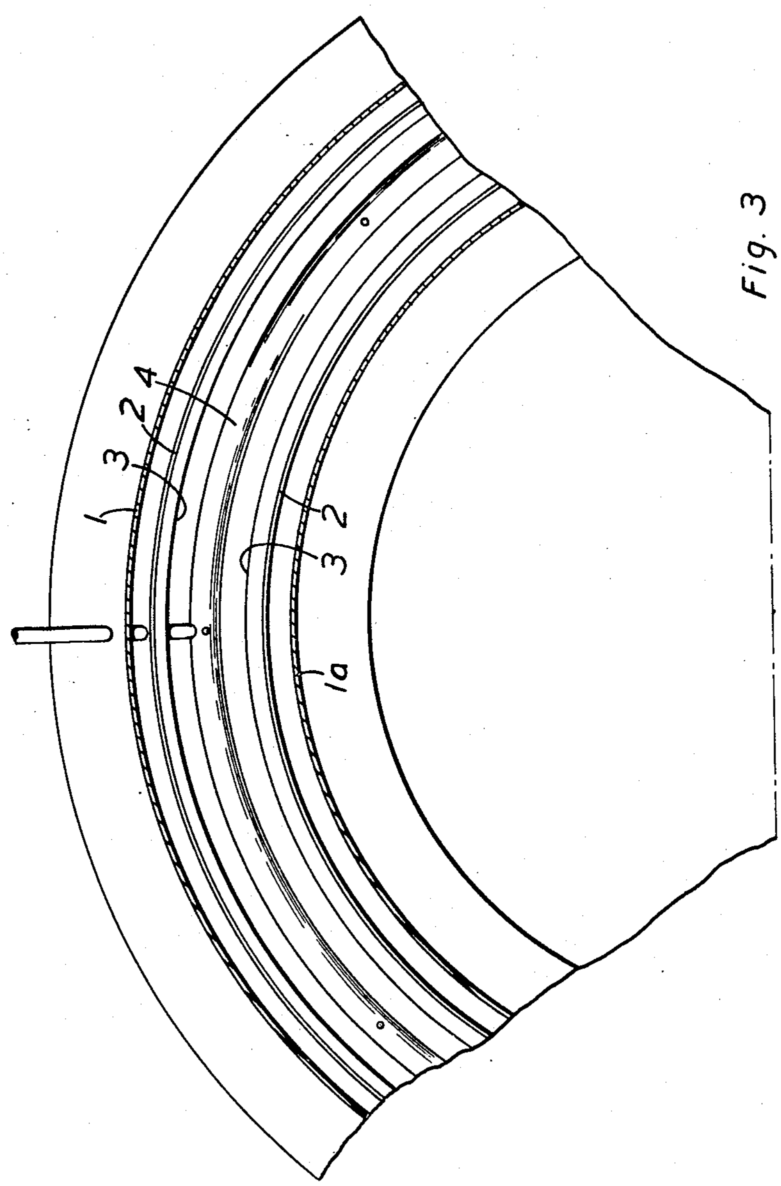

Fig. 3

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APPARATUS FOR BURNING FUEL IN A FAST MOVING GAS STREAM

Filed Oct. 14, 1948 5 Sheets-Sheet 4

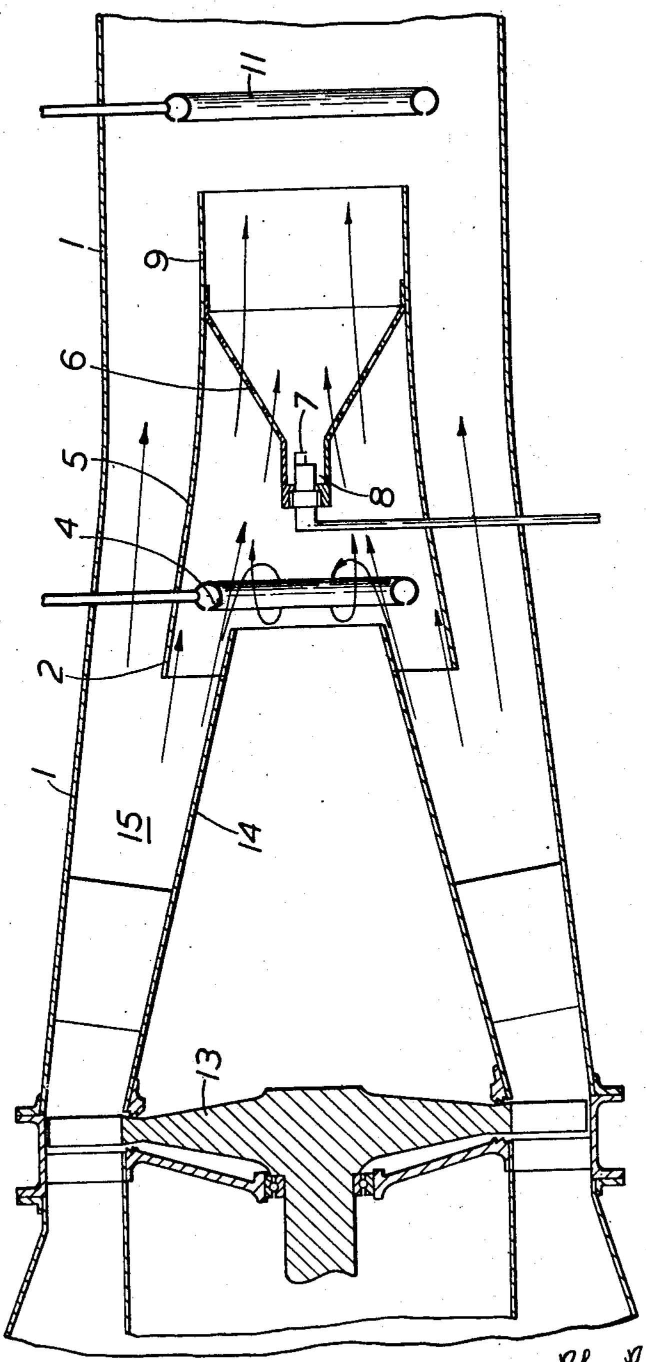

Fig. 4

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Filed Oct. 14, 1948 5 Sheets-Sheet 5

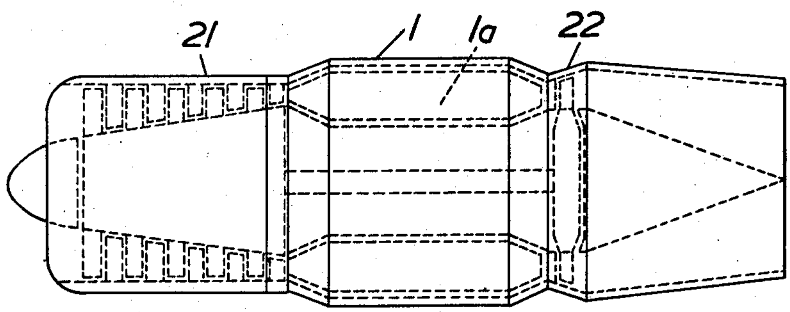

Fig. 5.

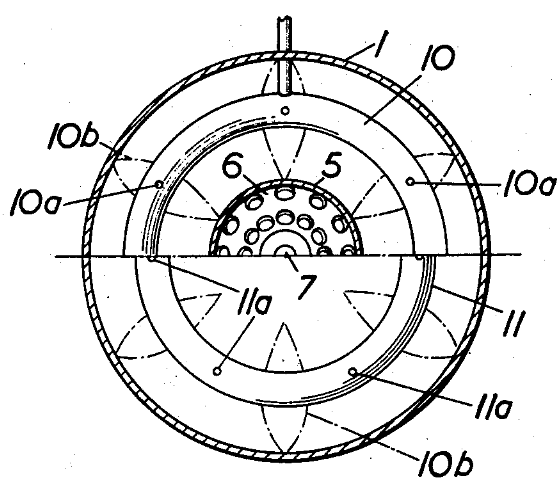

Fig. 6.

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APPARATUS FOR BURNING FUEL IN A FAST MOVING GAS STREAM

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Claims priority, application Great Britain October 21, 1947

6 Claims. (Cl. 60—39.72)

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This invention relates to combustion apparatus in which combustion is required to be supported by a flowing current of air or other gas (hereinafter referred to as "air") of flame-extinguishing velocity and its primary object, stated in general terms, is the provision of such an apparatus which will offer the possibility of effective and efficient combustion over a wide range of operating conditions.

Whilst, as will be seen after consideration of its details, the invention has possible application in a wider field, it is primarily concerned and is at present conceived to have its maximum utility in connection with combustion apparatus in which special problems arise due to the necessity for supporting continuous combustion by means of a fast moving air current involving a large mass flow, as for example, in gas turbine or other jet propulsion power units and in gas turbines for other purposes, the description "fast moving" being used here to indicate that the mean speed of the combustion supporting air current in its general direction of flow past a combustion zone, calculated from the ratio air volume passing in unit time/cross sectional area of flow path, is substantially higher than the speed of flame propagation in the fuel/air mixture concerned. For hydrocarbon fuels burning in air the speed of flame propagation is considered as being of the order of one foot per second at atmospheric temperature; the invention, on the other hand, is especially applicable to combustion apparatus for so-called "ram-jet" jet propulsion power units, as well as to other jet propulsion units and to gas turbine power units in general, in which the speed of the air current in its general direction of flow past a combustion zone, calculated on the basis indicated, might be of an order as low as 10 or as high as 500 feet per second or even more, depending on the design.

Satisfactory operation of a combustion system of the kind indicated over a wide range of air mass flow and density requires that the flame should not be extinguished under any conditions of operation and in order to prevent this the range of air/fuel ratio over which burning will take place must be as wide as possible whilst maintaining combustion efficiency at a reasonable level with weak mixture. Further, it is desirable that pressure losses should be low and that an even temperature distribution over the cross section of the flow should be achievable. Apart from the necessity for providing some means of preventing the flame from being blown out by the air flow, these requirements involve amongst other things the attainment of a high standard of mixing as between the combustion air and the fuel to be burnt, and of atomisation and distribution in the case of a liquid or powdered fuel. The usual practice in gas turbine and similar combustion systems is to inject liquid fuel into a region which is protected by a baffle from the full blast effect of the air flow, the fuel being ignited in this region to produce a pilot flame to which the main air flow is introduced at a downstream point, and the use of specially designed nozzles or of impact surfaces arranged in the path of the fuel jet being relied upon to achieve satisfactory atomisation of the fuel.

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According to the present invention there is provided a combustion apparatus in which combustion has to be supported by a ducted air flow of flame-extinguishing velocity and in which means are provided for forming in the flow a stabilised flame adapted to act as a pilot capable of maintaining combustion against an extinguishing velocity of the flow, wherein fuel to be burnt is introduced into air flowing into ignition relationship with said stabilised flame, and at a point upstream of that at which such relation is first established, the establishment of such relation at a point downstream of its point of introduction being relied upon for ignition of said fuel and the arrangement being such that in operation an opportunity is afforded to the fuel of mixing with the air flow prior to ignition.

Thus, in accordance with the invention, a combustion apparatus may comprise air ducting, means in said ducting adapted to form in a flow therethrough a combustion-stabilising zone in which a stable flame can be maintained notwithstanding a flame-extinguishing mean overall velocity of the flow past the combustion zone, and means for introducing fuel without ignition into a flow through the ducting at a point upstream of that at which said flow enters the stabilised flame zone.

According to a further feature of the invention means are provided for dividing the flow in the ducting and supplying a metered proportion thereof directly to the stabilised flame zone so that combustion therein is effected under controlled conditions of flow and fuel/air ratio, the remainder of the air flow being by-passed around said stabilised flame zone and mixing at the downstream side thereof with the hot gases generated therein.

In a preferred form of the invention the flame stabilising means is a baffle adapted to produce on its downstream side a localised reverse flow circulation system, said baffle being disposed to lie in a flow/air mixture derived from the introduction of fuel without ignition at a point upstream thereof; furthermore, the stabilising means preferably also provides for a pocket of "dead" air in which is disposed ignition means operable independently of the remainder of the system for starting purposes.

The fuel introduced upstream of the stabilising zone may, in some cases, constitute the sole or a main supply of fuel to be burnt, in which case the whole of the fuel introduced upstream of the flame stabilising zone may pass through said zone; according to a further feature of the invention, however, the stabilising zone is used only to produce a pilot flame, in which case whilst a part of the fuel introduced upstream thereof is made to pass through it, a further part of the fuel so introduced is by-passed around said zone and mixes at the downstream side thereof with the hot gases generated therein.

It will be appreciated from the foregoing that the invention is based on the idea of introducing fuel into the air flow at some substantial distance upstream of the point at which burning commences, and of maintaining a standing flame upon reaching which the fuel is ignited. Whilst such an arrangement has the advantage of improving the combustibility of the mixture by allowing the fuel to vapourise and diffuse before ignition, it may effect such improvement to the extent of giving rise to a dangerously explosive condition. With a view to meeting this difficulty the invention accordingly further contemplates an arrangement in which at least a part of the fuel supplied upstream of the zone of the stabilised flame is so introduced that a non-uniform fuel/air ratio is produced over the cross-section of the flow to be ignited in said zone, and further fuel to be burnt is introduced at a zone preferably downstream, and in any case not substantially upstream, of that at which such flow first enters the zone of the stabilised flame, the distribution of such further fuel supply over the cross section of the flow being complementary to that of the first-mentioned supply in the sense of rendering the fuel/air ratio more uniform over the cross section of the flow.

A valuable feature of the invention, particularly when the air flow is very fast moving is that it allows the fuel supplied to be exposed to the full impact effect of the air blast in order to assist in atomising and distributing the fuel. In this connection, this advantage may be enhanced, according to one further feature of the invention, by providing a flow-accelerating restriction in a region of fuel introduction and according to a second further feature by providing that the fuel to be burnt is injected in liquid form upstream into the air flow.

For the better understanding of the invention three examples of its application are illustrated in the accompanying diagrammatic drawings.

Figure 1 is a longitudinal section of a combustion apparatus for a "ram jet" or a propulsive duct type of jet propulsion device.

Figure 2 is a longitudinal half-section of an annular combustion chamber for a gas turbine plant.

Figure 3 is a fragmentary transverse section taken on the line III—III in Figure 2.

Figure 4 is a longitudinal section of a turbine exhaust duct having provision for reheating the turbine exhaust gases.

Figure 5 is an elevation of a gas turbine plant embodying the combustion chamber shown in Figure 2.

Figure 6 is a transverse section on the line VI—VI in Figure 1.

In the arrangement illustrated in Figure 1, 1 represents a duct which is presumed to receive atmospheric air due solely to its forward motion at high velocity, the arrow A representing the direction of the relative air flow in the duct, and to discharge it as a propulsive jet after the energy of the air flow has been increased by combustion of fuel therein. The combustion apparatus, following the invention, includes an inner duct comprising an entry portion 2 adapted to pass only a part of the air flow, this portion preferably containing a flow-accelerating restriction 3 in the neck of which liquid fuel is injected upstream by means of a simple spray jet 4. The entry portion 2 is followed downstream by a divergent diffuser or mixer portion 5 of which the downstream end contains a conical perforated baffle 6 having at its apex an ignition device 7 in a pocket 8, and downstream of which again is a cylindrical discharge portion 9. The parts so far described together form a pilot flame device; fuel injected by the jet 4 is atomised by the air flow and mixes and evaporates therein before passing through the holes in the baffle 6. The air/fuel mixture is discharged through these holes as small jets which, due to their inclination, set up standing eddies of local reverse flow circulation as indicated by arrows in the drawing, thereby providing the conditions required for a stable flame. The flow velocity in the diffuser 5 in use is of course far greater than the possible rate of upstream flame propagation by nomal combustion, so that there is no combustion upstream of the baffle 6 in the conditions of use. Ignition is best effected by arranging for the pocket 8 to constitute a "dead" region without mixture injection, the actual ignition device being either an electric spark gap as illustrated or a pyrotechnic cartridge.

The main body of fuel to be burnt is introduced (again by upstream injection of liquid fuel) in two stages at 10 and 11, the fuel supply 10 being into the main air flow by-passed around the inner duct, 2, 5, 9, but substantially upstream of the outlet from 9 at which the main air flow first enters ignition relationship with the pilot flame emerging therefrom, and the fuel supply 11 being downstream of the outlet from 9. The purpose of this two stage arrangement is to allow the fuel at 10 to be introduced deliberately with a markedly non-uniform distribution over the cross section of the air flow in order to avoid the formation of an explosive mixture upstream of the outlet from 9, the pattern of the supply at 11 being made complementary to that at 10 in the sense of rendering the flame intensity more uniform downstream of the outlet 9. For each stage of fuel supply a simple ring type liquid injection nozzle is used. As shown in the upper part of Figure 6, the upstream fuel supply ring 10 may have six nozzles 10a symmetrically disposed around its circumference, which will give rise to six streams of fuel which trail downstream from the ring 10, and which are ignited at the outlet from 9 to form six petal-like streaks of flame as indicated in dotted lines at 10b. The downstream fuel supply ring 11 also has six nozzles 11a symmetrically disposed around its circumference, but as shown in the lower half of Figure 6, these nozzles are circumferentially staggered with respect to the nozzles 10a so that the patterns of the fuel supply at 10 and 11 are complementary (in a circumferential sense) to one another, as mentioned above. Further the radius of the ring 11 is somewhat less than that of the ring 10 so that the fuel supply patterns of the two rings are also complementary in a radial sense.

A particular advantage of the method of flame formation in accordance with the invention is that it may readily be applied to shapes of combustion chamber not possessing circular symmetry with respect to the path of the air flow. For example, in the design of annular combustion chambers for gas turbines it is difficult to make full use of the air for primary combustion when the fuel, as is customary, is injected directly into the primary combustion zone. By the use of the invention the whole cross section of an annular flow to a primary or pilot combustion zone may have a relatively uniform distribution of fuel and air since the location and distribution of the fuel injectors, being separate from and upstream of the stabilised flame zone, do not control the requirements of the mixture flow in the stabilised flame zone. An example of application of the invention is illustrated in Figures 2 and 3, similar reference numbers to those in Figure 1 being used to indicate like or equivalent parts. In this case the main air duct is formed as an annular air casing bounded by outer and inner walls 1, 1*a*, and contains an inner duct, also formed as an annulus, which comprises an annular entry portion 2 provided with a flow-accelerating restriction 3 and spray jet 4 as in Figure 1, followed by a diffuser or mixer portion 5, and a perforated baffle 6 (which in this case is annular) provided at one or more points in the peripheral direction with an igniter device 7 in a pocket 8. In place of the short discharge portion 9, however, is an annular flame chamber 9*a* having a convergent annular discharge portion 9*b* whose outlet is coincident with that from the air casing 1, 1*a*, the flame chamber 9*a*, 9*b* having ports 12 for the entry of air from the air casing 1, 1*a*. The mode of operation is, in general, similar to that described with reference to Figure 1, except that the whole of the fuel to be burnt passes through the flame stabilising zone formed downstream of the baffle 6, which constitutes a primary or pilot combustion zone in which part of the fuel is burnt, the remainder being burnt and the combustion products diluted by the admission in the flame chamber 9*a*, 9*b*, in successive stages through the ports 12 of all the air by-passed at the entry 2 around the flame chamber 9*a*, 9*b*. The combustion apparatus illustrated in Figures 2 and 3 is intended to be used in a continuous combustion gas turbine of the kind shown in Figure 5 comprising a compressor 21 supplying air by way of a combustion system to a turbine 22, the air casing 1, 1*a*, being fed with air from the compressor outlet and discharging into the turbine nozzle, all of which is conventional and requires no further description.

Figure 4 is a longitudinal section illustrating a combustion turbine exhaust duct having the invention applied thereto for reheating the turbine exhaust gases, the same reference numerals as in the previous figures again being used as far as possible to indicate like or equivalent parts. In this case the main air duct 1 is the exhaust duct of an axial flow combustion turbine wheel 13, there being a blunt-ended fairing 14 downstream of the turbine wheel 13 defining with the duct 1 an annular channel 15. There is also an inner duct comprising an entry portion 2 forming, with the blunt downstream end of the fairing 14 a restricted annular inlet for the exhaust gases, the main flow of which is by-passed around the inner duct. The fuel spray 4 is in this case of the ring type to conform to the annular inlet and is followed as before by a diffuser or mixer portion 5, a conical perforated baffle 6 with igniter 7 and pocket 8, and a discharge portion 9. Downstream of this, again, is a second stage fuel supply 11. The mode of operation in this case is similar to that described with reference to Figure 1 except for the omission of the first stage of fuel supply at 10 in Figure 1 and that the blunt end of the fairing 14, together with the ring type spray 4, is used to form a local reverse flow circulation such as is indicated by the arrows in Figure 4 to increase the possibility of vapourizing and mixing of the fuel before ignition downstream of the baffle 6.

I claim:

1. Combustion apparatus in which fuel is to be burnt in a fast moving gas flow comprising a duct conveying said gas flow, an open ended tubular member located within and extending longitudinally of said duct, said member having a section which is divergent in the downstream direction, and forming a further duct through which a portion of the gas flow is passed, a stabilizing baffle located in a downstream region of said further duct, which baffle forms a stabilized combustion zone on its downstream side, means for introducing fuel into the portion of the gas flow passing through the tubular member in an upstream region thereof and also into the gas flow outside said tubular member, and ignition means located in said stabilized combustion zone.

2. Combustion apparatus in which fuel is to be burnt in a fast moving gas flow comprising a duct conveying said gas flow, an open ended tubular member located within and extending longitudinally of said duct, said member having a section which is divergent in the downstream direction, and forming a further duct through which a portion of the gas flow is passed, a stabilizing baffle located in a downstream region of said further duct, which baffle forms a stabilized combustion zone on its downstream side, fuel injection means located in an upstream region of said tubular member introducing fuel into the portion of the flow passing therethrough, further fuel injection means within the first-mentioned duct but outside said tubular member introducing fuel into the gas flow outside said tubular member and ignition means located in said stabilized combustion zone.

3. Combustion apparatus in which fuel is to be burnt in a fast moving gas flow, comprising a duct conveying said gas flow, an open ended tubular member located within and extending longitudinally of said duct, said member having a section which is divergent in the downstream direction, and forming a further duct through which a portion of the gas flow is passed, a stabilizing baffle located in a downstream region of said further duct, which baffle forms a stabilized combustion zone on its downstream side, fuel injection means located in an upstream region of said tubular member introducing fuel into the portion of the flow passing therethrough, fuel injection means symmetrically distributed around the first mentioned duct in the region of the downstream end of said tubular member, and ignition means located in said stabilized combustion zone.

4. Combustion apparatus in which fuel is to be burnt in a fast moving gas flow comprising a duct conveying said gas flow, an open ended tu-

bular member located within and extending longitudinally of said duct, said member having a flow accelerating restriction at its upstream end and a portion which is divergent in the downstream direction, and forming a further duct through which a portion of the gas flow is passed, a stabilizing baffle in a downstream region of said further duct, which baffle forms a stabilized combustion zone on its downstream side, fuel injection means located within said flow accelerating restriction introducing fuel into the portion of the flow passing through the tubular member, fuel injection means symmetrically distributed around the first-mentioned duct in the region of the downstream end of said tubular member, further fuel injection means symmetrically distributed around said first-mentioned duct externally of said tubular member and intermediate its ends, and ignition means located in said stabilized combustion zone.

5. Combustion apparatus in which fuel is to be burnt in a fast moving gas flow comprising a duct conveying said gas flow, an open ended tubular member located within and extending longitudinally of said duct, said member having a section which is divergent in the downstream direction, and forming a further duct through which a portion of the gas flow is passed, a conical foraminated baffle having its apex directed upstream located in a downstream region of said further duct, which baffle forms a stabilized combustion zone on its downstream side, fuel injection means located within said first mentioned duct and upstream of said baffle, introducing fuel into said portion of the gas flow flowing through the tubular member, and ignition means located in said stabilized combustion zone.

6. Combustion apparatus in which fuel is to be burnt in a fast moving gas flow comprising a duct conveying said gas flow, an open ended tubular member located within and extending longitudinally of said duct, said member having a section which is divergent in the downstream direction and forming a further duct through which a portion of the gas flow is passed, a stabilising baffle located in a downstream region of said further duct, which baffle forms a stabilised combustion zone on its downstream side, fuel injection means located in an upstream region of said tubular member introducing fuel into the portion of the flow passing therethrough, further fuel injection means disposed within said first mentioned duct externally of said tubular member and intermediate its ends and ignition means located in said stabilised combustion zone.

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