Nov. 1, 1960 F. J. BAYLEY 2,958,194

COOLED FLAME TUBE

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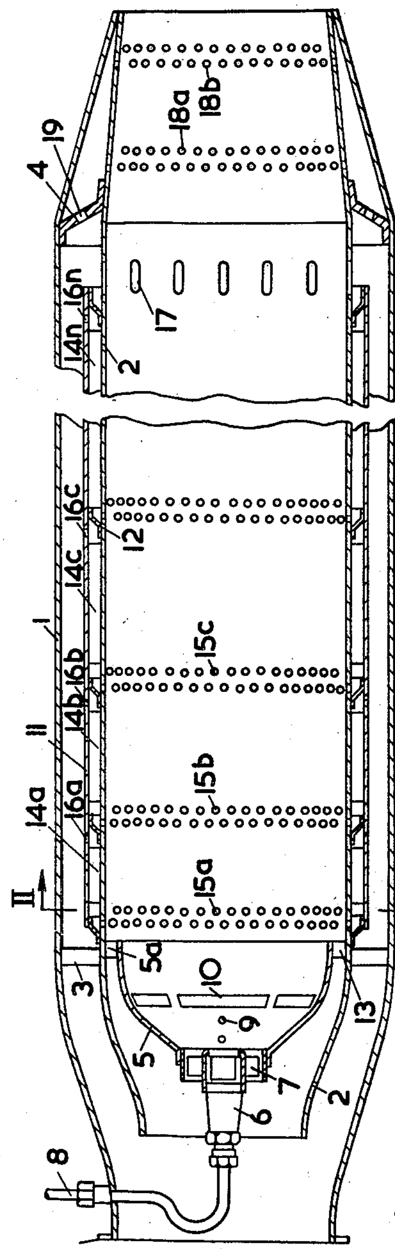

Fig. 1.

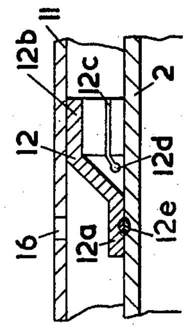

Fig. 3.

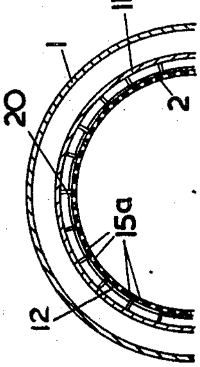

Fig. 2.

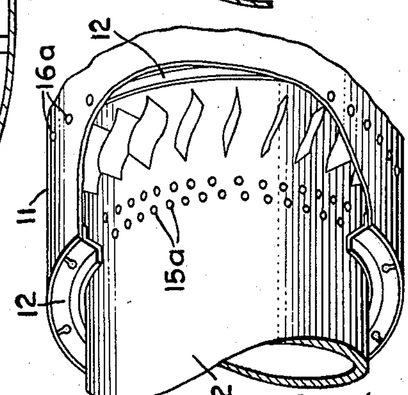

Fig. 1a

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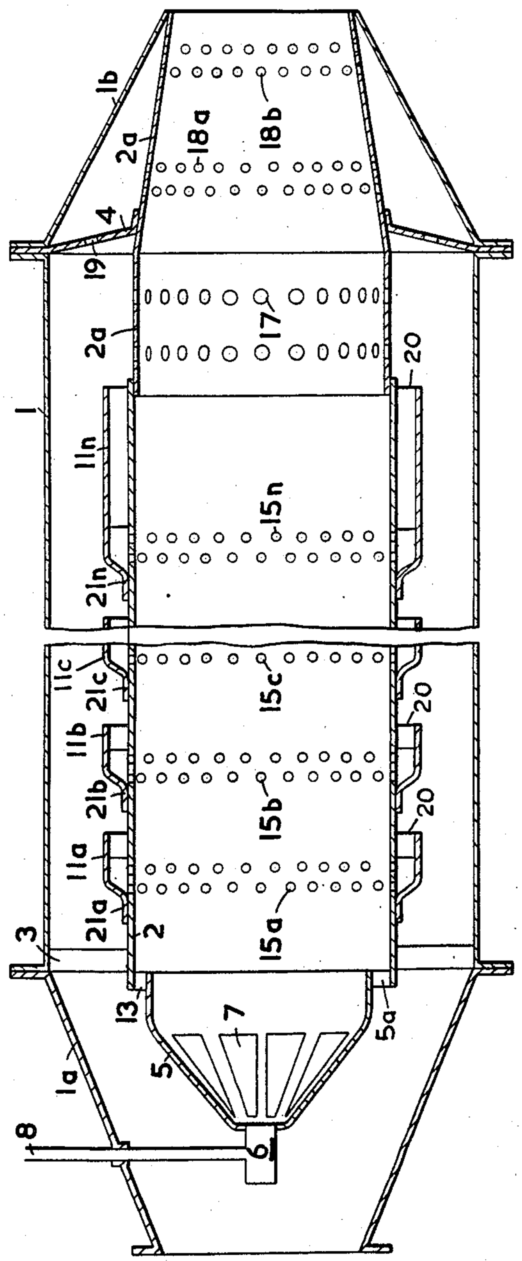

FIG. 4

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COOLED FLAME TUBE

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11 Claims. (Cl. 60—39.65)

This invention relates to combustion apparatus and is particularly concerned with the problem of cooling the walls of flame tubes and like devices enclosing a space in which combustion takes place. It is particularly applicable to combustion chambers, such as those used in gas turbine plants, which comprise a flame tube mounted within an enclosing air casing, part of the air supply entering the flame tube at one end as primary air, and part flowing around the outside thereof and entering further downstream as secondary and/or cooling air, or in some cases mixing with the hot gases leaving the flame tube.

The air flowing around the outside of the flame tube has some cooling effect. This may be supplemented by introducing a fairly small amount of air into the upstream end of the flame tube so that it flows at the same speed as the hot gases along the wall as a thin film or layer, thus protecting the wall from the direct effect of the hot gases. A system of this type is described in United States patent to Lloyd et al., No. 2,664,702, issued January 2, 1954. The effectiveness of this method is limited by the difficulty of maintaining this cooling layer for an adequate distance along the length of the flame tube, and it is accordingly necessary to renew the layer at frequent intervals.

Accordingly the present invention provides combustion apparatus comprising a flame tube and an enclosing jacket annularly spaced from the peripheral wall thereof, the space between the flame tube and the jacket being divided into a plurality of axially successive sections, and each section being open at one end to the exterior of the jacket and at the other end to the interior of the flame tube to form a passage for the flow of cooling air therethrough.

So as to form the thin cooling layer of air next to the wall of the flame tube, the passages for cooling air are preferably so dimensioned that the cooling air enters with a radial velocity substantially equal to and in any case not greater than the axial velocity of the gases within the flame tube.

The invention will be more fully described with reference to the accompanying drawings, of which:

Figure 1 is a longitudinal section of one embodiment of the invention.

Figure 1*a* is a fragmentary perspective view of the flame tube shown in Figure 1.

Figure 2 is a half section on the line II—II in Figure 1.

Figure 3 shows a detail of the embodiment of Figure 1.

Figure 4 is a longitudinal section of a second embodiment.

Referring to Figure 1 a combustion chamber for a gas turbine plant comprises an air casing **1** and a flame tube **2** within it. The upstream end of the air casing is generally frusto-conical in shape, being divergent in the downstream direction and is provided with a flange **22** for attachment to the duct carrying the air supply, for example, from a compressor. The downstream end of the air casing is also somewhat tapered, being convergent in the downstream direction and may fit into a chute leading to the turbine nozzle. The flame tube **2** is similarly formed

with divergent and convergent portions at its upstream and downstream ends respectively. It is supported in the air casing **1** by brackets **3** towards its upstream end and by a frusto-conical flange number **4** towards its downstream end.

Mounted within the upstream end of the flame tube **2** is a generally frusto-conical baffle **5** supported therein by brackets **5***a*, so that its wider end forms with the flame tube wall an annular gap **13** for cooling air. A fuel injector **6** extends into the upstream end of the baffle, being supported therein by swirl vanes **7**, and is connected to a fuel supply by pipe **8**. The baffle is perforated at **9**, **10** for the admission of combustion air to the space within the baffle.

Surrounding the peripheral wall of the flame tube **2** is a jacket **11**. The jacket is carried on a number of annular bracket members **12** (shown in more detail in Figure 3) which also constitute walls dividing the annular space between the flame tube and the jacket into a number of axially successive annular sections **14***a*, **14***b*, **14***c* . . . **14***n*. The flame tube is formed with a double row of small apertures **15***a*, **15***b*, etc. at the upstream end of each of these sections, while the jacket is formed with a ring of small apertures **16***a*, **16***b*, etc. at the downstream end of each section. The apertures and annular sections thus constitute a number of separate annular passages for cooling air.

The jacket **11** does not extend the full length of the flame tube, and beyond its downstream end the flame tube is formed with a number of comparatively large elongated apertures **17** for the admission of dilution air. The tapered portion at the downstream end of the flame tube is also formed with two axially spaced series of small holes **18***a*, **18***b*, each series consisting of two rings of holes similar to the holes **15***a*, **15***b*, etc. The annular bracket member **4** is perforated at **19** to allow air to enter the space between the downstream ends of the air casing **1** and the flame tube **2** to flow through the holes **18***a*, **18***b* as cooling air.

Referring to Figure 2, the annular sections **14***a*, **14***b*, etc. between the flame tube **2** and jacket **11** are divided circumferentially by longitudinally extending fins **20** attached to the flame tube walls and forming secondary cooling surfaces.

Figure 3 shows on an enlarged scale one of the bracket members supporting the jacket **11** on the flame tube **2**. The brackets are approximately Z-shaped in section, and one arm **12***a* is attached, for example by welding **12***e*, to the flame tube wall. The other arm **12***b* is not attached to the jacket which is free to slide thereon. Thus if differential thermal expansion should arise through the flame tube expanding to a greater extent than the jacket, the central frusto-conical part of the bracket will be able to bend over slightly to allow for the reduced radial dimension of the annular space. The arm **12***b* and the central portion of the bracket are formed with a number of narrow axially extending slits **12***c* terminating in holes **12***d* to facilitate this bending.

In operation, air enters the air casing **1** and part is divided off and enters the upstream end of the flame tube **2**. Of this part of the air, some passes into the interior of the baffle **5** through the swirl vanes **7** and the perforations **9** and **10** as primary combustion air. The baffle forms a stabilised combustion zone in which the fuel from the injector **6** is burnt and the resultant stream of hot combustion gases passes down the flame tube towards the outlet at a high velocity.

A comparatively small part of the air entering the flame tube passes through the accelerating passage formed between the baffle **5** and the upstream part of the flame tube wall and enters the main part of the flame tube through the annular gap **13**. This gap is so dimensioned that in some particular condition of operation, for example full power, the axial velocity of the stream of air therethrough is substantially the same as and in any case not greater than the axial velocity of the stream of combustion gases along the flame tube. As explained in said United States Patent No. 2,664,702, the air thus tends to form an annular layer of cool air next to the flame tube wall, thus protecting it from the full heating effect of the hot gases. As previously mentioned however, this layer may not persist. There is a great deal of turbulence within the baffle 5 and the cooling layer tends to be drawn into this turbulent zone, and hence its cooling effect may not persist very far downstream.

The part of the air not passing into the flame tube passes around the outside thereof in the conventional manner and thus has a certain cooling effect. A comparatively small amount of this air passes through the apertures **16a** in the jacket **11** into the space **14a** and then through the apertures **15a** into the interior of the flame tube. In flowing through the space **14a** the air has a considerable convective cooling effect. It is intended that the air on entering the flame tube shall flow along the wall thereof as a cooling layer in the same way as the air entering through the gap **13**. It is found by experiment that for this purpose the air should enter through the apertures **15a** with a radial velocity not greater than the axial velocity of the hot gases. The pressure of the air in the air casing is higher than the pressure of the hot gases in the flame tube, so there will be no difficulty in maintaining the cooling flow and the apertures **15a** can be so dimensioned to give the required velocity. If the pressure drop caused by the apertures **15a** is insufficient, an additional pressure drop can be achieved by suitably dimensioning the apertures **16a**. Alternatively or in addition the fins **20** within the jacket may be spirally disposed so that the effective cross-sectional area of the flow path for the cooling air through the section **14a** is reduced and the air consequently will achieve a greater velocity. This arrangement will enhance the convective cooling effect of the air before it enters the flame tube.

To establish a satisfactory cooling layer of air within the flame tube, the air should ideally enter the flame tube through an aperture constituting a complete circumferentially extending annulus. In practice it would be difficult to maintain the accurate dimensioning of such an aperture due to thermal expansion of the flame tube and so it is preferred to use two or more rows of circular holes, staggered with respect to one another so that they in effect form a complete ring. In the embodiment shown in Figure 1, two rows are used, the holes being pitched circumferentially and axially one diameter apart, and the two rows being staggered. Holes of the order of 1/16" diameter are found to give satisfactory results. In the drawings however, these holes are shown as enlarged out of proportion to the rest of the assembly.

From experiment it is found that the cooling air as it enters the flame tube produces a considerable local cooling effect on the part of the wall immediately around the apertures **15a**. The air then mixes with a certain amount of the hot gases, consequently increasing in temperature, and then flows in a thin layer along the inside of the flame tube wall. This layer decays by mixing with the hot gas stream and accordingly its temperature gradually rises. The wall temperaure is initially lower than that of the cooling layer, due to the initial cooling effect of the air, but its temperature rises at a greater rate than that of the cooling layer so that their temperatures soon tend to the same value. This temperature will be allowed to rise until it reaches a value corresponding to the maximum permissible temperature of the wall. At this point the layer is renewed by a further stream of cooling air flowing through the apertures **16b** in the jacket, the section **14b** and then entering the flame tube through apertures **15b**. This cooling layer in turn decays and is replaced by a new layer formed at the apertures **15c**, and so on down the flame tube. Each section **14b**, **14c** etc. and its apertures is designed to produce the pressure drop necessary to promote the desired flow velocity as described above. Each section will include spirally disposed fins if necessary and the flame tube apertures will consist of double rows of holes similar to those at **15a**.

From theoretical considerations it can be shown that ideally the cooling layer decays, i.e. its temperature increases, in accordance with an exponential law, and hence the axial spacing of the rows of apertures could be calculated. This can only be used as a guide however, since it is difficult to predict the performance of the flame tube from purely theoretical considerations particularly at the upstream end of the flame tube. This is partly due to the violent turbulence associated with the primary combustion zone which tends to break up the cooling layer more rapidly than would otherwise be the case, and partly due to the fact that the above theoretically consideration does not take into account the effects of radiation. When the fuel is such as to burn with a very luminous flame, the heating effects thereof are considerable since the cooling layer offers little or no resistance to radiation. The flame tube wall temperature therefore increases at a greater rate than would appear from theoretical considerations and it is found necessary to reduce the axial spacing of the injection apertures **15a**, **15b** etc. and consequently the length of the annular sections **14a**, **14b**, etc. at least at the upstream end of the flame tube. Further downstream however the disturbing factors have less influence and the axial spacing of the apertures may be progressively increased as shown in Figure 1.

It will thus be seen that the air entering through the flame tube walls has a double cooling effect. First in passing through the annular sections **14a**, **14b**, it has a convective cooling effect which may be augmented by the use of the fins **20** as secondary cooling surfaces. Secondly, on entering the flame tube the air forms a protective cooling layer next to the wall on the flame tube. This layer is renewed as it reaches a maximum permissible temperature, the air entering at **15a** replacing the layer formed by gap **13**, the air entering at **15b** replacing the layer formed at **15a**, and so on.

Since the cooling air within the jacket flows in the opposite direction to the cooling layer within the flame tube, there is a greater tendency for the wall to assume a uniform temperature, since the hottest part of the layer is where the air is coolest, that is, where it enters within the jacket.

As mentioned above the jacket does not extend the full length of the flame tube. The greater part of the air flowing around the outside of the flame tube enters therein as dilution air through the apertures **17** downstream of the jacket. A small portion of air passes through metering orifice **19** in the bracket **4** and enters the discharge end of the flame tube as cooling air through sets of apertures **18a**, **18b**. Each set consists of a double row of holes similar to those at **15a**, **15b**. This air is also intended to form a cooling layer, so again the radial velocity of the air passing through the holes should be equal to the axial velocity of the hot gases, and the metering orifices **19** are designed to produce the required pressure drop. Conditions in this part of the flame tube will not be so severe as further upstream since the gas temperature has been reduced by the introduction of dilution air through apertures **17**.

The embodiment shown in Figure 4 is the same in principle as the embodiment of Figure 1 but differs in constructional detail. The same reference numerals have been used as far as possible for corresponding parts.

The combustion chamber comprises an outer air casing **1** having a divergent inlet portion **1a** and a convergent outlet portion **1b**. The flame tube **2** differs from the flame tube in Figure 1 in that it has no divergent portion at its upstream end but it has an outlet section **2a** fitting into its downstream end. A baffle **5** fits into the upstream of the flame tube 2 defining therewith an annular gap 13 for cooling air, and fuel is supplied to the interior of the baffle by pipe 8 and fuel injector 6. The baffle is provided with apertures for the admission of combustion air and swirlers 7 are located in these apertures.

The main difference in the construction is that the jacket is made up of a number of individual jacket members **11***a*, **11***b*, **11***c* . . . **11***n*. Each is attached at its upstream end to a cylindrical portion **21***a*, **21***b*, **21***c* . . . **21***n* of reduced diameter which is welded or otherwise secured to the flame tube wall. The upstream end of each jacket section is left open to constitute an inlet for cooling air. Cooling fins **20** are provided within the jacket members and the air is led into the flame tube through double rows of holes as in the first embodiment. As before the dimensioning of the cooling air passages will be such as to give rise to a layer of cooling air next to the flame tube wall.

Downstream of the last jacket member **11***n*, the outlet section **2***a* of the flame tube wall is formed with perforation **17** for the admission of dilution air, and the outlet portion of the flame tube is cooled in exactly the manner described with respect to Figure 1.

I claim:

1. In combustion apparatus comprising an aircasing having an air inlet, and an elongated flame tube enclosed by and spaced from the walls of the aircasing and having a tubular peripheral wall, an air inlet at one end, means for supplying fuel to said end of the flame tube for combustion therein, and an outlet at the other end, whereby the flame tube defines a path for a stream of hot combustion gases flowing axially thereof; means for forming a layer of cooling air along the inside of the flame tube peripheral wall, said means comprising a tubular jacket enclosing the flame tube for at least part of its length and radially spaced from the peripheral wall thereof to define therewith an annular space; a wall closing one end of said space; the flame tube peripheral wall being formed with plurality of radially facing openings together extending around substantially the whole circumference of the flame tube connecting the space to the interior of the flame tube and the space being open to the exterior of the jacket at a position axially spaced along its length from the radially facing opening; the openings and annular space constituting a passage for the flow of cooling air from the exterior of the jacket to the interior of the flame tube, and being so dimensioned in relation to the conditions inside the flame tube and outside the jacket that the radial velocity of the stream of cooling air through said radially facing openings is at most equal to the velocity of said stream of combustion gases axially of the flame tube.

2. In combustion apparatus comprising an aircasing having an air inlet, and an elongated flame tube enclosed by and spaced from the walls of the aircasing and having a tubular pheripheral wall, an air inlet at one end, means for supplying fuel to said end of the flame tube for combustion therein, and an outlet at the other end, whereby the flame tube defines a path for a stream of hot combustion gases flowing axially thereof; means for forming a layer of cooling air along the inside of the flame tube peripheral wall, said means comprising a tubular jacket enclosing the flame tube for at least part of its length and radially spaced from the peripheral wall thereof to define therewith an annular space; a wall closing one end of said space; the flame tube peripheral wall being formed with plurality of radially facing openings together extending around substantially the whole circumference of the flame tube at the upstream end of the annular space, in relation to the direction of flow of the combustion gases, connecting the space to the interior of the flame tube and the space being open at the other end to the exterior of the jacket; the openings and annular space constituting a passage for the flow of cooling air from the exterior of the jacket to the interior of flame tube, and being so dimensioned in relation to the conditions inside the flame tube and outside the jacket that the radial velocity of the stream of cooling air through said radially facing openings is at most equal to the velocity of said stream of combustion gases axially of the flame tube.

3. Combustion apparatus according to claim 2 wherein the plurality of radially facing openings comprise two axially spaced rows of holes extending circumferentially of the flame tube, the holes of the two rows being staggered with respect to one another and each hole having a circumferential width at least equal to the distance between the edges of adjacent holes in the other row.

4. Combustion apparatus according to claim 2 further comprising fins in heat conducting relationship with the flame tube peripheral wall and extending outwardly therefrom into said annular space.

5. Combustion apparatus according to claim 4 wherein said fins are spirally arranged with respect to the flame tube axis.

6. In combustion apparatus comprising an aircasing having an air inlet, and an elongated flame tube enclosed by and spaced from the walls of the aircasing and having a tubular peripheral wall, an air inlet at one end, means for supplying fuel to said end of the flame tube for combustion therein and an outlet at the other end, whereby the flame tube defines a path for a stream of hot combustion gases flowing axially thereof; means for forming a layer of cooling air along the inside of the flame tube peripheral wall, said means comprising annular walls outside the flame tube peripheral wall and defining therewith a plurality of axially successive annular spaces surrounding and spaced along the length of the flame tube; the flame tube peripheral wall being formed with plurality of radially facing openings together extending around substantially the whole circumference of the flame tube connecting each annular space to the interior of the flame tube, and each annular space being open to the interior of the aircasing at a position axially spaced along its length from its radially facing openings; the openings and annular spaces constituting passages for the flow of cooling air from the interior of the aircasing to the interior of the flame tube and being so dimensioned in relation to the conditions inside the flame tube and inside the aircasing that the radial velocity of the streams of cooling air through said radially facing openings is at most equal to the velocity of said stream of combustion gases axially of the flame tube.

7. In combustion apparatus comprising an aircasing having an air inlet, and an elongated flame tube enclosed by and spaced from the walls of the aircasing and having a tubular peripheral wall, an air inlet at one end, means for supplying fuel to said end of the flame tube for combustion therein and an outlet at the other end, whereby the flame tube defines a path for a stream of hot combustion gases flowing axially thereof; means for forming a layer of cooling air along the inside of the flame tube peripheral wall, said means comprising annular walls outside the flame tube peripheral wall and defining therewith a plurality of axially successive annular spaces surrounding and spaced along the length of the flame tube; the flame tube peripheral wall being formed with plurality of radially facing openings together extending around substantially the whole circumference of the flame tube at the upstream end of each annular space, in relation to the direction of flow of the combustion gases, connecting the spaces to the interior of the flame tube and each space being open at the other end to the interior of the aircasing; the openings and annular spaces constituting passages for the flow of cooling air from the interior of the aircasing to the interior of the flame tube and being so dimensioned in relation to the conditions inside the flame tube and inside the aircasing that the radial velocity of the streams of cooling air through said radially facing

openings is at most equal to the velocity of said stream of combustion gases axially of the flame tube.

8. In combustion apparatus comprising an aircasing having an air inlet, and an elongated flame tube enclosed by and spaced from the walls of the aircasing and having a tubular peripheral wall, an air inlet at one end, means for supplying fuel to said end of the flame tube for combustion therein and an outlet at the other end, whereby the flame tube defines a path for a stream of combustion gases flowing axially thereof; means for forming a layer of cooling air along the inside of the flame tube peripheral wall, said means comprising a tubular jacket enclosing the flame tube for at least part of its length and radially spaced from the peripheral wall thereof to define therewith an annular space; walls dividing said space into a plurality of axially successive annular sections; the flame tube peripheral wall being formed with plurality of radially facing openings together extending around substantially the whole circumference of the flame tube connecting each annular section to the interior of the flame tube, and the jacket being formed with openings connecting each annular section to the exterior of the jacket at a position axially spaced along its length from its radially facing openings; the openings and annular sections constituting passages for the flow of cooling air from the exterior of the jacket to the interior of the flame tube and being so dimensioned in relation to the conditions inside the flame tube and outside the jacket that the radial velocity of the streams of cooling air through said radially facing openings is at most equal to the velocity of said stream of combustion gases axially of the flame tube.

9. In combustion apparatus comprising an air casing having an air inlet, and an elongated flame tube enclosed by and spaced from the walls of the aircasing and having a tubular peripheral wall, an air inlet at one end, means for supplying fuel to said end of the flame tube for combustion therein and an outlet at the other end, whereby the flame tube defines a path for a stream of combustion gases flowing axially thereof; means for forming a layer of cooling air along the inside of the flame tube peripheral wall, said means comprising a tubular jacket enclosing the flame tube for at least part of its length and radially spaced from the peripheral wall thereof to define therewith an annular space; walls dividing said space into a plurality of axially successive annular sections; the flame tube peripheral wall being formed with plurality of radially facing openings together extending around substantially the whole circumference of the flame tube at the upstream end of each annular section, in relation to the direction of flow of the combustion gases, connecting the sections with the interior of the flame tube, and the jacket being formed with openings at the other end of each section connecting the sections to the exterior of the jackets; the openings and annular sections constituting passages for the flow of cooling air from the exterior of the jacket to the interior of the flame tube and being so dimensioned in relation to the conditions inside the flame tube and outside the jacket that the radial velocity of the streams of cooling air through said radially facing openings is at most equal to the velocity of said stream of combustion gases axially of the flame tube.

10. In combustion apparatus comprising an air casing having an air inlet, and an elongated flame tube enclosed by and spaced from the walls of the aircasing and having a tubular peripheral wall, an air inlet at one end, means for supplying fuel to said end of the flame tube for com-

bustion therein, and an outlet at the other end, whereby the flame tube defines a path for a stream of hot combustion gases flowing axially thereof; means for forming a layer of cooling air along the inside of the flame tube peripheral wall, said means comprising a plurality of axially successive tubular jackets together enclosing the flame tube for at least part of its length and radially spaced from the peripheral wall thereof to define therewith a plurality of axially successive annular spaces; walls closing one end of each said space; the other end of each jacket being axially spaced from the adjacent end of the adjacent jacket to define an opening connecting the space within the jacket with the exterior of the jackets; the flame tube peripheral wall being formed with plurality of radially facing openings together extending around substantially the whole circumference of the flame tube connecting each annular space to the interior of the flame tube at a position axially spaced from said first mentioned opening; the openings and annular spaces constituting passages for the flow of cooling air from the exterior of the jackets to the interior of the flame tube and being so dimensioned in relation to the conditions inside the flame tube and outside the jackets that the radial velocity of the streams of cooling air through said radially facing openings is at most equal to the velocity of said streams of combustion gases axially of the flame tube.

11. In combustion apparatus comprising an aircasing having an air inlet, and an elongated flame tube enclosed by and spaced from the walls of the aircasing and having a tubular peripheral wall, an air inlet at one end, means for supplying fuel to said end of the flame tube for combustion therein, and an outlet at the other end, whereby the flame tube defines a path for a stream of hot combustion gases flowing axially thereof; means for forming a layer of cooling air along the inside of the flame tube peripheral wall, said means comprising a plurality of axially successive tubular jackets together enclosing the flame tube for at least part of its length and radially spaced from the peripheral wall thereof to define therewith a plurality of axially successive annular spaces; walls closing the upstream ends, in relation to the direction of flow of the combustion gases, of each said space; the downstream end of each jacket being axially spaced from the upstream end of adjacent jacket to define an opening connecting the space within the jacket with the exterior of the jackets; the flame tube peripheral wall being formed with plurality of radially facing openings together extending around substantially the whole circumference of the flame tube at the upstream end of each annular space connecting each annular space with the interior of the flame tube; the openings and annular spaces constituting passages for the flow of cooling air from the exterior of the jackets to the interior of the flame tube and being so dimensioned in relation to the conditions inside the flame tube and outside the jackets that the radial velocity of the streams of cooling air through said radially facing openings is at most equal to the velocity of said stream of combustion gases axially of the flame tube.

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