Aug. 30, 1955 S. WAY 2,716,330

COMBUSTION APPARATUS HAVING PRIMARY AIR PREHEATING DUCTS

Filed June 24, 1950 2 Sheets-Sheet 1

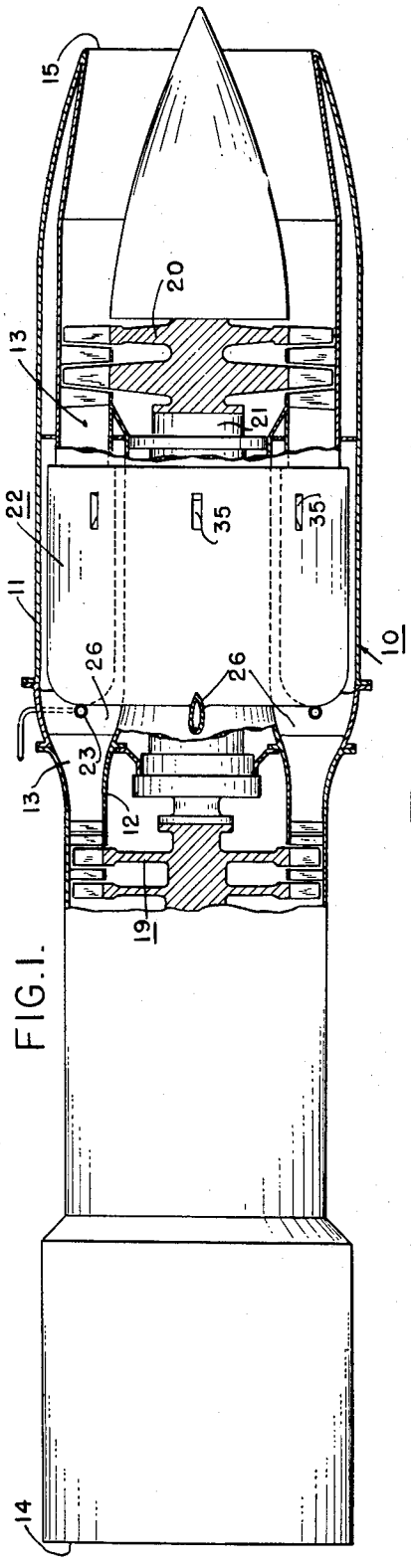


FIG. 1.

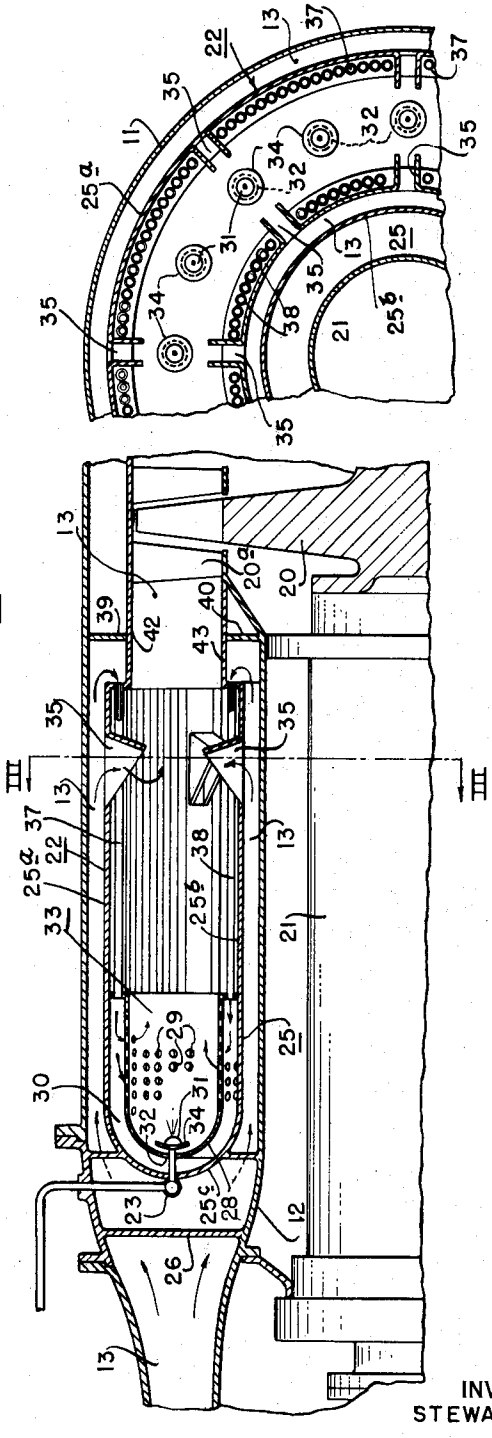


FIG. 2.

FIG. 3.

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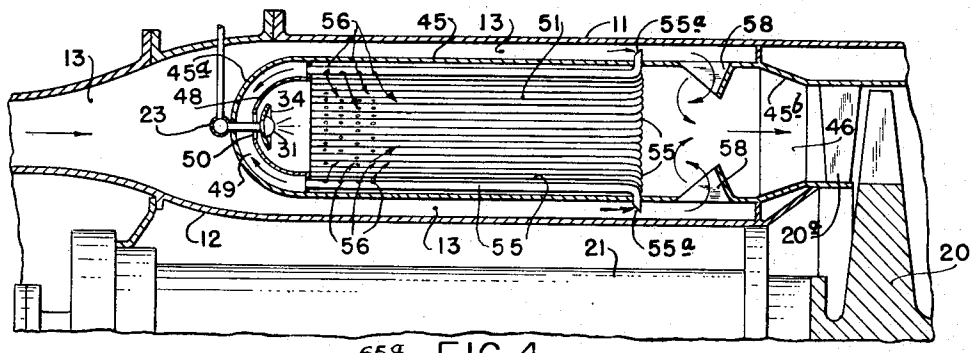


FIG. 4.

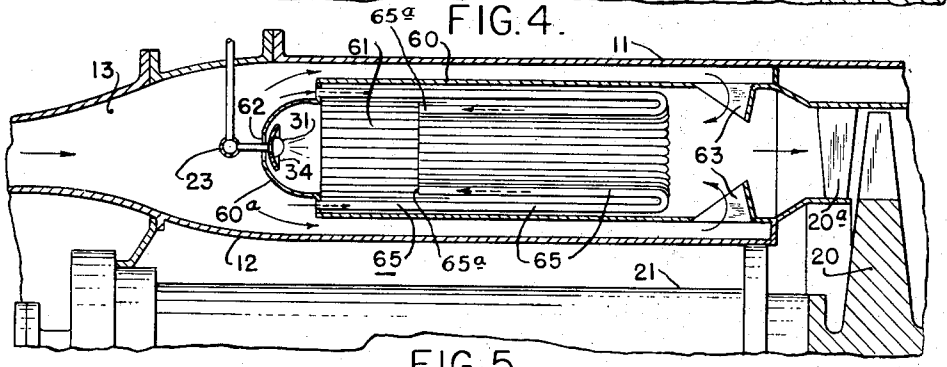


FIG. 5.

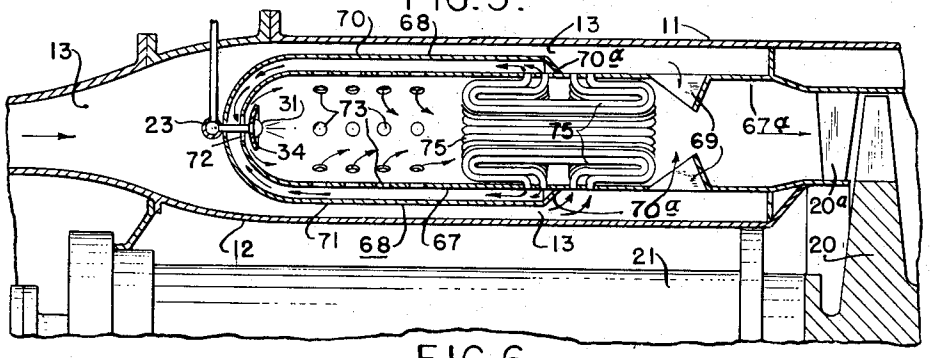


FIG. 6.

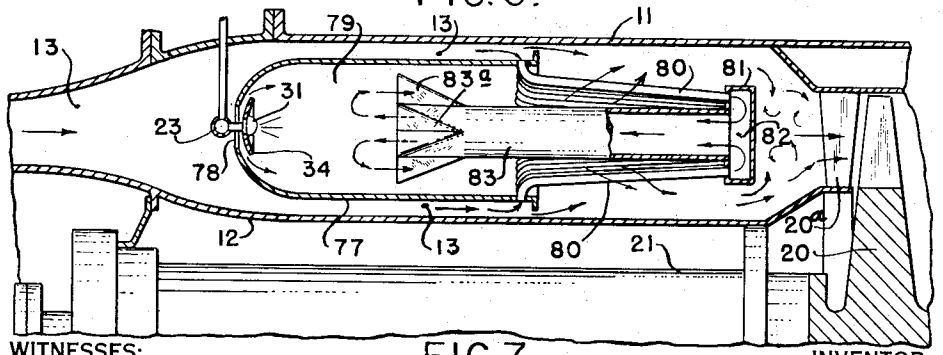


FIG. 7.

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United States Patent Office 2,716,330
Patented Aug. 30, 1955

2,716,330

COMBUSTION APPARATUS HAVING PRIMARY AIR PREHEATING DUCTS

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Application June 24, 1950, Serial No. 170,170

8 Claims. (Cl. 60—39.65)

This invention relates to combustion apparatus, and more particularly to fluid fuel combustion equipment for a gas motivated power plant, such as a gas turbine engine, aviation turbojet, or the like.

The designer of a typical gas turbine power plant has at hand various types of combustion apparatus operative with more or less efficiency to effect sufficient release of energy from fluid fuel to deliver an effective motivating thrust or shaft power, as the case may be. It has been proposed, in connection with certain of these designs, to preheat air prior to introduction thereof into the combustion zone, for facilitating rapid and efficient burning.

It has been demonstrated that an increase in inlet temperature consistently improves and extends the performance of gas turbine combustors. On the other hand, decrease in pressure or inlet temperature renders more pronounced the flame extinction effect caused by relatively cool surfaces. A reduction in mixture temperature leads to substantial reduction in flame propagation velocity. A reduction in inlet temperature also slows up the process of vaporization of liquid fuel droplets.

To preheat all the primary and secondary air is unnecessary from the standpoint of improved combustion, and may even be undesirable where the required construction is subject to considerations of space and weight. The preheating of the combustion or primary air alone, however, may offer considerable advantages and improved efficiency in the combination process, under extreme conditions of inlet pressure and temperature.

Such preheating of primary air in a gas turbine engine need not be carried out by transfer of heat from the exhaust gas stream beyond the turbine, as in the case of a conventional regenerative cycle, involving the provision of long and cumbersome ducting. It is an object of the present invention to provide improved combustion apparatus constructed and arranged to effect efficient preheating of primary air locally from the flame gases in the combustion chamber itself.

Another object of the invention is the provision of improved combustion apparatus for a gas turbine engine, comprising a heater structure having a heat-transfer surface exposed on one side to the flame gases and combustion products and in contact on the opposite side with a stream of primary air flowing toward the combustion zone.

In effecting the preheating of primary air, a member having a heat-transfer surface of large expanse cannot always be subjected to temperatures as high as the metal can withstand, because of the likelihood of buckling and distortion of such a member. Small heat conductive tubes can be run much hotter, on the other hand, provided there is accommodation for axial expansion. It is another object of the invention to provide an improved combustion chamber equipped with a grid of small primary air preheat tubes, to achieve rigidity of the heat exchange surfaces while operating said surfaces at a temperature approaching the oxidation or scaling limits for the material.

A further object is to provide an air preheat tube structure adapted to be operated to facilitate attainment of higher average flame temperatures by minimizing the quenching effect of inlet air on the combustion reaction.

It is also an object to provide a primary air preheater construction in which the heating surface forms a grid lining or screen over a major portion of the interior surface of the flame tube, so that the heat, which otherwise might pass into the flame tube with adverse results, or which might be transferred through it and dissipated uselessly in the secondary air stream, will now be absorbed into the primary stream with highly beneficial results.

Still another object of the invention is the provision of improved combustion apparatus with the foregoing characteristics and having features of construction that may be embodied either in an annular structure or in a burner of the multiple unit or cell type.

These and other objects are effected by the invention as will be apparent from the following description and claims taken in connection with the accompanying drawings, forming a part of this application, in which:

Fig. 1 is a diagrammatic longitudinal view of a gas turbine engine, partly sectioned to show one form of combustion apparatus constructed in accordance with the invention;

Fig. 2 is a fragmentary sectional view, in enlarged detail, of the combustion apparatus shown in Fig. 1;

Fig. 3 is a fragmentary sectional view taken along the line III—III of Fig. 2; and

Figs. 4, 5, 6 and 7 are views similar to Fig. 2 but illustrating various other species of the invention.

As shown diagrammatically in Fig. 1, a typical gas turbine power plant **10** with which the invention is adapted to be associated may comprise an outer generally cylindrical casing structure **11** having longitudinally mounted therein a core structure **12**, forming an annular passageway, generally indicated at **13**, which constitutes a fluid flow communication extending through the plant from a forwardly directed air inlet opening **14** to a rearwardly disposed exhaust nozzle **15**. The usual operating elements of the power plant **10** are arranged in axial alignment therein, and include an axial-flow compressor **19**, a driving turbine **20** connected thereto by means of a shaft **21**, and combustion apparatus **22**, which is interposed in the passage **13** and surrounds the shaft **21** between the discharge end of the compressor and the inlet of the turbine. In operation, air entering the inlet opening **14** is compressed by the compressor **19** and delivered through passage **13** to the combustion apparatus **22**. Fuel supplied to the latter, by way of a suitable manifold **23**, is burned in the stream of air under pressure, creating motive gases which are expanded through the turbine **20** and finally discharged to atmosphere through the nozzle **15**, establishing a propulsive thrust.

It will be understood that the invention may be utilized equally well with gas turbines which produce primarily shaft power rather than a propulsive jet. In such case, a more powerful turbine would be used, and the final pressure drop beyond the turbine would be reduced to a minimum. The propulsion engine **10** herein disclosed has been illustrated merely as an example.

The combustion apparatus **22** is illustrated in Figs. 2 and 3 as comprising an annular chamber construction, although the features of the invention therein embodied may readily be utilized in cell units or can-type combustors. According to the invention, an annular outer shell **25** is supported in the annular passage **13** by suitable radial struts including a strut **26** extending between the outer casing **11** and core structure **12**. The shell **25** has parallel outer and inner walls **25*a*** and **25*b***, which are joined by an annular curved upstream head wall **25*c***,

and extend in spaced relation with respect to the casing and core structure. An inner annular burner **28** of U-shaped longitudinal section having lateral air inlet apertures **29** is mounted within the upstream end of the shell **25**, forming an annular U-shaped passage **30** having outer and inner branches adjacent the respective walls **25***a* and **25***b* and encompassing the apertured burner **28**, as best shown in Fig. 2. Mounted on the annular fuel manifold **23** are a number of nozzles **31**, which project through the passage **30** and suitable openings **32** in the burner for spraying fuel into a combustion chamber **33** formed therein. Each nozzle **31** preferably carries a shield disc **34** spaced inwardly of the adjacent opening **32**. A plurality of radially extending elongated ducts **35** are disposed in the downstream portions of walls **25***a* and **25***b*, respectively.

Mounted downstream of and communicating with the respective outer and inner annular branches of the passage **30** are a plurality of parallel outer air tubes **37** longitudinally aligned along the shell wall **25***a*, and a plurality of similar inner tubes **38** surrounding the inner shell wall **25***b*. The tubes **37** and **38** thus form protective grid structures for shielding major portions of the walls of the shell **25** from heat. The opposite ends of the tubes may be suitably supported in apertured headers or the like, to permit thermal expansion. The rear ends of the tubes **37** and **38**, constituting the upstream ends thereof, communicate with the passageway **13** adjacent outer and inner annular baffles **39** and **40**, which are adapted to terminate the passageway **13** and to compel flow to take place through the respective banks of tubes. The usual turbine inlet nozzle blade structure **20***a* may be supported between outer and inner annular shrouds **42** and **43**, the upstream portions of which extend between the annular baffles **39** and **40** and abut the adjacent ends of the tubes **37** and **38**, respectively, to enclose an annular passageway for conducting motive gases from the combustion chamber **33** to the turbine.

With the power plant **10** in operation, assuming that ignition of fuel in the combustion apparatus has been effected, air under pressure flows through the passageway **13** along the outer surfaces of the shell **25**. The portion of the total air volume constituting primary or combustion air is then drawn into the banks of tubes **37** and **38** adjacent the baffles **39** and **40** and thence flows through the tubes to the passage **30**, from which the primary air passes through apertures **29** and **32** to the combustion chamber **33**. Fluid fuel issuing from the nozzles **31** is thereby entrained and mixed with the primary air to facilitate combustion, which may be effected throughout the length of the combustion chamber **33**. The primary air passing through the tubes **37** and **38** is efficiently preheated by the process of combustion in chamber **33**. Some of the air from the passageway **13** at the same time flows through the ducts **35** into the downstream portion of the combustion chamber, to effect cooling of the products of combustion to the desired turbine inlet temperature.

It will thus be seen that the combustion apparatus illustrated in Figs. 2 and 3 is adapted to afford both combustion shell protection and primary air preheating. Since the shell structure is shielded by the relatively small tubes **37** and **38**, which are arranged for axial expansion and carry primary air at high velocity, efficient combustion temperatures may safely be maintained in the chamber **33** without danger of buckling or distortion of the assembly. On the other hand, the air flowing in these tubes will be preheated and rendered effective in the ignition and reaction zones of the combustion chamber to produce rapid and efficient combustion of the fuel. Since the combustion apparatus including tubes **37** and **38** may be run at temperatures in the neighborhood of 1500 to 1800° F., the quenching effect thereof on the reaction will be much less than that of a conventional air-blanketed combustion structure.

Referring to Fig. 4, a different form of the invention is therein disclosed, the combustion apparatus chosen for convenience of illustration being of the multiple unit or "can" type. It will be understood, however, that this form of the invention may readily be adapted for construction of an annular combustion chamber similar to that already described, if preferred. According to the invention as shown in Fig. 4, each of a plurality of cylindrical shells **45** is mounted on suitable struts (not shown) within passageway **13** of the engine, and disposed in spaced relation between the outer engine casing structure **11** and the inner core structure **12**. The upstream end of the shell **45** is closed by a generally hemispherical upstream portion **45***a*, while the downstream end converges at **45***b* to form a discharge opening **46** communicating with the adjacent passages of the turbine inlet nozzle blading **20***a*. A rounded or dome-shaped liner section **48** is mounted in the upstream portion **45***a*, forming a curved space **49** which communicates, by way of an axial opening **50** formed in the section **48**, with a combustion chamber **51** extending through the shell **45**. Nozzle **31** carrying shield **34** extends through the opening **50** from the fuel manifold **23**, for supplying fluid fuel to the combustion chamber **51**.

The inside wall of the shell **45** is lined with a plurality of longitudinally arranged tubes **55**, each of which communicates at the forward end with the space **49** surrounding the liner section **48**. The rearmost open ends **55***a* of the tubes, which constitute the upstream ends thereof with relation to flow of primary air therethrough, are bent outwardly and project through openings in the shell **45** into the passageway **13**. The tube ends **55***a* are preferably provided with canted edges to facilitate collection of primary air from the air stream flowing through the passageway **13**. A plurality of outlet ports **56** are formed in the inner side of each tube **56** adjacent the downstream end thereof which is connected to the space **49**. For admitting secondary air to the combustion chamber **51**, the shell **45** has formed therein a plurality of radially inwardly projecting elongated ducts **58**, which are disposed downstream of the tubes **55** and may be canted forwardly for guiding air from the passageway **13** in a counterflow direction into the combustion chamber.

Operation of the apparatus shown in Fig. 4 will readily be understood from the description hereinbefore presented with reference to the first three figures of the drawing. It will be noted that the primary air tubes **55** are adapted to protect the major portions of the shell **45** surrounding the ignition and reaction zones, while supplying preheated primary air to the region into which fuel is sprayed from the nozzle **31**, by way of the ports **56**, and through the opening **50** upstream of the nozzle. The products of combustion, thoroughly mixed with secondary air supplied by way of the ducts **58**, are then delivered to the turbine **20** in the usual manner.

Referring to Fig. 5 of the drawings, combustion apparatus of the multiple unit type constructed in accordance with another form of the invention is shown, a single unit or "can" of the assembly being illustrated as comprising a cylindrical shell **60** forming a combustion chamber **61** and having its downstream end connected to the turbine inlet nozzle structure **20***a* in the conventional manner. The upstream end **60***a* of the shell is dome-shaped, and is provided with an inlet opening **62** through which extends the usual fuel nozzle **31** carrying the shield **34**. A number of secondary air inlet ducts **63**, similar to the ducts **58** shown in Fig. 4, are formed in the wall of the shell upstream of the turbine nozzle assembly **20***a*.

A plurality of primary air preheating tubes **65** are mounted along the inner surface of the shell **60** and parallel to the axis thereof, the tubes being closely disposed as in the case of the tubes **55** of Fig. 4, for protecting the shell from the heat of combustion. Each of

the tubes 65 is retrorse or U-shaped, however, and has an open upstream end connected to the forward end of the shell outwardly of the domed portion 60*a*, for receiving air flowing in an axial direction from passageway 13. The open ends of the reentrant portion 65*a* of the tubes 65 terminate downstream of the fuel nozzle 31, and are adapted to discharge preheated primary air in an upstream direction into the combustion zone of the chamber 61 for mixture with the fuel along with air flowing axially downstream through the inlet opening 62. The combustion apparatus shown in Fig. 5 thus serves to combine the desired functions of preheating primary air and of effectively shielding the shell walls from the high temperatures attained in the reaction zone. Though the arrangement shown in Fig. 5 has been discussed in reference to a single cell of a multiple cell burner, the same features could be embodied, obviously, in an annular type of combustion chamber.

In Fig. 6, the invention is illustrated in still another form, embodied in combustion apparatus of the multiple unit type comprising a tubular main burner shell 67 rounded at the upstream end to form a combustion chamber 68, and having its discharge end 67*a* disposed in communication with the nozzle assembly 20*a* of the turbine 20. Inwardly projecting ducts 69 are provided near the end 67*a* of the shell for supplying secondary air to the combustion chamber. From a point intermediate its ends, the upstream portion of the shell 67 is telescoped by and spaced within a cylindrical outer casing 70, the forward closed end of which is rounded to conform with the upstream end of the burner shell. An annular passage 71 is formed between the shell 67 and casing 70, the annular end 70*a* of which is bent inwardly into engagement with the shell. The usual nozzle 31 projects from the fuel manifold 23 through suitable apertures in the casing 70 and shell 67, the aperture in the latter, designated 72, being large enough to admit primary air from the passage 71 to the chamber 68. Other primary air inlets 73 are formed in the upstream wall of the shell 67 for facilitating further flow of primary air from the passage 71. A number of pairs of primary air preheating tubes 75 are provided within the combustion chamber 68, the inlet ends of the tubes being connected to the passageway 13 through suitable openings formed in the shell downstream of the end 70*a* of the outer casing. The tubes 75 are looped or doubled and project into the combustion chamber 68 to subject substantial surface area to the heat within the flame zone. The outlet ends of the tubes 75 are mounted in the shell 67 in communication with the passage 71, upstream of the inlets 73 with respect to the flow of air in passage 71.

It will thus be apparent that the tubes 75 of the apparatus shown in Fig. 6 constitute submerged heater means providing for conduction of the primary air on one side of the heat transfer surface and flame gases and combustion products on the other side. In operation, air under pressure flowing from the passageway 13 is preheated in passing through the tubes 75 and thence flows through passage 71, and inlet openings 72 and 73 to the chamber 68, where combustion of fuel supplied by way of the nozzle 31 is effected. Some of the heat of the combustion gases is transferred to the tubes 75 as the gases flow toward the downstream portion 67*a* of the shell to become mixed with secondary air from the ducts 69, prior to expansion of the resultant motive fluid in the turbine. This particular arrangement of the invention could also be utilized in conjunction with an annular type combustor with minor modifications, though it is perhaps best adapted to cell type burners.

In the form of combustion apparatus constructed in accordance with the species of the invention illustrated in Fig. 7, a relatively short burner shell 77 is provided in the usual passageway 13 of the engine, the forward end of the shell having a central opening 78 for receiving the fuel nozzle 31 and for admitting a portion of the necessary primary air to a combustion chamber 79. Secured to the opposite open end portion of the shell 77 are the open upstream ends of a plurality of primary air preheater tubes 80, which converge rearwardly and communicate at the downstream ends thereof with a manifold 81 having a chamber 82. The tubes 80 may be spaced apart for at least a portion of the axial extent thereof for facilitating flow of gaseous products of combustion from the chamber 79 toward the turbine inlet nozzle 20*a*. For conducting primary air from the manifold chamber 82 to the reaction zone downstream of the nozzle 31, an axially disposed heater conduit 83 is provided. The rear end of the conduit 83 is suitably secured to an interior flange of the manifold 81. The opposite free end of the conduit constitutes a radially diffusive or flaring star-shaped portion 83*a*, having a radially branched outlet area opening into the flame zone for distributing primary air in a counterflow direction throughout the radial extent of the combustion chamber 79.

It will thus be understood that during operation of the combustion apparatus disclosed in Fig. 7, the relatively reduced fluid pressure existing in the combustion chamber 79 will effect flow thereto, as indicated by the arrows, of primary air from the passageway 13 by way of the opening 78 upstream of the fuel nozzle 31, and also through the several tubes 80 and heating conduit 83, the major portion of primary air being thereby preheated by absorption of heat from the flame gases. The products of combustion issuing from the chamber 79 between the tubes 80 is then efficiently mixed with the secondary air in the region surrounding and downstream of the manifold 81, in flowing toward the turbine 20.

Summarizing, it will be understood from the foregoing that with combustion apparatus constructed in accordance with any of the several species of the invention disclosed in the drawings, efficient primary air preheating can be accomplished, without unduly extending the length of the combustion equipment and without necessitating the use of long and bulky regenerating ducts. By utilizing simply constructed preheating tubing submerged in or disposed around the reaction zone of the combustion apparatus, in combination with the effective means disclosed for supplying secondary air, the improved equipment can readily be installed within the limited space available in a power plant of the desired type. The features of the invention, as disclosed in the various forms illustrated, are adapted to be employed either in annular combustion chamber equipment, or in the individual units of multiple cell combustion apparatus.

Though tubes of essentially round cross section have been mentioned as elements of the primary air heat transfer unit in the preceding description of this invention, these passages need not necessarily be round. Indeed, flattened ducts, of narrow rectangular, triangular, oval or other appropriate cross section could also be used, and might have advantages in certain instances.

While the invention has been shown in several forms, it will be obvious to those skilled in the art that it is not so limited, but is susceptible of various other changes and modifications without departing from the spirit thereof.

What is claimed is:

1. Combustion apparatus for a gas motivated power plant, comprising elongated shell structure adapted to be mounted in an air stream and forming a combustion chamber, said chamber having its longitudinal axis disposed parallel with said air stream and having upstream and downstream ends, nozzle means for supplying fluid fuel to the upstream end of said chamber, and a plurality of primary air preheating ducts carried by said shell structure, the major portions of said ducts extending longitudinally relative to the axis of said combustion chamber, said ducts being nested closely and circumferentially of said combustion chamber, said ducts being

exposed to said combustion chamber and having means forming outlets communicating therewith adjacent said nozzle means, said ducts having inlets at the ends remote from said outlets for receiving primary air from said air stream, and means whereby such primary air is conducted in a direction opposite that of said air stream through at least part of the course between said inlets and said outlets for facilitating the preheating of such primary air.

2. Combustion apparatus for a gas motivated power plant as set forth in claim 1, wherein the primary air preheating ducts are supported in said shell structure and projecting into submerged relation in the reaction zone of said combustion chamber, and a plurality of secondary air inlet ducts carried by said shell structure and communicating with said chamber downstream of said submerged preheating ducts.

3. Combustion apparatus for a gas motivated power plant, comprising elongated shell structure adapted to be mounted in an air stream and forming a combustion chamber disposed parallel to said air stream and having an upstream end and an open downstream end, nozzle means for supplying fluid fuel to the upstream end of said chamber, a plurality of relatively small primary air heater tubes extending rearwardly from said shell structure and having inlets disposed outwardly thereof for receiving primary air from said air stream, a heater conduit mounted axially within said shell structure, the end of said conduit remote from said nozzle means being connected in communication with the outlet ends of said tubes, and a substantially radially diffusive outlet carried on the other end of said conduit adjacent said nozzle means for discharging heated primary air in a direction opposite that of said air stream and in counterflow relation to the flow of fuel from said nozzle means.

4. In combustion apparatus for a gas motivated power plant, in combination, cylindrical casing structure forming an annular passageway adapted to receive a high velocity stream of air under pressure, shell structure mounted in spaced relation in said passageway and having a combustion chamber disposed parallel to the air stream, said combustion chamber having a rounded wall at the upstream end and an outlet in the downstream end thereof for discharge of products of combustion, a bank of relatively small diameter, elongated air preheating tubes mounted longitudinally along the interior surfaces of said shell structure, said tubes encompassing a major portion of the combustion chamber and having inlet ends and outlet ends, the inlet ends of said tubes being open to said passageway outwardly of said shell structure for receiving primary air from said air stream, fuel injection means mounted in the upstream end of said shell structure and extending into said combustion chamber, and air discharge means connecting the outlet ends of said tubes to said combustion chamber adjacent said fuel injection means, said tubes being adapted to conduct primary air in upstream direction relative to the direction of said high velocity air stream for facilitating the preheating thereof.

5. In combustion apparatus for a gas motivated power plant, in combination, cylindrical casing structure forming an annular passageway adapted to receive a high velocity stream of air under pressure, shell structure mounted in spaced relation in said passageway and having a combustion chamber, said shell structure extending parallel to said stream of air between upstream and downstream zones thereof, an outlet in the downstream end of said shell structure for discharge of products of combustion, a bank of relatively small diameter, elongated air preheating tubes mounted longitudinally along the interior surfaces of said shell structure, said tubes encompassing a major portion of the combustion chamber and having inlet ends and outlet ends, the inlet ends of said tubes being disposed downstream of the outlet ends with respect to said stream of air, said inlet ends being open to said passageway outwardly of said shell structure for abstracting primary air from said air stream, an apertured interior liner section spaced within the upstream end of said shell structure and forming a passage overlapping said chamber and communicating with the outlet ends of said tubes, and a fuel nozzle projecting through said shell structure and liner section into the upstream end of said combustion chamber into which preheated primary air is delivered by way of said tubes and said passage.

6. In combustion apparatus for a gas motivated power plant, in combination, cylindrical casing structure forming an annular passageway adapted to receive a high velocity stream of air under pressure, elongated shell structure mounted in spaced relation in said passageway and parallel to the air stream, said shell structure having a combustion chamber and an outlet in the downstream end thereof for discharge of products of combustion in the same direction as that of said air stream, a plurality of relatively small diameter, elongated air preheating tubes mounted longitudinally along the interior surfaces of said shell structure, said plurality of tubes encompassing a major portion of the combustion chamber, said tubes having open inlet and outlet ends, the inlet end of each tube being open to said passageway outwardly of said shell structure for receiving primary air from said air stream and said outlet end having spaced lateral ports therein, an interior liner section spaced within the upstream end of said shell structure and forming a passage overlapping said upstream end of the combustion chamber and communicating with said ports in the outlet ends of said tubes, and fuel supply means disposed in said upstream end of the combustion chamber, said tubes serving to effect flow of primary air in a direction opposite that of said air stream through at least part of the course between said inlet and outlet ends thereof and to feed preheated primary air progressively through the lateral ports of said tubes into said combustion chamber adjacent said fuel supply means.

7. Combustion apparatus as set forth in claim 1, further comprising a plurality of flow passages forming communication between the air stream and the combustion chamber downstream of the connection therewith of the outlets of the preheating ducts.

8. Combustion apparatus as set forth in claim 1, further comprising a gas discharge opening in the downstream end of the shell structure, and a plurality of circumferentially spaced secondary air inlets formed therein intermediate said gas discharge opening and the outlets of the primary air preheating ducts, for supplying the combustion chamber with secondary air from the air stream to supplement the preheated primary air.

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