COMBUSTION OF FUEL ON THE SURFACE OF A ROTATING DISC

Filed Sept. 15, 1953 3 Sheets-Sheet 1

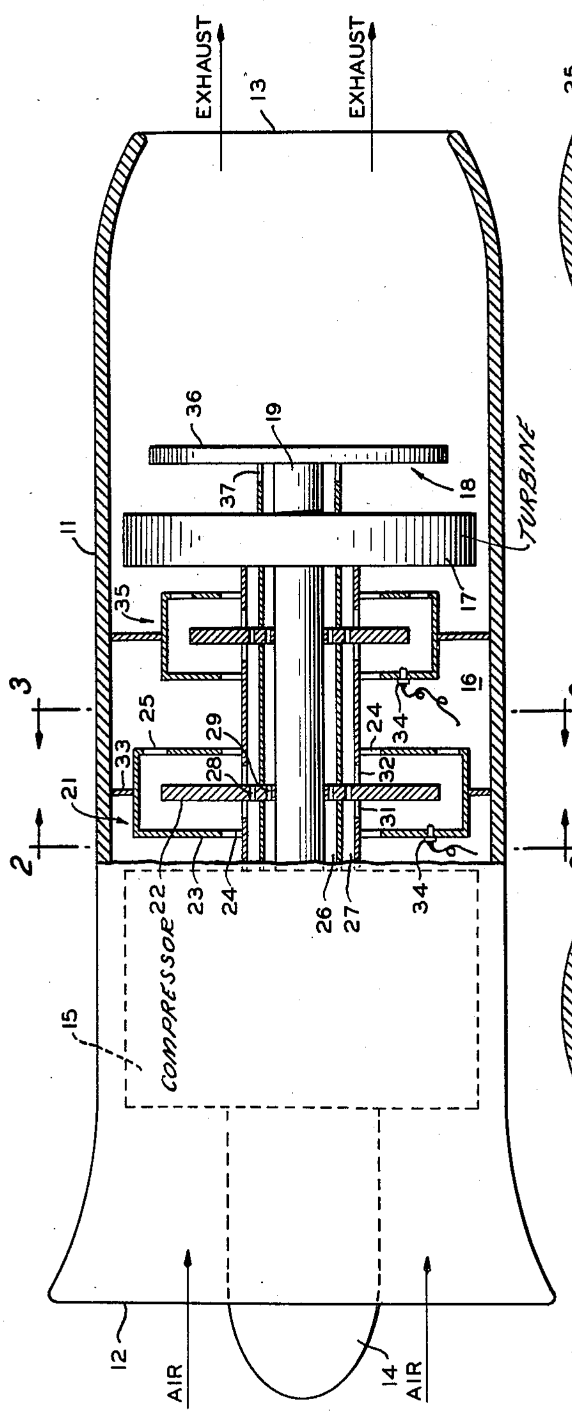

FIG. 1

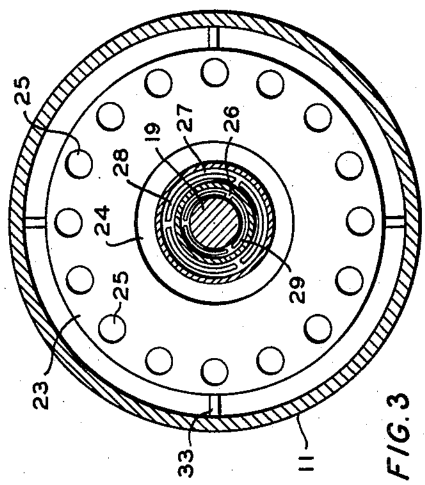

FIG. 3

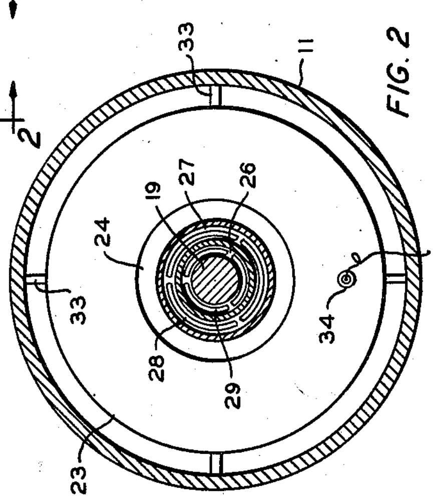

FIG. 2

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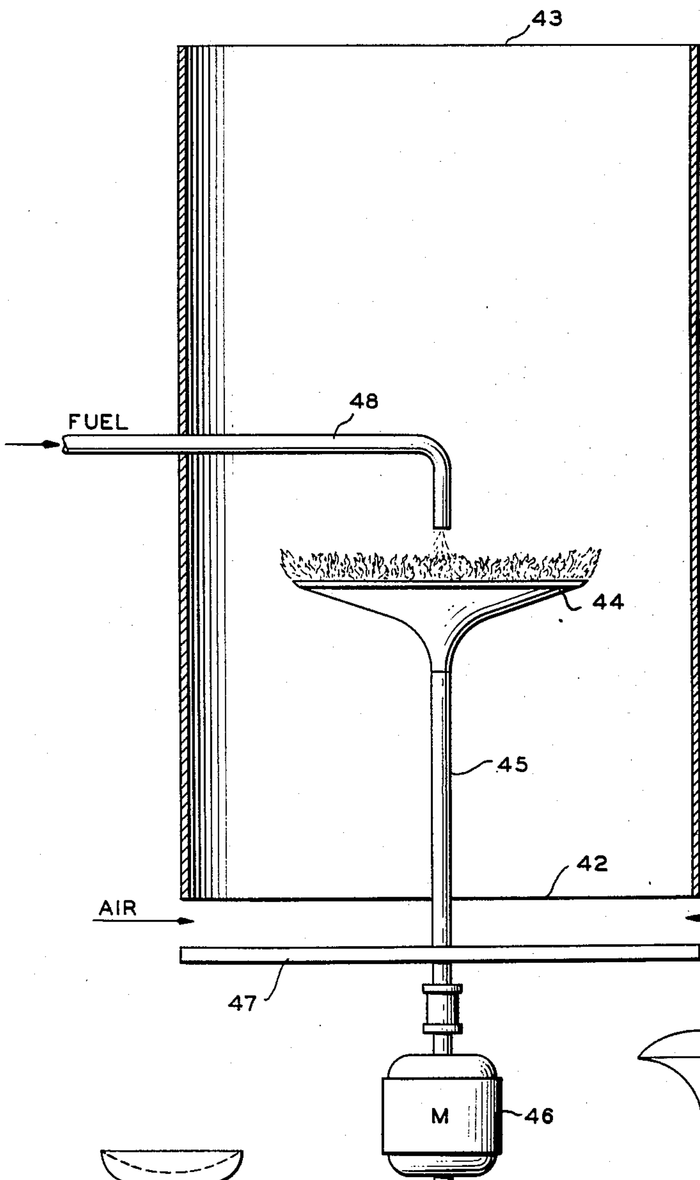
COMBUSTION OF FUEL ON THE SURFACE OF A ROTATING DISC

Filed Sept. 15, 1953 3 Sheets-Sheet 2



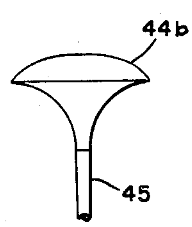


FIG. 4b

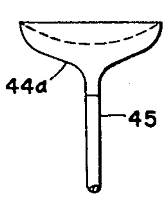


FIG. 4a

FIG. 4.

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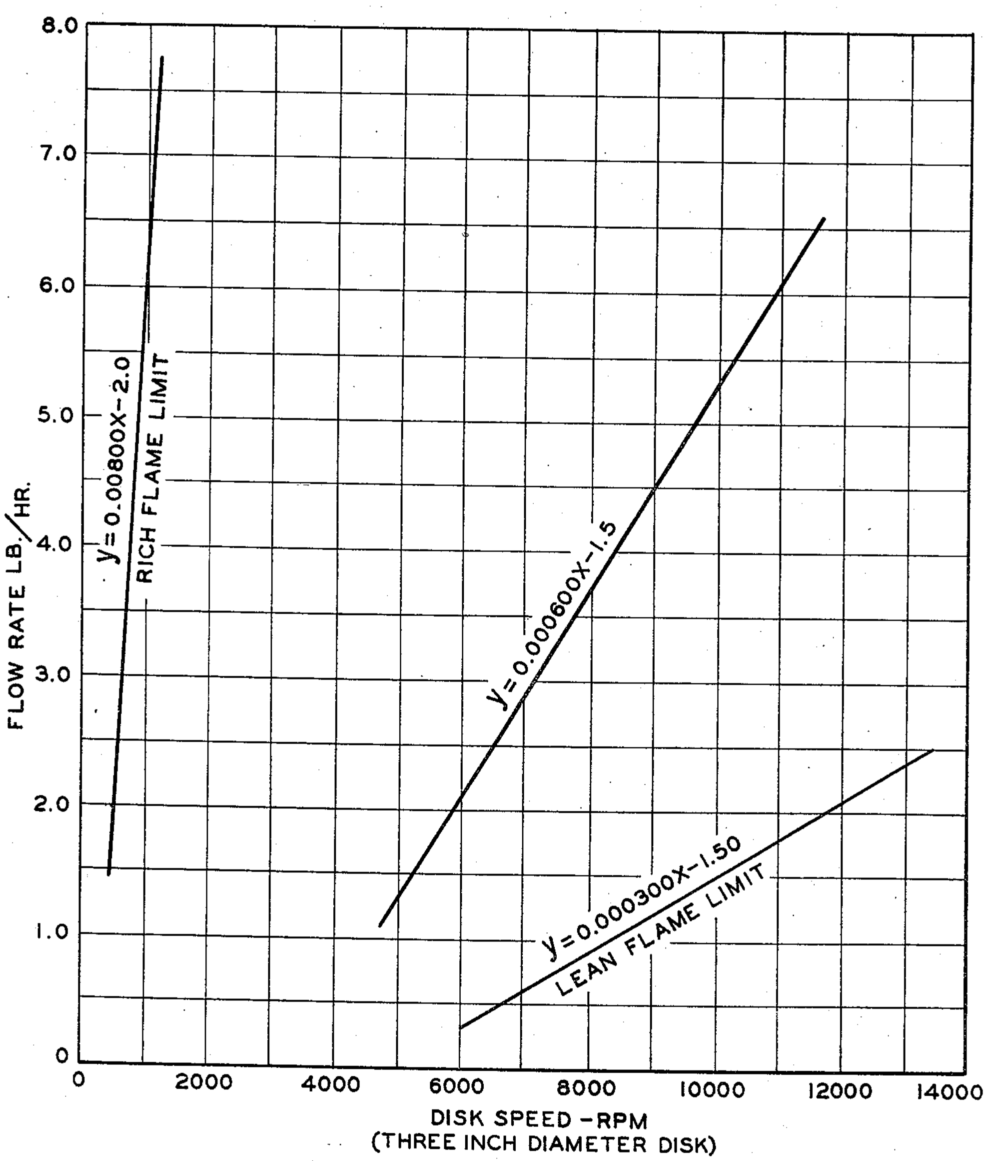

FIG. 5

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COMBUSTION OF FUEL ON THE SURFACE OF A ROTATING DISC

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Application September 15, 1953, Serial No. 380,324

4 Claims. (Cl. 60—39.74)

This invention relates to the improved combustion of fuels. In one of its more specific aspects, it relates to the combustion of fuels on the surface of a rotating disk. In another of its more specific aspects, it relates to an improved method of burning fuels. In another of its more specific aspects, it relates to improved jet engines. In still another of its more specific aspects, it relates to an improved process for operating jet engines.

Rotating disks have been widely used in spray dryers, humidifying equipment, and in oil burners to effect atomization of a liquid into a gas or fine mist. Heretofore, when rotating disks have been used in fuel burners, the fuel which had been fed to the center of the disk rotating at high speed was swept from the surface of the disk by centrifugal force, the fuel being caused to disintegrate as it moved through the air, thereby forming a ring of fuel mist as an annulus about the periphery of the disk. The annulus so formed was burned off the periphery of the disk, but such burning was very inefficient.

There is a continuing search for better apparatus and better methods for burning fuels. In fact, the improved efficiency of burning of fuels is one of the prime objects of manufacturers of burners and engines of all types.

The following objects of this invention will be attained by the various aspects of this invention.

An object of this invention is to provide an improved burner. Another object of the invention is to provide an improved method of operating rotary disk burners. Another object of the invention is to provide an improved jet engine. Another object of the invention is to provide an improved method of operating a jet engine. Another object of the invention is to provide a method of burning fuels with a rotary disk type burner with an increase in efficiency over conventional methods. Other and further objects of this invention will be apparent upon study of the accompanying disclosure and the drawings.

Broadly speaking, this invention comprises the burning of a fuel on a rotating surface. Fuel is fed onto the surface of a rotating disk at such a rate that vaporization of that fuel is obtained on the surface of the disk and the fuel is burned on the disk. The accomplishment of this type of burning is obtained by coordinating the fuel flow rate with the speed of rotation of the disk. Generally speaking, this type of operation can be obtained by maintaining a fuel flow rate, measured in pounds per hour, within the range of between

$$\frac{D^2(0.00800x-2.0)}{9}$$

to

$$\frac{D^2(0.000300x-1.50)}{9}$$

wherein D is the diameter of the disk in inches and x is the disk speed in revolutions per minute.

I have discovered that an increased heat release rate per unit burner volume is obtained by burning a fuel on the surface of a rotating disk. I have also discovered

the existence of a critical relationship between the process variables in the combustion of a fuel with a rotating disk burner. Also, by operating the burner within the critical range of such process variables, I have obtained a distinctive type of combustion process which provides an improved efficiency in the burning of a fuel. This new and improved process appears to be a diffusing type of combustion which takes place on the surface of the rotating disk, whereas combustion with a conventional rotating disk type burner has heretofore taken place as an annulus off the periphery of the disk. In my improved combustion process, flames cover the entire surface of the rotating disk and combustion is substantially complete, being indicated by the intense blue flames which are obtained. In conventional combustion processes utilizing rotating disks, where the flames burn as an annulus off the periphery of the disk, the flames are usually of a yellow color, thereby indicating incomplete combustion.

Better understanding of this invention will be obtained upon reference to the drawings in which

Figure 1 is a diagrammatic representation of a jet engine utilizing the disk type burner of this invention;

Figure 2 is a sectional view taken along the line 2—2 of Figure 1;

Figure 3 is a sectional view taken along the line 3—3 of Figure 1;

Figure 4 is a sectional elevation of a rotating disk type burner of this invention;

Figures 4*a* and 4*b* illustrate other modifications of an element of the apparatus illustrated in Figure 4;

Figure 5 is a graphic representation of stable combustion limits obtained by this invention.

Referring particularly to Figure 1 of the drawings, a turbo-jet engine is schematically shown and comprises an outer shell **11** having an inlet **12** and an exhaust nozzle **13**. Coaxially mounted within casing **11** is a fairing member **14** which may, if desired, house an auxiliary control apparatus. Also coaxially disposed within shell **11** is a compressor **15**, not shown, combustion section **16**, turbine **17**, and after-burner **18**. The compressor, turbine, disk burners in combustion zone **16**, and the after-burner are preferably mounted on a common shaft **19**.

The burners within combustion zone **16** comprise a primary combustor **21** which has a disk **22** mounted on shaft **19** within housing **23**. Housing **23** has air inlet openings **24** provided in its upstream and downstream end sections at its central portion and a combustion gas outlet **25** in its downstream side, preferably adjacent the periphery of housing **23**. Fuel conduits **26** and **27** are provided about shaft **19** and may be annular conduits or a plurality of individual fuel conduits spaced about the periphery of shaft **19** so as to be balanced thereon. It is preferred that these conduits be in the shape of annular conduits. If desired, a hollow shaft can be used as a fuel conduit and to replace shaft **19**. Openings **28** and **29** are provided through disk **22** so as to permit the flow of fuel therethrough to the downstream sections of fuel conduits **26** and **27**. Conduit **27** is provided with fuel outlets **31** and **32** at the upstream and downstream sides of disk **22**. Housing **23** is rigidly connected to shell **11** by means of hanger members **33**. Spark ignition means **34** are provided in the wall of housing **23** so as to facilitate the initial ignition of fuel within that housing.

Secondary combustor **35** is similar to that of primary combustor **21** and the numerals applied to primary combustor **21** can be applied in a like manner to the secondary combustor. After-burner **18** comprises a disk **36** which is rigidly connected to shaft **19** and fuel outlets **37** are provided in fuel conduit **26** so as to permit the flow of fuel onto the upstream side of disk **36**.

In operation of the jet engine shown in Figure 1 of the drawings, air flowing through the inlet opening **12** of the engine is supplied to compressor 15 which delivers air under pressure to the combustors in combustion zone 16. From the combustion zone 16, the heated motive fluid, under pressure, is expanded through turbine 17, heated to a still higher temperature in after-burner section 18 and is then discharged through exhaust nozzle 13 in the form of a jet, thus establishing a propulsive force. The combustion of fuel in combustion zone 16 is divided into two areas, a primary combustor 21 and a secondary combustor 35. In primary combustor 21, the oxygen-containing atmosphere for combustion of the fuel entering through openings 31 and 32 in fuel conduit 27 is supplied through openings 24. The air entering housing 23 through openings 24 passes along the surfaces of rotating disk 22, together with fuel introduced along the surfaces of disk 22 through fuel inlet openings 31 and 32. The fuel is burned on the surfaces of the disk and the combustion products are removed from housing 23 through outlets 25 adjacent the periphery of housing 23.

In secondary combustor 35, the oxygen-containing atmosphere for combustion of fuel entering the plurality of openings from fuel conduit 27, adjacent the upstream and downstream surfaces of the disk therein, is supplied through the openings in the upstream and downstream sides of the housing member for secondary combustor 35. The operation of this burner is the same as that described in connection with the primary combustor hereinabove. The oxygen-containing atmosphere which is supplied to this combustor is contaminated with combustion products from primary combustor 21. Actually, secondary combustor 35 provides additional utilization of the oxygen in the combustion gases from the primary combustor 21. The flow of air around primary combustor 21 serves to cool the walls of housing 23 and the dilution of combustion gas from primary combustor 21 by air, further serves to reduce the temperature of the gases surrounding the secondary combustor 35. The construction of the fuel conduits 26 and 27 around shaft 19 serves to cool this shaft and prevent its destruction by heat from combustion developed in the combustion zone.

The combustion products and heated compressed air which are discharged through turbine 17 are further heated in after-burner 18 by the combustion of fuel supplied to the upstream surface of disk 36 through outlet 37 in fuel conduit 26.

While my invention, with respect to jet engines, has been shown only in one form of turbo-jet engines, it can be used in stationary engines as well as other aircraft jet engines, such as turbo-prop engines. Other modifications and changes are within the concept of this invention. For instance, any type of compressor, such as a centrifugal or axial flow compressor, can be used in compressor zone 15. Furthermore, any number of rotating disk combustors may be used. Also, the embodiment of the invention shown in Figure 1 of the drawings, contains an after-burner, this after-burner may be entirely omitted in some modifications of this invention. Many other modifications will be obvious to those skilled in the art upon study of this disclosure.

Another adaptation of this invention is a heating furnace, such as that shown in Figure 4 of the drawings. This burner comprises an outer shell 41, open to the flow of air through its inlet end 42 and for the outlet of combustion products through its exhaust end 43. Burner disk 44 is supported and rotated by means of shaft 45 and motor 46. Shaft 45 extends through baffle member 47, which can be spaced from the inlet end of housing 41 so as to provide a proper amount of air for the combustion in the burner. Fuel inlet conduit 48 extends into shell 41 so as to introduce fuel onto the surface of disk 44. Although shown as entering through the side wall of shell 44, conduit 48 may extend through the upstream or downstream end of shell 41. Likewise, disk 44 can be rotatably supported in shell 41 on a stub shaft and motor 46 can be operatively connected to the stub shaft through the wall of shell 41.

The operation of the device shown in Figure 4 of the drawings is similar to that discussed hereinabove in connection with the jet engine. In the operation of this particular burner, however, the air will ordinarily not be under compression, although the use of compressed air is within the scope of this invention.

Although the disks shown in Figures 1 and 4 are flat surface type disks, it is within the scope of this invention to use disks having either convex or concave surfaces as illustrated in Figures 4*a* and 4*b*.

In the operation of my rotating disk type burners, it is necessary that the fuel flow rate in pounds per hour be maintained within the range of

$$\frac{D^2(0.00800x-2.0)}{9}$$

to

$$\frac{D^2(0.000300x-1.50)}{9}$$

preferably

$$\frac{D^2(0.00600x-2.0)}{9}$$

to

$$\frac{D^2(0.000400x-1.50)}{9}$$

D being the diameter of the disk in inches and x being disk speed in revolutions per minute. It will be noted that intermediate the lean flame limit and the rich flame limit shown in Figure 5 of the drawings, a third graphic limitation is shown. This limitation is one which must be crossed, in the direction of rich-mixture, during start-up before stable combustion can be obtained in the region between this intermediate line and the rich flame limit. I have designated this intermediate line as the surface burning limit which may be defined as the fuel flow in pounds per hour and the disk speed in revolutions per minute at which the flame traverses from the annular region off the periphery of the disk onto the surface of the disk. This limit, as I have pointed out above, must be approached from the low fuel-flow side, or may be approached from the high disk speed side. The rich flame limit is defined as that fuel flow and disk speed at which the flame, burning on the disk surface, changes from a steady, "tulip shaped" flame to a ragged inconsistent flame with accompanying smoky formation. For the paraffinic hydrocarbon fuels, the steady flame contains only small 'fingers" of yellow flame on a bluish back ground until after passing the rich limit, for that particular fuel, at which time the flame becomes predominantly yellow. Aromatic hydrocarbon fuels burn with a yellow flame, though of various shades, throughout the range of fuel flow. The steady flame with this type fuel is "tulip shaped" until the rich limit for that particular fuel is passed, at which time an abundance of smoke is encountered.

The lean flame limit is defined as that fuel flow and disk speed at which the steady flame on the surface of this rotating disk changes to either a thin, cool layer on the disk surface with thin, ragged fringes or the flame is completely extinguished. Such flame-outs ordinarily occur at high disk speeds. The region between the rich flame limit and the lean flame limit is defined as the steady flame region. The fuel flow rate in pounds per hour is set forth in rectangular coordinates with an origin of zero disk speed and fuel flow rate. In these equations, x represents the disk speed in revolutions per minute and y represents the fuel flow rate in pounds per hour. Each individual fuel has its own specific rich, lean, and surface burning limits. Each of the hydrocarbon and non-hydrocarbon type fuels, of which we presently know, falls within the range of operating conditions set forth in Figure 5.

Critical limits for certain selected hydrocarbon fuels on a three inch diameter rotating disk are set forth below in Table I. The limitations for these fuels are set forth as being exemplary and should not be construed to unduly limit this invention.

Table I

Fuel	Surface Burning Limits	Lean Flame Limits	Rich Flame Limits
n-Heptane	$y=0.000743_x-1.50$	$y=0.000533_x-1.52$	$y=0.00179_x-2.39$
n-Hexane	$y=0.000700_x-1.62$	$y=0.000450_x-1.94$	$y=0.00103_n-1.73$
iso-Octane	$y=0.000795_x-1.27$	$y=0.000538_x-1.48$	$y=0.00114_x-2.02$
Benzene	$y=0.000890_x-1.20$	$y=0.000518_x-1.51$	$y=0.00643_x-5.00$
Toluene	$y=0.000928_x-1.31$	$y=0.000643_x-1.34$	$y=0.00253_x-2.69$

Hydrocarbon fuels which may be used in the process and in the operation of the burners of this invention include the normally liquid paraffin, cycloparaffin, olefin, and aromatic hydrocarbons in the C_5 to C_{35} range or mixtures thereof. Examples of such hydrocarbon fuels in addition to those set forth in Table I above, include kerosene, diisobutylene, cyclohexene, cyclohexane, isodecane, methylcyclohexane, hexadecane, eicosane, hexacosane, tetratriacontane, picene, cyclononacosane, tetraphenylethylene, and the like. Hydrocarbons in the C_5 to C_{16} range are preferred. Normally liquid non-hydrocarbon fuels can also be burned by the process of this invention. Such fuels include slurries of powdered metals ranging from lithium to aluminum of the electromotive series, dissolved in a hydrocarbon disclosed above, preferably in kerosene. Organic fuels, including alcohols, such as methyl, ethyl, propyl and butyl alcohol, oxide type fuels, such as ethylene oxide and propylene oxide, ketones, such as methyl isobutyl ketone, organic sulfides, such as di-tertiary-butyl disulfide, and esters, such as tert-butyl perbenzoate are also useful and can be burned by the process of this invention. Mixtures of the above described materials are also used in this process.

Various modifications of this invention will be apparent to those skilled in the art upon study of the accompanying disclosure. Such modifications are believed to be within the spirit and scope of this invention.

I claim:

1. An improved jet engine which comprises, in combination: an outer shell having air inlet means in its upstream end portion and exhaust means in its downstream end portion; air compression means in the upstream end portion of said shell; turbine means spaced downstream from said air compression means within said shell; a rotatable shaft connecting said air compression means and said turbine means for driving said air compression means; at least one smooth surfaced disk attached to said shaft so as to be rotated by said shaft; fuel inlet conduit means coaxially mounted around said shaft for introducing fuel onto the surface of said disk near the periphery of said shaft; a housing enclosing each said disk, said housing being smaller in diameter than the inner diameter of said shell; an air inlet in at least one radial wall of each said housing so as to permit the flow of air into the interior of said housing and along said surface of said disk to provide for substantially complete combustion of said fuel on said surface of said disk; and a fuel combustion products outlet in the downstream side of each said housing.

2. The improved jet engine of claim 1 wherein said shaft extends downstream of said turbine means; a smooth surfaced disk is operatively connected to said extended shaft downstream of said shaft so as to be rotated thereby; and fuel conduit means are coaxially mounted around said extended shaft for feeding fuel onto said surface of said disk adjacent the periphery of said extended shaft for combustion on said disk.

3. An improved jet engine which comprises, in combination: an outer shell having air inlet means in its upstream end portion and exhaust means in its downstream end portion; air compression means in the upstream end portion of said shell; turbine means spaced downstream from said air compression means within said shell; a rotatable shaft connecting said air compression means and said turbine means for driving said air compression means; at least one smooth surfaced disk attached to said shaft so as to be rotated by said shaft; an annular fuel inlet conduit means coaxially mounted around said shaft for introducing fuel onto the upstream and downstream sides of said disk; a housing completely enclosing each said disk, said housing being smaller in diameter than the inner diameter of said shell and rigidly attached to said shell; an air inlet in at least one radial wall of each said housing so as to permit the flow of air into the interior of said housing and along said surface of said disk to provide for substantially complete combustion of said fuel on said surface of said disk within said housing; and a fuel combustion products outlet in the downstream side of each said housing.

4. An improved jet engine which comprises, in combination: an outer shell having air inlet means in its upstream end portion and exhaust means in its downstream end portion; air compression means in the upstream end portion of said shell; turbine means spaced downstream within said shell from said air compression means and together with said air compression means defining a combustion section within said shell between said air compression means and said turbine means; a rotatable shaft connecting said air compression means and said turbine means for driving said air compression means, said shaft also extending downstream of said turbine means; a primary combustor comprising a first smooth surfaced disk attached to said shaft so as to be rotated thereby and a first housing enclosing said first disk, said primary combustor being positioned in said combustion section downstream of said air compression means; a secondary combustor comprising a second smooth surfaced disk attached to said shaft so as to be rotated thereby and a second housing enclosing said second disk, said secondary combustor being positioned intermediate said primary combustor and said turbine means; a third smooth surfaced disk attached to said extended shaft downstream of said turbine so as to be rotated thereby; a first annular fuel conduit means coaxially mounted around said shaft for delivering fuel to the upstream side of said third disk; a second annular fuel conduit means coaxially mounted around said first fuel conduit means for delivering fuel onto the upstream and downstream sides of said first and said second disks; an air inlet in at least one radial wall of each said housing so as to permit flow of air into the interior of said housings and along said surfaces of said disks to provide for substantially complete combustion of said fuel on said surfaces of said disks within said housings; and a fuel combustion products outlet in the downstream side of each said housing.

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