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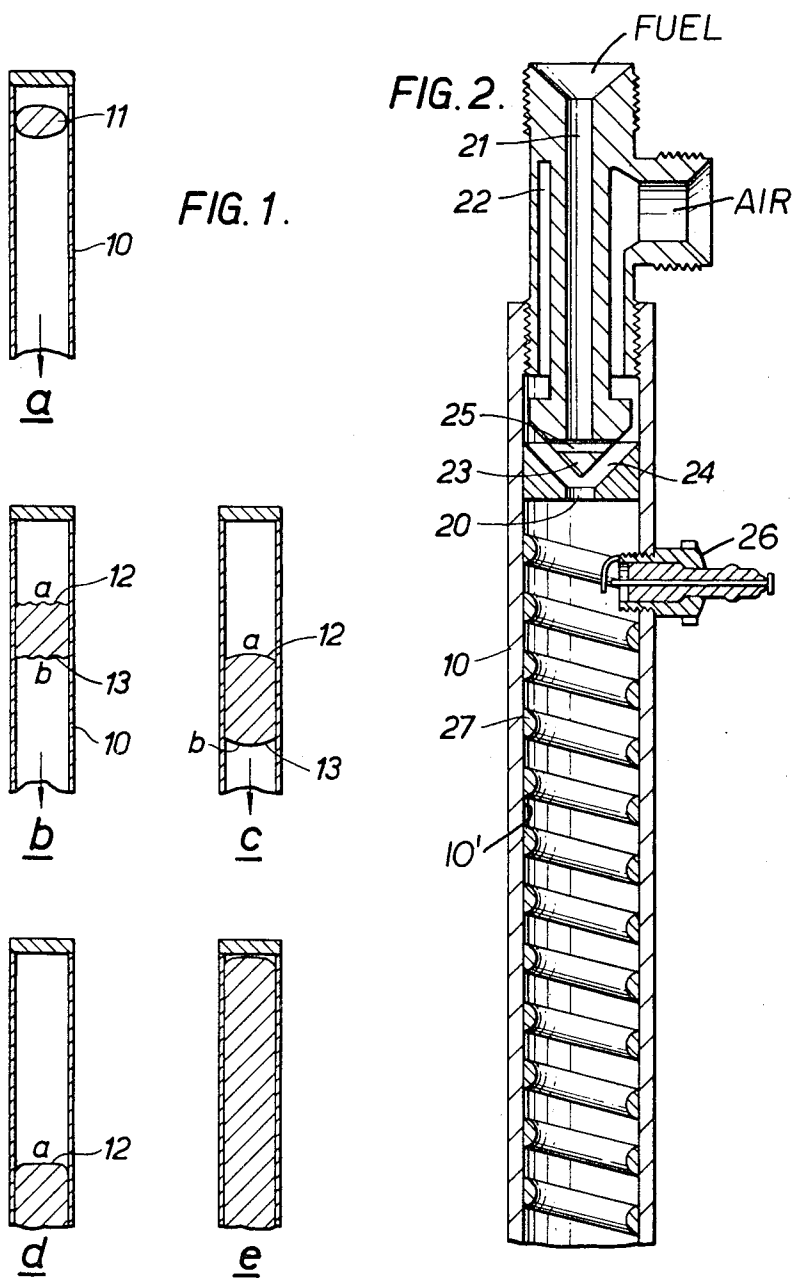
D. H. DESTY ET AL

3,674,409

BURNERS HAVING A PULSATING MODE OF OPERATION

Filed Aug. 26, 1969

4 Sheets-Sheet 1



INVENTORS

DENIS HENRY DESTY

BARRY HERBERT FRANCIS WHYMAN

BY

Morgan, Finnegan, Dunham & Price
ATTORNEYS

July 4, 1972

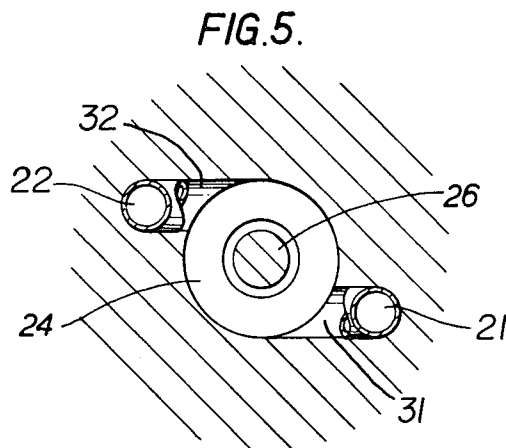
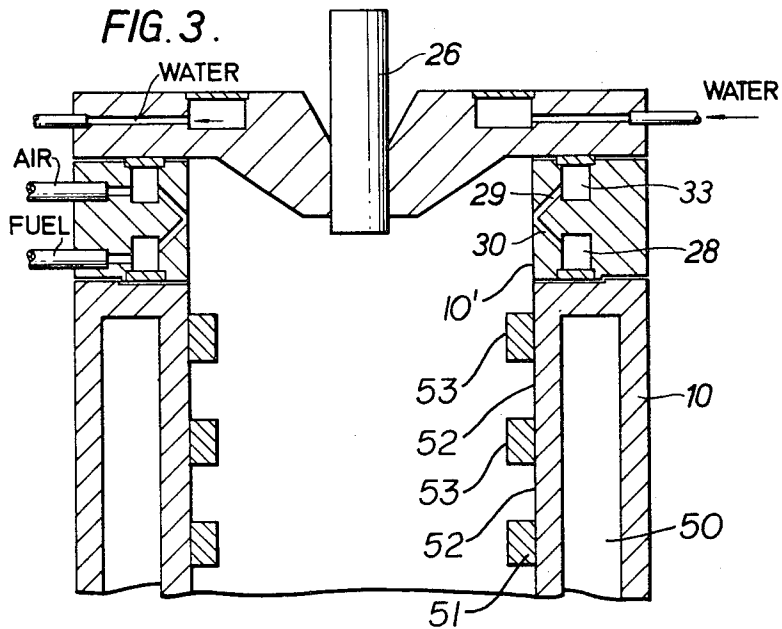
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4 Sheets-Sheet 2



INVENTORS

DENIS HENRY DESTY

BARRY HERBERT FRANCIS WHYMAN

BY

Morgan, Finnegan, Dunham & Pine
ATTORNEYS

July 4, 1972

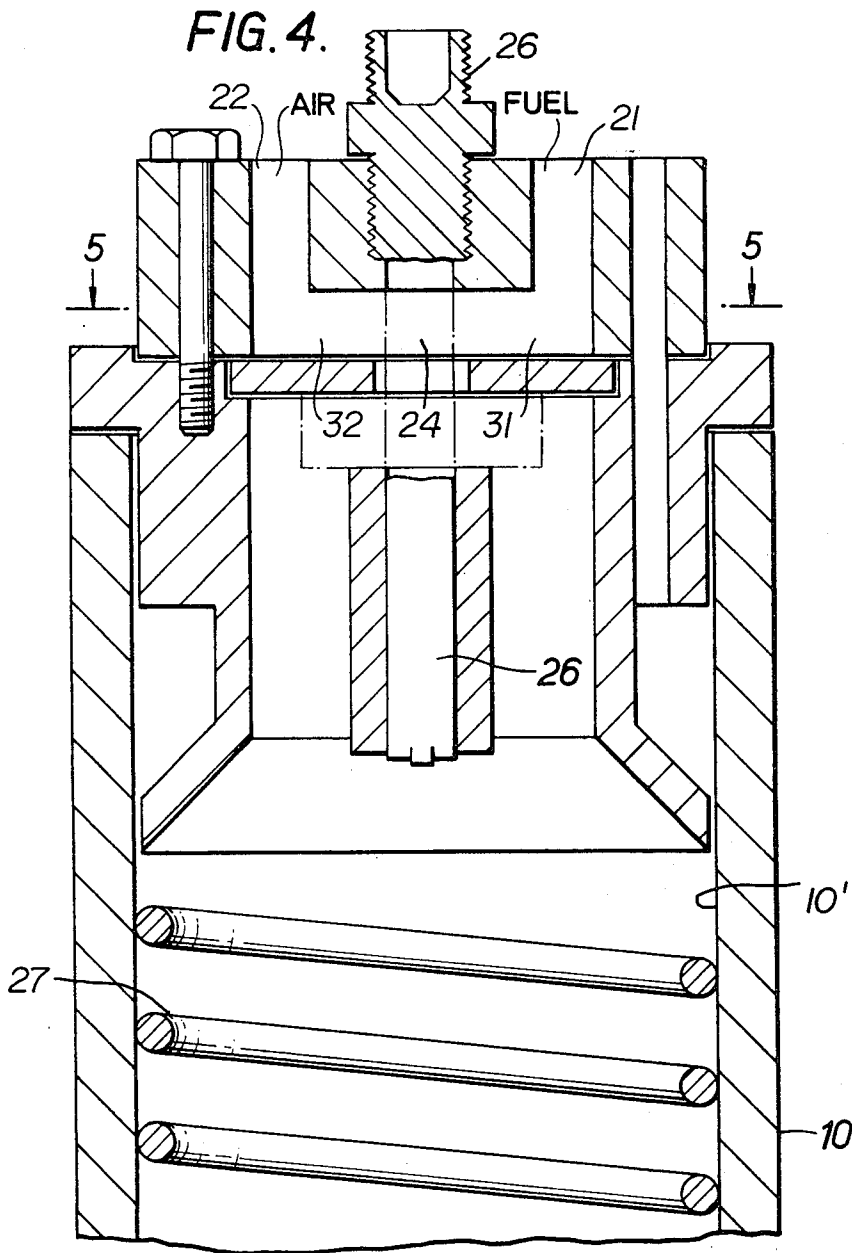
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4 Sheets-Sheet 3



INVENTORS

DENIS HENRY DESTY

BARRY HERBERT FRANCIS WHYMAN

BY

Morgan, Finnegan, Durham & Pine
ATTORNEYS

ATTORNEYS

July 4, 1972

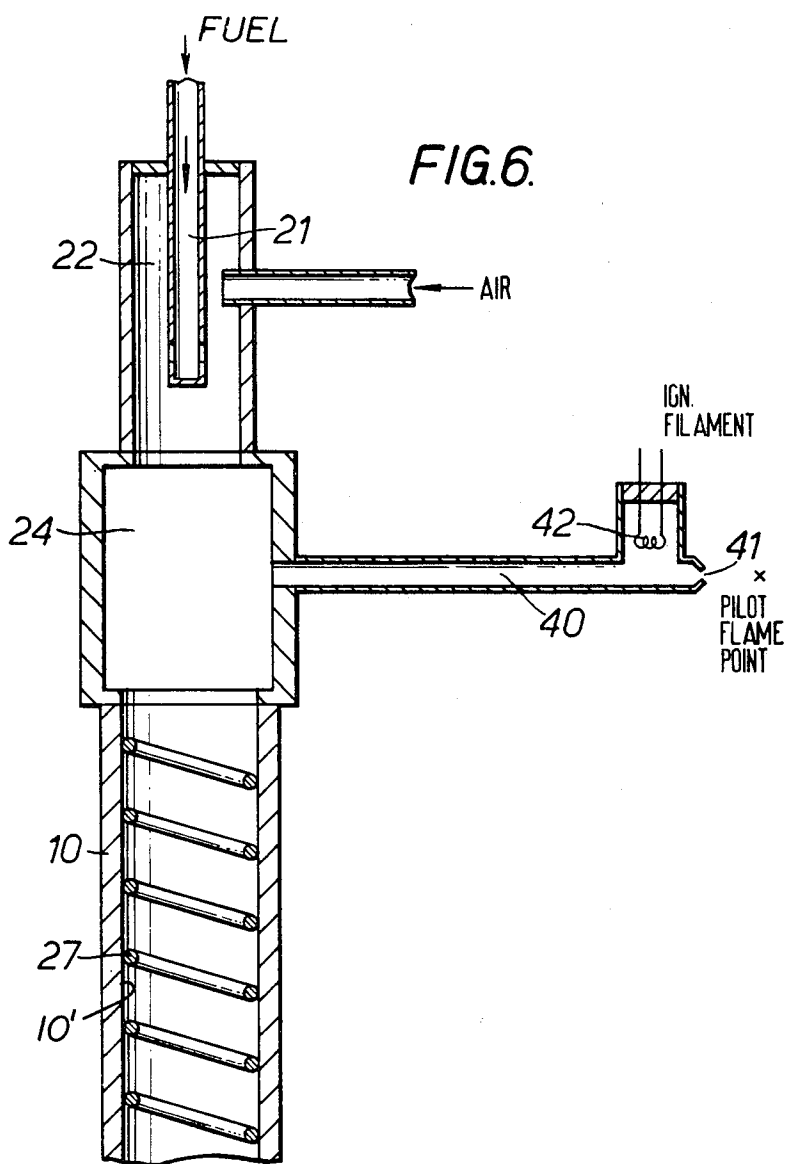
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INVENTORS

DENIS HENRY DESTY

BARRY HERBERT FRANCIS WHYMAN

BY

Morgan, Stinegar, Dunham & Paine
ATTORNEYS

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3,674,409

BURNERS HAVING A PULSATING MODE OF OPERATION

Denis Henry Desty, Weybridge, and Barry Herbert Francis Whyman, Teddington, England, assignors to The British Petroleum Company Limited, London, England
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3 Claims

ABSTRACT OF THE DISCLOSURE

A burner having a pulsating mode of combustion and which can be used to carry out free radical reactions comprises (a) a combustion chamber (preferably cylindrical with an actual length of at least ten times the average diameter) which has grossly rough walls, and (b) an oxygen/fuel inlet system which has a low resistance to gaseous flow. During use the continuously flowing fuel mixture is periodically ignited. One combustion wave travels downstream until the mixture is exhausted and the other travels up-stream until it reaches the point at which the fuel and oxygen inlet systems separate.

This invention relates to a burner which has a pulsating mode of operation, that is to a burner which burns its fuel in a series of discrete explosion waves and to a method of generating a series of combustion explosion waves from a gaseous oxygen/fuel mixture.

Burners which produce a series of explosion waves can be used for geological formation heating. In addition the pressure pulses can, under certain circumstances, be used as a replacement for a series of hammer blows.

According to the invention a burner having a pulsating mode of operation comprises:

- (a) a combustion chamber for the period explosive burning of an oxygen/fuel mixture continuously supplied thereto, which chamber has a grossly rough interior wall providing successive pressure wave reflection points for creating secondary ignition centres in advance of the combustion wave front of the mixture,
- (b) an oxygen/fuel inlet system for continuously supplying an explosive oxygen/fuel mixture to the combustion chamber, which system has a low resistance to gaseous flow and which is arranged to mix the fuel and oxygen at one end of the combustion chamber, and
- (c) an ignition source for periodically igniting the continuously supplied mixture at the mixing end of the combustion chamber,

whereby, during the use of the burner, a series of explosion waves is produced by repeated ignition of an explosive mixture formed in the combustion chamber.

Cylindrical combustion chamber are particularly suitable, especially those whose axial length is at least 10 times their average diameter.

The oxygen is supplied to the burner in the gaseous phase and it may be supplied as a gaseous mixture, e.g. air. As stated above the oxygen inlet system must offer a low resistance to the flow of the gaseous oxygen.

The fuel may be liquid in which case the fuel inlet system may take the form of an atomiser for spraying fine droplets of liquid fuel into the oxygen flow on entry to the combustion chamber.

Preferably the fuel is gaseous (or vapourised liquid) in which case the gaseous fuel inlet system must also offer a low resistance to the flow of (gaseous) fuel.

The inlet system may be arranged to admit the oxygen and fuel directly into the combustion chamber; this forms

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a mixing zone at one end of a cylindrical combustion chamber. Alternatively the oxygen and fuel may first pass into one or more small antechambers where mixing occurs before the oxygen and fuel pass into the combustion chamber.

During use an ignition source is positioned in the combustion chamber.

The invention will now be described by way of example with respect to the drawings in which:

FIGS. 1a-1e illustrate five stages in the propagation of one combustion wave,

FIGS. 2-4 are longitudinal cross sections showing various inlet systems and spark plug arrangements, and

FIG. 5 is a cross section on the line 5-5 of FIG. 4, and

FIG. 6 illustrates a burner with a continuous ignition source.

FIG. 1a shows a burner which comprises a cylindrical combustion chamber 10 just after the ignition spark, the inner wall of the chamber being macroscopically rough, that is, sufficiently rough to enable surface irregularities to be observed by the unaided eye, for reasons which are more fully set forth below. At this stage there is in the explosive gas mixture in the chamber, a spherical combustion wave or flame front 11 with a slug of hot burnt gas inside; as the time passes the slug of hot burnt gas grows larger as does its enveloping spherical combustion wave front and it also moves down-stream with the downwardly moving gas flow because the initial flame velocity of the explosive gas mixture is less than the velocity of the downwardly moving, incoming gas.

At the stage shown in FIG. 1b the spherical combustion wave front 11 has grown until its radius has exceeded that of the combustion chamber 10 so it has divided into two turbulent accelerating combustion wave or flame fronts 12 and 13 which are separated by an expanding, downwardly-moving slug of hot burnt gas; the wave front 12 travels up-stream and the wave front 13 travels down-stream. Both combustion wave fronts accelerate by a mechanism in which the associated pressure wave, that is, the pressure wave created in the explosive gas mixture in advance of each combustion wave front, is reflected from successive point on the macroscopically rough wall thus creating secondary ignition centres in the explosive gas mixture in advance of the combustion wave front. At the stages shown in FIGS. 1c and 1d, the expanding slug of burnt gas has continued its downward movement while the combustion wave fronts 12 and 13 continue to accelerate through the explosive mixture toward the top and bottom, respectively, of the chamber 10. Finally, as shown in FIG. 1e the wave front 12 reaches the inlet system where there are separate oxygen and fuel systems and the wave front 12 goes out. The chamber 10 then re-charges with explosive mixture so that the next cycle can start.

The inlet system shown in FIG. 2 joins the combustion chamber 10 at an inlet port 20 and it has an annular configuration with a central fuel pipe 21 surrounded by an air duct 22. Just upstream of the inlet port 20 there is a conical baffle 23 which forms an antechamber 24 adjacent to its conical surface. The conical baffle 23 has a flat base 25 which, during use, deflects the fuel flow into the air flow so that mixing begins in the antechamber 24. All the passages are so wide that the resistance to gas flow is low.

The mixture of air and fuel passes from antechamber 23 into the cylindrical combustion chamber 10 where it is ignited by successive sparks from the plug 26.

A spiral 27 of metal rod semicircular in cross-section, is secured to the inner wall 10' of the combustion chamber to form therewith a grossly rough, or macroscopically rough inner surface providing successive points for reflection of a pressure or compression wave created in the

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explosive gas mixture in advance of a combustion wave front initiated by ignition of the mixture, so that the combustion wave initiated by the spark plug 26 accelerates into an explosion wave.

(The burner was 25 cm. long and its inside diameter was 1.4 cm., ignoring the spiral which was formed of rod 0.2 cm. diameter. The pitch of the spiral was 0.5 cm.)

In the burner shown in FIG. 3 the spark plug 26 is situated centrally at one end of the combustion chamber 10.

The inlet system comprises an air gallery 33 and a fuel gallery 28. These galleries communicate with the combustion chamber 10 via (12) pairs of air ducts 29 and fuel ducts 30 which meet at right angles on the inner wall 10' of the combustion chamber. All the ducts have a sufficiently wide diameter to provide a low resistance to the flow of air and fuel so that an explosive mixture is produced in a mixing zone at the end of the combustion chamber. As can be seen the walls of the combustion chamber are water cooled through the provision of water gallery 50. Shoulders 51 rectangular in cross-section are secured to the inner walls 10' to form the desired grossly rough or macroscopically rough inner surface as aforesaid. As depicted, these extend radially inwardly from the wall for equal distances and are spaced axially from each other to provide alternating wide and narrow wall portions, that is, alternating maximum and minimum diameter portions 52 and 53, respectively, of the chamber.

In the burner embodiment depicted in FIG. 3, the combustion chamber 10 is 107 cm. long, its maximum internal diameter is 7.6 cm. and its minimum internal diameter is 6.0 cm. The axial length of each wide portion 52 is 0.8 cm. and the axial length of each narrow portion 53 is 0.8 cm. This ensures that the combustion waves accelerate into explosion waves due to compression wave reflections.

The burner shown in FIGS. 4 and 5 also has its spark plug 26 (with annular electrodes) situated centrally at one end of the combustion chamber 10; as can be seen from FIG. 3 the walls of the combustion chamber are externally water cooled.

The inlet system comprises a fuel pipe 21 and an air pipe 22, both parallel to the axis of the burner, with radial terminal sections 31 and 32, respectively. As can be seen more clearly in FIG. 5 the inlet system also comprises an antechamber 24 into which the two terminals sections 31 and 32 open tangentially. Thus the fuel and oxygen mix by swirling in the antechamber 24 and the mixture passes into the inlet end of the combustion chamber 10.

The size and arrangement of the walls of the combustion chamber are the same as in FIG. 2 save that the spiral 27 is formed of metal rod which is circular in cross-section.

The burners will operate provided that sparks occur when the combustion chamber contains sufficient fuel. Preferably the spark rate is adjusted to gas flow rate so that the time between sparks equals the time required to burn the previous charge (in practice this time is small enough to be neglected) plus the time required to re-fill the combustion chamber with fresh mixture. Variations from this setting mean that either unburnt gas leaves the burner or burning takes place in only a portion of the combustion space. For high flame speed fuel gases, e.g. hydrogen, quite small sparks, e.g. millijoule energy sparks such as are used in automobile practice, are suitable but with fuel gases of low flame speeds, e.g. methane and natural gas, a spark energy of 2-3 joules may be necessary to combat (a) poor mixing in the free flow system and (b) slow flame acceleration.

A burner with a modified ignition source is illustrated in FIG. 6. In general the burner is as illustrated in the previous figures with the modification of a side arm 40 having a vent 41 adjacent to a hot filament 42.

Shortly after a detonation the burner will, as described above, be full of burnt gas and it will be apparent that the side arm 40 will also be full of burnt gas. As the new

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charge re-fills the burner it will also enter the side arm 40 driving the burnt gas through the vent 41. When the new charge reaches the continuously glowing filament 42 ignition will occur and the flame will travel along the side arm 40 into the antechamber 24 and thereafter combustion propagation will take place as described above.

The timing of the ignition is controlled by the time taken for the next mixture to reach the glow wire 42 and, in its turn, this time is controlled by the size of the vent 41. Thus more frequent ignitions (i.e. smaller charges) can be achieved by opening the vent 41 to allow quicker access of combustion mixture to the glow filament 42. Similarly slower ignitions can be achieved by closing the vent 41. It will also be apparent that the ignition of full charges will occur when the vent 41 is of such a size that the side arm 40 fills in the same time as the combustion chamber 10.

All the embodiments so far described have required an electric power source (not shown in any drawing) for ignition. If no electric power is available ignition may be achieved by a simple modification of FIG. 6 which is not shown in any drawing. In this modification a pilot flame, operated from the fuel/air system, is positioned just outside the vent 41 and when fresh mixture exhausts through the vent ignition occurs.

The burners described above have been successfully operated at ambient pressures of up to 30 atmospheres. The following table lists some of the fuel/oxidant mixtures which have been successfully used in a burner having spark plug ignition and an internal diameter of 12 mm.

Fuel	Oxidant	Pressure rise
Hydrogen.....	Air.....	X3
Do.....	Oxygen.....	
Town's gas.....	Air.....	X2
Methane.....	Air.....	X1.5
Do.....	Oxygen.....	
Propane (commercial).....	Air.....	
Butane (commercial).....	Air.....	
Do.....	Oxygen.....	
Acetone.....	Air.....	
Heptane.....	Air.....	
Iso-octane.....	Air.....	
Kerosene.....	Air.....	

Burners according to the invention are suitable for carrying out chemical reactions, particularly chemical reactions which involve the free radicals which exist in high concentration (about 15%) in the combustion waves. Reactions will be described under three headings, namely combustion reactions which involve only the fuel and the oxidant, gas phase reactions which involve gaseous phase material specially added to the combustion mixture, and heterogeneous reactions which involve non-gaseous components, e.g. liquids flowing down the walls of the burner.

Combustion reactions

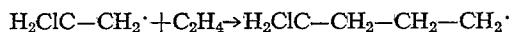
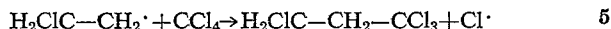
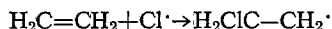
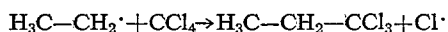
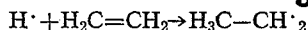
These use the natural quenching effect behind a rapidly moving detonation type wave to stabilize certain products. For example hydrogen peroxide can be prepared from hydrogen/oxygen mixtures near the oxygen rich limit, where the formation of H_2O_2 controls the reaction $OH \cdot + OH \cdot \rightarrow H_2O_2$.

In the case of hydrocarbon fuels, aldehydes (i.e. partial combustion products) can be obtained e.g. formaldehyde with methane as the fuel.

Gas phase reactions

These are mainly reactions involving free radicals. Any added material must be reasonably stable at high temperatures, e.g. water and haloalkanes (carbon tetrachloride). One possible reaction is that between ethylene and carbon tetrachloride to produce chlorinated telomers and addition compounds, carbon tetrachloride would be added to the ethylene fuel stream and reaction schemes such as that below would lead to the chlorinated products.

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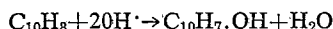


Heterogeneous reactions

Free radicals such as hydroxyl, methyl, methylene (carbene) and hydrogen atoms will come into contact with the wall liquid film and react. 10

Systems include

- (i) Homolytic aromatic substitution by alkyl radicals and hydroxyl (e.g. free radical attack on benzene rings) such as the formation of 1-naphthol from naphthalene 15



- (ii) Hydration of long chain (e.g. with 10 to 20 carbon atoms) olefines via hydroxyl radicals. 20

- (iii) Insertion and addition reactions of carbenes with aromatic systems and olefins. 20

We claim:

1. A burner having a pulsating mode of operation, which burner comprises: 25

- (a) a combustion chamber for the timed periodic explosive burning of successive separate charges of an explosive oxygen/fuel mixture continuously supplied to said burner, the inner wall of said chamber being cylindrical and having a spiral of metal rod secured to the inner wall to form successive pressure wave reflection points extending generally radially inwardly of said chamber from said wall at selected successive intervals along the length of said chamber, for reflecting pressure waves resulting from burning of each explosive mixture charge to create secondary ignition centres in the explosive mixture charge in advance of combustion wave fronts initiated by ignition of the charge; 30 35

- (b) an oxygen/fuel inlet system for continuously supplying oxygen and fuel to the burner at one end of the combustion chamber, which system has a low resistance to gaseous flow and which is arranged to mix the fuel and the oxygen at said one end of the combustion chamber so as to continuously provide successive separate explosive mixture charges in said chamber; and, 40 45

- (c) an ignition source at said one end of said combustion chamber for initiating, at selected periodic intervals, ignition of the continuously provided successive separate explosive mixture charges at said one end of said chamber, 50

whereby, during use of the burner, a series of explosion waves is produced in said burner by periodic ignition of the successive separate explosive mixture charges.

2. A burner according to claim 1 in which said spiral is of uniform pitch.

3. A burner having a pulsating mode of operation, which burner comprises:

- (a) a combustion chamber for the timed periodic explosive burning of successive separate charges of an 60

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explosive oxygen/fuel mixture continuously supplied to said burner, the inner wall of said chamber having a macroscopically rough surface providing successive pressure wave reflection points extending generally radially inwardly of said chamber from said wall at selected successive intervals along the length of said chamber, for reflecting pressure waves resulting from burning of each explosive mixture charge to create secondary ignition centres in the explosive mixture charge in advance of combustion wave fronts initiated by ignition of the charge;

- (b) an oxygen/fuel inlet system for continuously supplying oxygen and fuel to the burner at one end of the combustion chamber, which system has a low resistance to gaseous flow and which is arranged to mix the fuel and the oxygen at said one end of the combustion chamber so as to continuously to provide successive separate explosive mixture charges in said chamber, said oxygen/fuel inlet system comprising an ante-chamber communicating with one end of said combustion chamber, in which ante-chamber the fuel and oxygen are mixed before passing into the combustion chamber and said system also comprising means forming an inlet port joining said system to said one end of said combustion chamber, a central fuel pipe, an annular air duct surrounding said fuel pipe, and a conical baffle disposed upstream of said inlet port and beneath said fuel pipe and forming said ante-chamber adjacent to the conical surface of said baffle, said baffle having a flat base for deflecting fuel flow from said central fuel pipe into the air flow from said annular air duct, so that mixing begins in said ante-chamber; and,

- (c) an ignition source at said one end of said combustion chamber for initiating, at selected periodic intervals, ignition of the continuously provided successive separate explosive mixture charges at said one end of said chamber,

whereby, during use of the burner, a series of explosion waves is produced in said burner by periodic ignition of the successive separate explosive mixture charges.

References Cited

UNITED STATES PATENTS

1,381,095	6/1921	Starr	239—404 X
1,434,256	10/1922	Thompson	431—1
1,841,169	1/1932	Butz	431—353 X
2,425,975	8/1947	Witte et al.	431—1 X
2,715,436	8/1955	Lafferentz et al.	431—1
3,473,879	10/1969	Berberich	431—1
3,516,253	6/1970	Allport et al.	60—39.77
2,612,749	10/1952	Tenney et al.	60—249

FOREIGN PATENTS

174,726	3/1961	Sweden	431—1
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CARROLL B. DORITY, JR., Primary Examiner

U.S. Cl. X.R.

431—353; 60—39.77