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(56) Documents Cited:
GB 2204121 A **GB 1353335 A**
GB 0222188 A **EP 1041344 A1**
US 5941075 A **US 5558515 A**
US 5274995 A

(58) Field of Search:
UK CL (Edition V) **F4T**
INT CL^7 **B01F, F23D, F23R**
Other: **Online: WPI, EPODOC, JAPIO**

(54) Abstract Title: **A mixer for two fluids having a venturi shape**

(57) A mixer for mixing a first and second fluid in a passageway 1 comprises a venturi having at least one injection port 11 in a peripheral wall 12 introducing the second fluid upstream of a conical divergent section 7 of the venturi and a swirl generating device 13 upstream of a conical convergent section 6 of the venturi. The two fluids maybe air and a combustible gas or air and a liquid fuel. The swirl generator 13 may have a variable swirl angle in the radial direction and may increase with distance from an axis 2 of the passageway 1 and its location in combination with the angle of the peripheral wall 12 with the axis 2 reduces vortex breakdown and flashback. The peripheral wall 12 maybe coated with a catalytic material for quenching radicals and preventing flashback and flame anchoring. Injection ports 11 may be holes facing or skewed to axis 2, and maybe symmetrically (Fig 4a) or angularly (Fig 4b) arranged around the passageway 1. Swirl generator 13 may surround a central mandrel for injecting air or a central fuel injection lance. The mixer may be used in a combustion device having multiple burners 14. A flow straightening device 16 with channels coated with a catalyst for quenching radicals and also prevents flashback may be used.

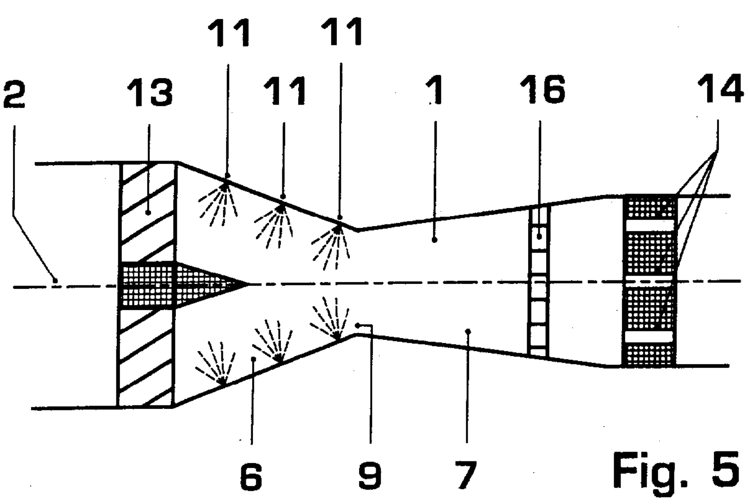

Fig. 5

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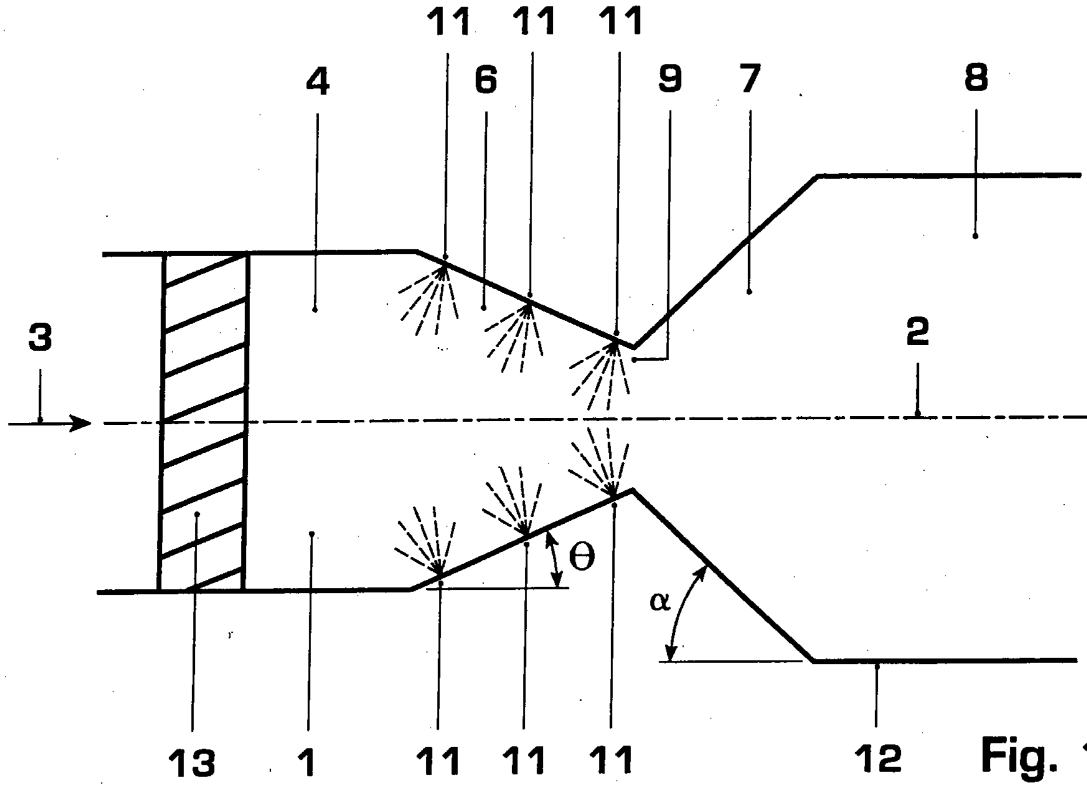

Fig. 1

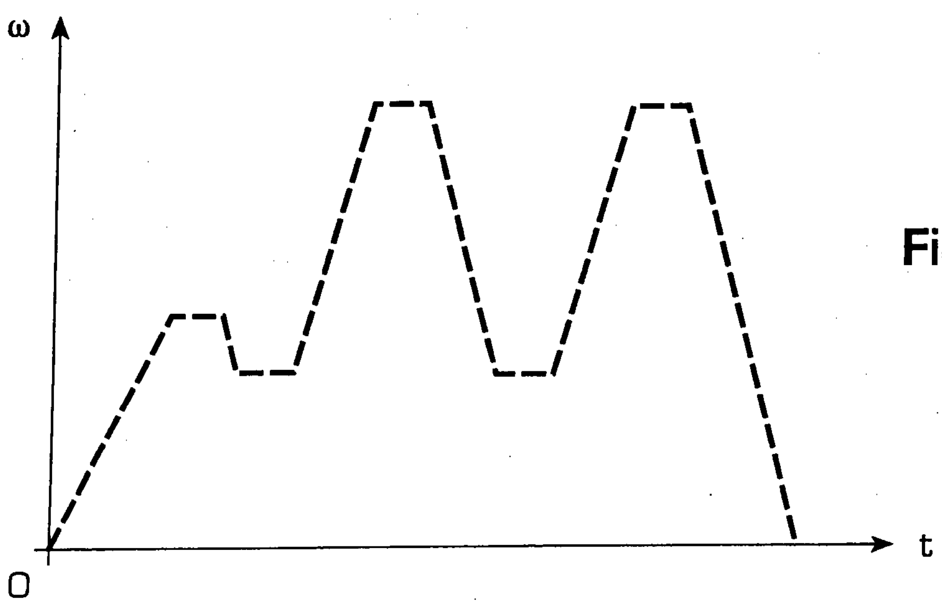

Fig. 2

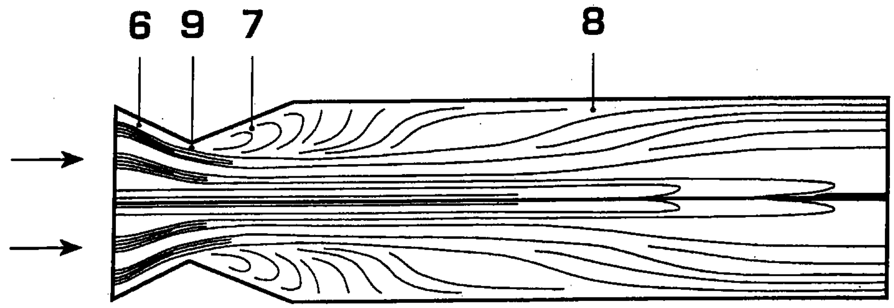

Fig. 3

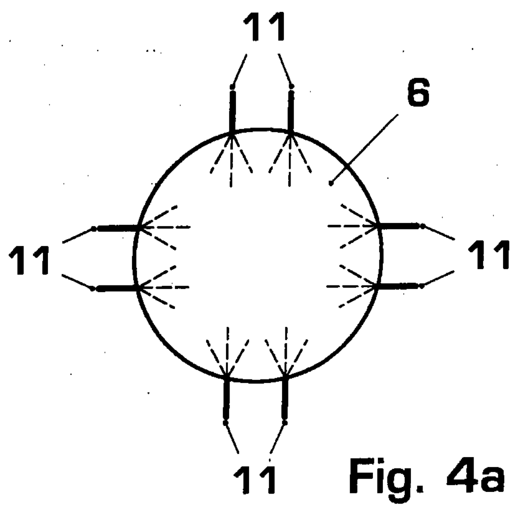

Fig. 4a

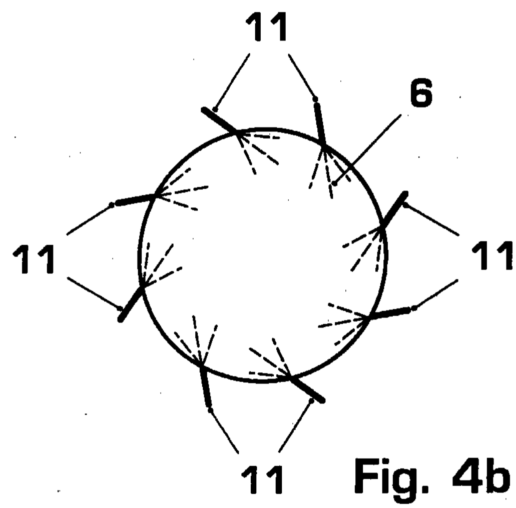

Fig. 4b

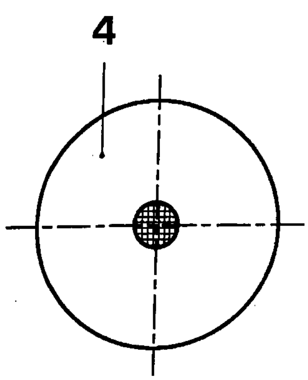

Fig. 6

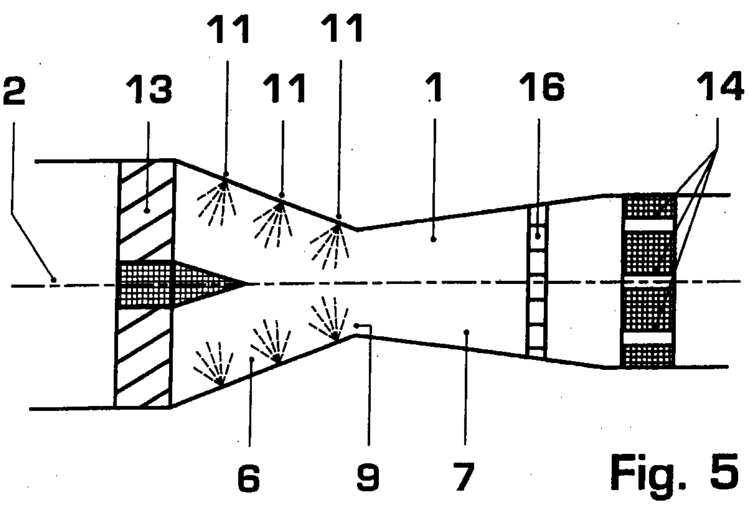

Fig. 5

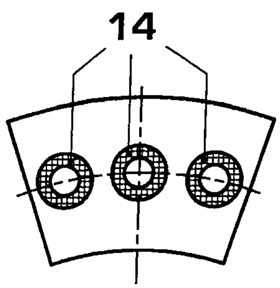

Fig. 7

MIXER

This invention relates to a mixer and a method for mixing first and second fluids. The two fluids may be gases, e.g. air and a combustible gas, or a gas and a liquid, e.g. air and a liquid fuel, or liquids. The mixer may, in particular, form part of a combustion device.

A number of applications require that separate fluid streams be thoroughly mixed. One such application is catalytic combustion, where the fuel and air must be very well mixed prior to entry in the catalyst. This requirement also holds true for conventional lean-premix burners. However, current mixing techniques generally do not achieve homogeneous mixtures, and therefore the resulting combustion process is non-uniform; large temperature variations are observed, and significant NOx emissions associated with high-temperature areas are recorded.

Attaining high levels of mixedness between fluids is normally accompanied by large, undesirable pressure losses. The most promising option to date is that involving counter-swirling flows. However, complex aerodynamic designs (i.e. aerofoil sections) are essential components of such units, because the structures generating swirl must not form wakes including recirculation zones (which can lead to flashback and severe damage); furthermore, there is scope for significant improvement in mixing quality. For certain applications, e.g. those involving catalytic units, the catalyst inlet velocity distribution must be as uniform as possible; this is a difficult objective for conventional mixers which employ swirling flows. A further problem with many units is that of flashback, i.e. the phenomenon which entails a homogeneous flame moving upstream and into the mixer, often resulting in damage.

Venturi injectors are relatively simple devices for attaining reasonable mixing; however, the quality falls short of that achieved by the swirl-based concepts. Venturi units rely upon low local pressures to draw additive fluid into a carrier fluid; mixing is attained by virtue of the shear layer across the longitudinal jet of fluid, whose principal velocity component is axial. US 4,123,800 describes a mixer in which a certain degree of twisting motion is imparted to the flow downstream of the Venturi constriction, to further aid in mixing, by means of skewed grooves machined into the walls of the divergent section downstream of a throat section into which the additive fluid is injected. However, this twisting motion is only imparted near the walls, without significantly affecting the bulk of the flow, and does not meaningfully assist the mixing process.

The present invention provides a passageway along which a stream comprising the first fluid flows along an axis of the passageway, the passageway having, in sequence in the downstream direction, a convergent section, a throat, and a divergent section; an injector for introducing the second fluid into the stream in the passageway upstream of the divergent section; and a swirl generator in the passageway upstream of the convergent section.

The invention also provides a method of mixing fluids, comprising the sequential steps of

(a) providing a stream comprising a first fluid and having an axis along which the stream flows,
(b) inducing swirl in the stream about its axis,
(c) causing the stream to converge towards its axis, and
(d) causing the stream to diverge from its axis,

the method including introducing a second fluid into the stream before step (d).

The invention will be described further, by way of example only, with reference to the accompanying drawing, in which:

Figure 1 is a schematic axial section through one embodiment of a mixer;

Figure 2 is a graph of angular velocity, ω, in the circumferential direction against radial distance, r, from the axis of a swirling stream created in a preferred embodiment of the mixer;

Figure 3 shows the angular velocity field produced by the swirling stream having the radial distribution of angular velocity shown in Figure 2;

Figure 4a is a cross-section through the convergent section of a mixer, showing one possible arrangement of injectors;

Figure 4b in a view similar to Figure 4a, showing another possible arrangement of injectors;

Figure 5 is a schematic axial section through a mixer combined with a burner sector;

Figure 6 is an inlet end view of the mixer in Figure 5; and

Figure 7 is an outlet end view of the burner sector.

The mixer illustrated in Figure 1 comprises a passageway 1 having an axis 2 along which a stream of air (the carrier fluid or first fluid) flows in the direction of the arrow 3. The passageway 1 has an upstream end portion or inlet section 4 which is cylindrical, a convergent section 6 which is conical and which converges at an angle θ with respect to the axis 2, a divergent section 7 which is conical and diverges at an angle α with respect to the axis 2, and a downstream end portion or outlet section 8 which is cylindrical. The passageway has a throat 9 between the convergent and divergent sections 6, 7; in the embodiment illustrated, the throat 9 is of negligible axial length. The convergent section 6, throat 9, and divergent section 7 together constitute a Venturi section.

An injector comprising a plurality of injection ports 11 in the peripheral wall 12 of the passageway 1 introduces fuel (the additive fluid or second fluid) into the stream in the convergent section 6 at multiple locations along and around the axis 2. If the additive fluid is a liquid, it can be injected as sprays, and droplet atomisation and penetration can be enhanced by using high-pressure injectors.

A swirl generator 13 is provided in the inlet section 4 of the passageway 1. This imparts swirl to the bulk flow of the carrier fluid prior to the convergent section 6 and prior to the injection of the fuel. Conservation of angular momentum results in increased angular velocities of the swirling stream at the throat 9. Such a configuration enhances mixing between the carrier fluid and additive fluid by virtue of the circumferential shear layers which are formed. These shear layers promote cross-stream diffusion. Mixing begins earlier than in a conventional Venturi injector and results in a longer time being available for mixing and a more uniform concentration profile.

Mixing can be significantly improved by generating angular velocity profiles which form a number of intense circumferential shear layers. The intensity of these shear layers is directly proportional to $d\omega/dr$ (the radial gradient of the angular velocity). Thus, abrupt changes in the circumferential component of the angular velocity are desirable. Figure 2 is a graph of the angular velocity, ω, in the circumferential direction against radial distance, r, from the axis 2, illustrating a radical form of such an angular velocity profile. A swirling velocity field resulting from the application of inlet angular velocities similar to those of Figure 2 is depicted in Figure 3. Whilst distinct swirling annular bodies are clearly visible at the inlet of the convergent section 6, these are seen to merge with each other as the longitudinal distance from the inlet increases. Such "blurring" of the annular layers is indicative of cross-stream interactions, which result in mixing of the first and second fluids.

In order to generate such an angular velocity profile, a swirl generator 13 is used in which the swirl angle varies in the radial direction, typically increasing with distance from the axis.

Whilst strong levels of swirl are beneficial to mixing, vortex breakdown has to be avoided if flashback is to be prevented in combustion applications. Although studies have demonstrated that vortex breakdown is promoted by expansion downstream of a swirl generator, we have found that vortex breakdown does not occur so readily if a convergent section is placed between the swirl generator and the divergent section. Also, studies have shown that abrupt changes in tangential velocity profiles tend to reduce the tendency of vortex breakdown. Instead, flashback is hindered by the strongly swirling axial jet which is formed. The value of θ required to avoid vortex breakdown is a function of the angular velocity profile produced by the swirl generator 13. For example, we have found that (for a given operating condition, i.e. velocity, pressure, temperature) if the swirl angle varies (radially) between 15° and 45°, θ should lie between 15° and 25°, whereas in a configuration where the swirl angle changes from 15° to 30°, θ may be reduced to less than 15°.

The nature of the divergence downstream of the throat 9 can be selected for various needs. If recirculation zones are not desired, expansion must not be sudden, so a more gradual increase in the cross-section of the divergent section 7 is needed. Such a configuration may be applicable to cases where no negative axial velocities are desired, for example in catalytic combustion. On the other hand, the mixer may be used for premixed combustion, in which case sudden expansion serves to aerodynamically anchor the homogeneous flame.

The mixer does not require the large inlet to throat diameter ratio (typically 2) normally necessary for strongly accelerating a carrier fluid, because of the high degree of mixing resulting from tangential shear in the carrier fluid, for which the axial velocities need no longer be so high. Conventional Venturi injectors require small angles of divergent (diffuser angles), typically α = 5°, if flow separation is to be avoided, but the resulting long diffuser lengths result in significant pressure losses such that, in a typical conventional Venturi injector, 95% of the loss is incurred during diffusion. In the present mixer, if flow separation is to be avoided, small angles of divergence are still necessary, but the relatively large throat diameter results in shorter diffusers and hence smaller pressure losses. Such a saving of space may be highly advantageous in catalytic combustion applications.

The peripheral wall 12 of the passageway, particularly the Venturi section constituted by the convergent and divergent sections 6, 7, may be coated with a catalytic material for the purpose of quenching radicals, which are precursors of homogeneous ignition and combustion. This assists in preventing flashback and flame anchoring, these two phenomena being encouraged by the lower velocities encountered in the boundary layer near the peripheral wall.

The injection ports 11 may simply be holes which each face the axis 2. However, introducing the additive fluid in a direction which is skewed to the axis 2 results in increased turbulence and better mixing of the additive fluid with the carrier fluid. Figures 4a and 4b show possible orientations of the injection ports 11. In Figure 4a the ports 11 are symmetrically arranged with respect to planes containing the axis of the passageway. In Figure 4b the ports 11 are angled so as to assist the swirling motion of the carrier fluid. However, the injection ports may instead be angled in the opposite sense with respect to the swirl direction of the carrier fluid.

Injection ports 11 of different sizes may be provided in order to achieve different depths of penetration of the additive fluid into the stream. Fuels which are particularly prone to causing flashback due to their high flames speeds and diffusivity, for example hydrogen-containing gases such as synthesis gas, can be used in the mixer because of the very high velocities achievable and the possibility of avoiding recirculation zones. The swirl generator 13 may surround a central member or mandrel, which may be in the form of a central injection tube for providing a central air jet hindering the formation of recirculating regions at the exit. Whilst the recirculation zones which tend to form behind a solid mandrel would not normally cause flame attachment (because the axial velocities at the throat 9 are very high, typically tens of times the homogeneous flame speed of natural gas), extra caution has to be exercised when hydrogen-containing fuels are used, because of the very high flame speed and diffusivity of hydrogen.

The swirl generator 13 may circumferentially surround a central fuel injection lance, which could additionally inject air, in order to further enhance mixing.

Increasing the size of the mixer makes it possible to generate a larger number of coaxial swirling layers. It may therefore be advantageous to use the mixer in a combustion device having multiple burners, by using one mixer for a burner sector (comprising a number of burners). Figure 5 illustrates such an embodiment. The circular cross-section of the divergent section 7 gradually changes into a sector of an annulus (Figure 7) in which a number of burners 14 are located (three burners being shown by way of example). The burners 14 may be very simple (e.g. utilising sudden expansion without swirl) because complete fuel / air mixing has already been achieved prior to entry into the burners.

A flow straightener 16, which has also has the function of flashback prevention is placed near the exit of the divergent section 7, upstream of the burners 14. The flow straightener 16 has a similar construction to the swirl generator 13, except that it has straight channels. Flow straightening ensures that the flow distribution into each burner is identical. Small channels (hydraulic diameter typically less than 5mm) act as flame arrestors. The channels may be coated with a catalyst for quenching radicals, further hindering flashback. In order to minimise pressures losses, the flow straightener has a very small axial length, typically less than 15mm. The fact that the mixing process is decoupled from the burners results in more uniform burner entry conditions (flow distribution, pre-mixedness, temperature) and hence more uniform combustion among the burners and fewer instabilities (which may arise if there are differences between burners). This embodiment is thus especially applicable to catalytic combustion.

The embodiment of Figure 5 can be used for liquid fuels if the geometry ensures very high velocities such that the mixer residence time (i.e. the time taken for the fuel to move from the injection point to the burners) is very short, typically less than 3 ms at 3 bar.

Various modifications may be made within the scope of the invention. In particular, although the mixer has been particularly described in the context of mixing air and fuel, the mixer could be used for mixing any two (or more) different fluids. It is possible to introduce the second fluid into the passageway at any convenient location upstream of the divergent section 7. In particular, the throat 9 may be of substantial length and the second fluid may be introduced into the throat. Alternatively, or additionally, the second fluid may be introduced into the inlet section 4 (upstream or, preferably, downstream of the swirl generator 13). Alternatively, or additionally, the second fluid may be introduced through a tube extending along the axis 2. It is also possible to introduce at least one further fluid into the passageway upstream of the divergent section 7.

CLAIMS:

1. A mixer for mixing first and second fluids, comprising:

a passageway along which a stream comprising the first fluid flows along an axis of the passageway, the passageway having, in sequence in the downstream direction, a convergent section, a throat, and a divergent section;

an injector for introducing the second fluid into the stream in the passageway upstream of the divergent section; and

a swirl generator in the passageway upstream of the convergent section.

2. A mixer as claimed in claim 1, in which the injector introduces the second fluid into the stream in the convergent section of the passageway.

3. A mixer as claimed in claim 1 or 2, in which the injector includes at least one injection port in a peripheral wall of the passageway.

4. A mixer as claimed in claim 3, in which there are at least two injection ports of different sizes.

5. A mixer as claimed in any of claims 1 to 4, in which the injection introduces the second fluid at a plurality of locations along the passageway.

6. A mixer as claimed in any of claims 1 to 5, in which the injector introduces the second fluid in at least one direction which is skew to the axis of the passageway.

7. A mixer as claimed in any of claims 1 to 6, in which the swirl generator has a swirl angle which varies as a function of the distance from the axis.

8. A mixer as claimed in claim 7, in which the swirl angle varies such that there is at least one abrupt change in circumferential velocity of the stream about its axis, between one radial position and another.

9. A mixer as claimed in any of claims 1 to 8, including a central injection tube opening in the passageway upstream of the divergent section.

10. A mixer as claimed in claim 9, in which the swirl generator circumferentially surrounds the central injection tube.

11. A mixer as claimed in any of claims 1 to 10, in which the upstream and downstream ends of the convergent section have a diameter ratio of less than 2.

12. A mixer as claimed in any of claims 1 to 11, in which the convergent section converges at an angle of at most 25° with respect to the axis of the passageway.

13. A mixer as claimed in claim 12, in which the said angle is at least 10°, preferably at least 15°.

14. A mixer as claimed in any of claims 1 to 13, in which a peripheral wall of the passageway has a coating of a catalyst for quenching radicals which are precursors to ignition of the mixture of fluids.

15. A mixer as claimed in any of claims 1 to 14, further comprising a flow straightener in the passageway downstream of the throat

16. A mixer as claimed in claim 15, in which the flow straightener has channels with a hydraulic diameter of at most 5mm.

17. A mixer as claimed in any of claims 15 to 16, in which the flow straightener carries a catalyst for quenching radicals.

18. A mixer as claimed in any of claims 15 to 17, in which the length of the flow straightener in the axial direction is at most 15mm.

19. A mixer as claimed in any of claims 1 to 18, in which the passageway forms part of a combustion device.

20. A mixer as claimed in claim 19, in which the combustion device comprises a plurality of burners supplied with a mixture of the fluids by the passageway.

21. A mixer as claimed in claim 20, in which the said burners constitute a burner sector, the downstream end portion of the passageway gradually changing cross-section into a sector of an annulus.

22. A method of mixing fluids, comprising the sequential steps of

(a) providing a stream comprising a first fluid and having an axis along which the stream flows,

(b) inducing swirl in the stream about its axis,

(c) causing the stream to converge towards its axis, and

(d) causing the stream to diverge from its axis,

the method including introducing a second fluid into the stream before step (d).

23. A method as claimed in claim 22, in which the second fluid is introduced into the stream during step (c).

24. A method as claimed in claim 22 or 23, in which the second fluid is introduced into the stream in a direction which is skew to the axis of the stream.

25. A method as claimed in any of claims 22 to 24, in which the swirl angle of the swirl induced in step (b) varies as a function of the distance from the axis.

26. A method as claimed in claims 22 or 25, in which the swirl induced in step (b) is such that there is at least one abrupt change in circumferential velocity of the stream about its axis, between one radial position and another.

27. A method as claimed in any of claims 22 to 26, including introducing a fluid into a central region of the stream after step (b) and before step (d).

28. A method as claimed in claim 27, in which the said fluid is the first fluid.

29. A method as claimed in claim 27, in which the said fluid is the second fluid.

30. A method as claimed in claim 20, including additional introducing the first fluid into the central region of the stream together with the second fluid introduced into the central region.

31. A method as claimed in any of claims 22 to 30, including straightening the flow of the stream after step (d).

32. A method as claimed in any of claims 22 to 31, in which at least one of the first and second fluids is a gas.

33. A method as claimed in claim 32, in which the first fluid is a gas and the second fluid is a liquid.

34. A method as claimed in any of claims 32 or 33, in which the first fluid is air and the second fluid is a combustible fluid.

35. A mixer substantially as described with reference to Figure 1 or Figure 5 of the accompanying drawings.

36. A method of mixing fluids, substantially as described with reference to Figure 1 or Figure 5 of the accompanying drawings.

Application No: GB 0303495.6
Claims searched: 1 & 22 at least
Examiner: Stephen Hart
Date of search: 25 June 2003

Patents Act 1977 : Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance	
X	1 & 22 at least	GB 2204121 A	(GEN ELECTRIC CO) fig 1, page 4 lines 27 - 29 and page 7 lines 19 - 28.
X	1 & 22 at least	GB 1353335	(GEN ELECTRIC CO) fig 2, page 2 lines 90 - 99 and page 2 line 110 - page 3 line 12.
X	1 & 22 at least	GB 0222188	(KOUSNETZOFF) figs 1 & 2, page 2 lines 96 - 99 & 111 - 117 and page 3 lines 17 - 28.
X	1 & 22 at least	EP 1041344 A1	(GEN ELECTRIC CO) fig 2 and col 3 lines 29 - 42.
X	1 & 22 at least	US 5941075	(SNECMA) figs 1 & 4 and col 2 lines 45 - 61.
X	1 & 22 at least	US 5558515	(ABB) figs 1 & 2 and col 4 lines 12 - 20.
X	1 & 22 at least	US 5274995	(GEN ELECTRIC CO) fig 4 and col 4 line 67 - col 5 line 14.

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^{V}:

F4T

Worldwide search of patent documents classified in the following areas of the IPC^{7}:

B01F, F23D, F23R

The following online and other databases have been used in the preparation of this search report:

Online: WPI, EPODOC, JAPIO