



INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification ⁵ :F23C 7/00, F23D 11/10
B01F 5/00, B05B 7/10

A1

(11) International Publication Number:

WO 92/16794

(43) International Publication Date:

1 October 1992 (01.10.92)

(21) International Application Number: PCT/NL92/00055

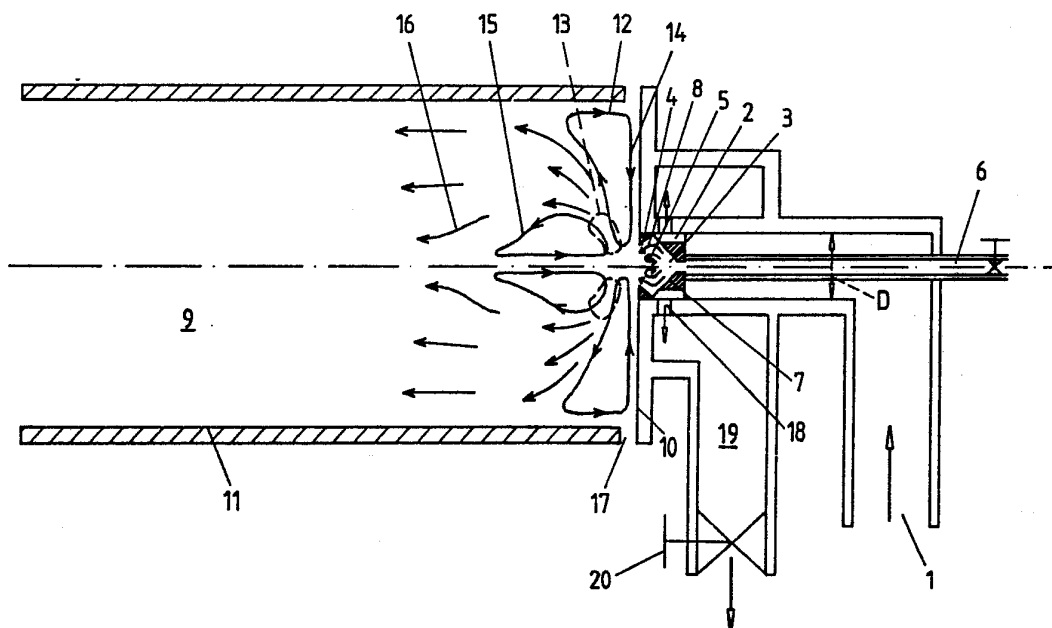
(22) International Filing Date: 19 March 1992 (19.03.92)

(30) Priority data:
9100490 20 March 1991 (20.03.91) NL(71)(72) Applicant and Inventor: WITTEVEEN, Gustaaf, Jan
[NL/NL]; Stationsstraat 41, NL-6584 AS Molenhoek
(NL).(74) Agent: DE WIT, G., F.; Octrooi- en Merkenbureau De Wit
B.V., Breitnerlaan 146, NL-2596 HG Den Haag (NL).(81) Designated States: AT, AT (European patent), AU, BB, BE
(European patent), BF (OAPI patent), BG, BJ (OAPI pa-
tent), BR, CA, CF (OAPI patent), CG (OAPI patent),
CH, CH (European patent), CI (OAPI patent), CM (OA-
PI patent), CS, DE, DE (European patent), DK, DK (Eu-
ropean patent), ES, ES (European patent), FI, FR (Euro-
pean patent), GA (OAPI patent), GB, GB (European pa-
tent), GN (OAPI patent), GR (European patent), IT (Eu-
ropean patent), JP, KP, KR, LK, LU, LU (European pa-
tent), MC (European patent), MG, ML (OAPI patent),
MN, MR (OAPI patent), MW, NL, NL (European pa-
tent), NO, PL, RO, RU, SD, SE, SE (European patent),
SN (OAPI patent), TD (OAPI patent), TG (OAPI pa-
tent), US.

Published

*With international search report.**Before the expiration of the time limit for amending the
claims and to be republished in the event of the receipt of
amendments.*

(54) Title: MIXING DEVICE AND METHOD FOR GASEOUS, LIQUID OR PULVERISED SOLID SUBSTANCES



(57) Abstract

Device for mixing gas, liquids or pulverised solid substances with a gas flow (1), whirling (vortex) around an axis in the flow direction. The whirling gas flow is guided through a converging passage (4) and, during or after being charged with the substance, abruptly widens in cylindrical space (11), as a result of which vortex break down occurs and an exceptionally thorough mixing and/or atomizing of the substance is obtained. Application in a burner improves the combustion result, keeps the NOX-values low and prevents the flame from being blown off.

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AT	Austria	FI	Finland	ML	Mali
AU	Australia	FR	France	MN	Mongolia
BB	Barbados	GA	Gabon	MR	Mauritania
BE	Belgium	GB	United Kingdom	MW	Malawi
BF	Burkina Faso	GN	Guinea	NL	Netherlands
BG	Bulgaria	GR	Greece	NO	Norway
BJ	Benin	HU	Hungary	PL	Poland
BR	Brazil	IE	Ireland	RO	Romania
CA	Canada	IT	Italy	RU	Russian Federation
CF	Central African Republic	JP	Japan	SD	Sudan
CG	Congo	KP	Democratic People's Republic of Korea	SE	Sweden
CH	Switzerland	KR	Republic of Korea	SN	Senegal
CI	Côte d'Ivoire	LI	Liechtenstein	SU	Soviet Union
CM	Cameroon	LK	Sri Lanka	TD	Chad
CS	Czechoslovakia	LU	Luxembourg	TG	Togo
DE	Germany	MC	Monaco	US	United States of America
DK	Denmark	MG	Madagascar		
ES	Spain				

Mixing device and method for gaseous, liquid or pulverised solid substances

The invention relates to mixing a gas flow with a gaseous, liquid or pulverised substance, such as fuel, where a rotation enforcing body for the gas flow has been devised in order to feed an introduced gas flow to a mainly axially symmetrical tube with an axial component in the axial direction of the tube and with a rotation component relative to the axial direction, while the tube has been tapered down (narrowed) in the direction of the axial component.

10

Such mixing methods are known in many forms.

GB - A - 2005 006 shows a burner that has a mixing method such as the one mentioned above, where the mixing of oil with the combustion air takes place under the effect of high pressure atomization of the oil. Here an extremely strong atomization and mixing of the oil and the combustion air are only obtained to the usual extent and combustion with a low NOX level and little or no excess of air is only obtainable to a limited extent.

20

US - A - 2 806 517 shows a burner with a rotating combustion air flow which is conducted through a tapering down and in which oil is atomized centrally. In the combustion cone following the tapering down, vortices occur on both sides of the atomization cone of the oil.

The invention is based on the understanding that a gas flow with a strong rotation around the flow axis compared to the axial component, can, with a sudden widening of the flow diameter, induce a sudden and very strong turbulence in the flow, in the following referred to as 'vortex break down'. This vortex break down manifests itself in a shattering or explosion of the jet while forming very strong local turbulence which leads to an extremely thorough mixing of the substances in the flow.

35

In addition a very stable vortex is created in which a very thoroughly mixed fuel-air mixture can be burnt in a short period of time so that exceptionally low NOX values occur. The same thorough mixing allows complete combustion with
5 virtually no excess of air. As the tangential component increases to the same extent as the axial component with the increase of the gas velocity, blowing off the flame is virtually impossible. Another property of vortex break down is that an axial counter flow is induced, which in the
10 invention flows back through the tapering down and, by doing so, forces the substance that is to be mixed towards the outer side and preferably even against the wall of the tapering down.

15 In order to build up a turbulence that is suitable for a vortex break down the invention provides that before the tapering down a widening is present.

It is pointed out that the tapering down can consist of a
20 material tapering down of the tube as well as of a gas, which is introduced with a radial component and which compresses the jet in radial direction, or of a radial component of the jet which causes it to be narrowed.

25 While tapering down a jet rotating around its axis, the energy fed to the jet is being converted into rotation energy by means of the Coriolis forces. As a result the ratio between the rotation component, in particular on the outside of the jet, and the translation component
30 increases. This results in a fall of pressure in the centre of the jet, which can lead to underpressure, as a result of which in principle a flow can be created that is directed against the axial direction of the flow.

35 For preference the invention provides that the tapering down reduces the diameter of the tube to 0.9 - 0.7 of the diameter prior to the narrowing. Within this range, which is only preferential, vortex break down can in practice be achieved with a in pressure difference for the thrust of

the jet from 3 to 5 cm of water (300 to 500 N/m²).

In case of a material tapering down of the flow it is preferably provided that the narrowing includes an angle
5 with the axis of the tube, which angle increases in the direction of the flow.

It is preferably provided that the narrowing includes at its end an angle with the axis of over 50 degrees. Herewith
10 it is pointed out that also in case of acuter angles with the axis at the end of the narrowing good results are to be obtained, but that with angles of 50 degrees to about 60 degrees an adequate rapid compression of the jet can be
15 combined with a short transit time and, therefore, little thrust and formation of micro-turbulence in the rotating flow itself.

In accordance with a further aspect of the invention, it can be provided that the rotation enforcing body is
20 connected only to the outside shell of the tube. This means that the inside area of the jet, which is the area within the outside shell, is also made available to the axial flow of the jet. As a result of which it is possible, while
25 increasing the rotation component of the jet, to cause the total section to become larger because the cross-sectional area of the outside shell is smaller than the total sectional area in the tapering down. This means a decrease of the axial velocity of the flow and, therefore, an
30 increase of the ratio between the rotational component and the axial component of the flow.

In accordance with the invention, it is provided that at the rear side of the tube there is a back surface with an opening for the introduction of the mixing substance.
35 Important is that in the centre of the jet an underpressure is created with a counterflow near the axis. This throws the mixing substance towards the back surface. In the process the strong rotation will contribute to the fact that, when the mixing substance is a fluid such as oil, it

will move along the surface of this back surface. By this it is achieved that the fluid can be carried along to the areas of the vortex which are located more to the outside, where the velocity of the vortex flow is high so that the liquid can be atomized.

The mixing substance, however, is subject to the strongest atomization and mixing when it is thrown off the edge of the tapering down and enters the vortex break down area. As a result it is possible to obtain a very good atomization of oil, which is introduced under a very low pressure, for instance 5 cm of water.

A further refinement of this is that the back surface is conically widened in the direction of the flow. As a result the gravity component, which has its effect on the mixing substance, is partially compensated by the inclination of the back surface, which ensures a better symmetrical discharge of the mixing substance.

As has been mentioned above, the tapering down need not be a material section reduction of a material tube. Accordingly, an embodiment of the invention provides that the narrowing is formed by a gas flow which, with a radially inward directed component, is introduced to the circumference of the tube. In order to avoid big differences in flow velocity at the confrontation of this gas flow and the whirling gas flow, it will, of course, be ensured that the gas flow which causes the narrowing has a whirling motion and possibly an axial movement as well.

It is also possible to devise the rotation enforcing body in such a manner that the flow itself, leaving the rotation enforcing body, will cause the narrowing. Accordingly, in this case it is provided that the rotation enforcing body is devised to introduce a gas flow with besides the tangential component an inwards directed radial component around the tube and through the cylinder surface of the tube. As has been mentioned above, the vortex break down

will occur when the flow section is widened. It is to be recommended that this widening will be abrupt and that the flow section for small burners (up to circa 50 kW) will preferably be enlarged at least five times in relation to that of the tapering down, and for large ones circa 2.5 to 3.5 times.

The above has been found favourable for the operation of a burner which is supplied with the abovedescribed device.

10 Due to the vortex break down, such a burner has an exceptionally thorough mixing of fuel with combustion air in a very short range. In addition, it has been found that in the area direct behind the widening a vortex occurs, which has not only a rotation component around the axis of
15 the flow but also a rotation perpendicular to it, which means that gas is fed back to the back wall of the widening and from there back again to the base of the flame. This means that the base of the flame also receives an already completely or partially burned and cooled off gas mixture,
20 as a result of which the combustion temperature remains lower and, consequently, the formation of nitrogen oxides is countered.

When a burner is operated in such a way that vortex break
25 down occurs, it is possible to ensure that the diameter of the burner cone has such a taper that, past a underpressured space caused by the explosion of the jet, a stable gas body comes into being, which prevents gas flowing back from the end area of the burner cone to the
30 underpressured space. Should the vortex already play an important part in the prevention of the blowing off of the flame direct behind the widening, this above indicated taper of the burner cone, which causes sufficient outflowing gas to be bent inwards, ensures even more the
35 prevention of the blowing off of the flame. It is pointed out that, due to the application of the invention, a large part of the flow energy has the form of turbulence and, as a result, blowing off is actually already countered. In practice, a stable burner of relatively small dimensions

can be obtained wherein blowing off the flame is impossible.

Moreover, the formation of nitrogen oxides can be countered
5 by providing that the back wall of the burner cone is cooled.

Furthermore, the created vortex at the widening near the burner can be employed by installing the burner cone near
10 its back surface an inlet slot for air, residual gas and waste gas that is to be destroyed by combustion. This slot pulls one of the gases towards the centre, where cool air ensures a reduction in temperature of the flame base.

15 In order to provide a burner wherein the invention is applied and that is controllable, it will be clear that the air velocity, also in a lower setting and resulting, therefore, in a limited air supply, has to meet minimum requirements. Accordingly, amplification of the invention
20 provides that a controllable air tap of the air that passed through the rotation enforcing body is present.

As will be further discussed below, an analytical examination of the flow before and past the tapering down,
25 indicates that no solutions exist for a continuous flow in case of a adequate high vortex intensity and a widening of the flow section. The result of this examination is that, when the equation:

$$\frac{U_1}{U_0} - 1 + \left(\frac{k^2 r_0^2}{k^2 r_1^2} - 1 \right) \cdot \frac{\frac{k}{2} r_1}{J_1(k r_1)} \cdot J_0(k r_1)$$

wherein U_0 = axial velocity in the tapering down;
30 U_1 = axial velocity in the burner cone;
 $k = 2 \Omega / U_0$ with Ω = the angular velocity and
 J_0 and J_1 are Bessel functions of the zeroth and first order, has no real solution, vortex break down is to be expected.

The formulas, however, are developed based on a flow free of turbulence and of dissipation, which, of course, is not entirely consistent with reality so that these formulas give only an indication whether vortex break down will occur.

In the following, the invention is further explained by means of the drawing wherein:

- 10 fig.1 shows schematically a burner provided with the invention and the flows occurring within;
fig.2 indicates schematically the occurrence of the vortex;
fig.3 illustrates the flow picture to prevent a counterflow;
- 15 fig.4 shows schematically a cross-section of a vortex device in accordance with the invention;
fig.5 shows a schematic cross-section of another embodiment, and
fig.6 shows a graph to illustrate the analytical method for
20 determining vortex break down.

In fig.1 an air supply for a burner is indicated by 1 where the air has undergone pressure-increase up to 5 cm of water column or 500 N/m^2 . This air is introduced through
25 axially and tangentially directed slots 2 to a vortex chamber 3. This vortex chamber has on its exit side a tapering down 4, which causes the air vortex to be even stronger before flowing out. The strong vortex leads to underpressure in the axial area and, therefore, to a
30 counterflow, as is schematically indicated with the flow lines 5.

By means of a central oil feeding line 6, oil is introduced to the conical back surface 7 of the vortex
35 chamber 3. By means of the counterflow and vorticity of the air in the vortex chamber 3, oil is forced out along the cone 7 to reach, via the wall parts between the passages 2, the surface, which tapers towards the opening 4, where the vortex air flow 8 ensures that the oil in a thin film moves

along this surface at a relatively high speed. In the tapering down 4 delamination of the oil film takes place, which atomizes directly. Due to the vortex break down, which occurs right after the tapering down 4 in the burner cone 9, an extremely fine atomization takes place. This burner cone has a back surface 10 and a cone wall 11, drawn as a cylinder.

The flow that leaves the vortex chamber 3, explodes while forming a very strong turbulence, as a result of which axially an underpressure is created and a counterflow vortex 12 that flows along the back wall 20 and attaches itself in a stable way to the back wall, partly due to the underpressure created by the local flow velocity.

When the flame is ignited, a very concentrated combustion takes place in the area 13, indicated by a dotted line, the counterflow 14 from the vortex 12, however, provides cooling of the flame. In the central part in front of the discharge area of the flow from the vortex chamber 3, an underpressure occurs and as a result a vortex can occur, as is indicated by 15. This vortex, too, is stable and impossible to be blown off. Because the main flow, as is indicated at 16, moves again to the axis of the burner cone, it is impossible for gas coming from the exhaust area of the burner or even the middle area, to flow back to the area of the flame.

The slot 17 between the burner cone 11 and the back surface 10 may provide a secondary-air supply, if so desired. Moreover, the back surface 10 may be cooled, for instance by water in case the burner is used for the heating of water in, for example, a central heating boiler. In stead of secondary air, residual gas or a gaseous product that is to be burnt may be introduced, in which case the very thorough mixing by the vortex break down ensures a most efficient combustion.

As the rotation velocity is only allowed to decrease a

little or not at all, in order to obtain vortex break down by means of controlling the burner, a control may be obtained by bringing the combustion air at full speed and subsequently feeding-back part of this air, as is

5 schematically indicated by the slots 18 that give access to a space 19 that has an air exhaust through a control cock 20.

In accordance with this drawing, the burner has not only a

10 high stability in order to prevent blowing off and an exceptionally thorough mixing of combustion air and fuel and, therefore, a short flame, it also ensures that a mixture containing oxygen and nitrogen is at a high temperature for a short while only. This is an additional

15 reason why this burner emits few nitrogen oxides.

The drawn vortex chamber 3 receives its rotating gas through the slots 2. The axial velocity of the air flowing out, is now inversely proportional to the sectional area of

20 the annular slot zone 2 and the circular exhaust in the tapering down. It is very well possible that the latter may be larger than the section of the annular slot, in which case the axial velocity is lower when flowing out of the vortex chamber than when entering it, which increases even

25 further the ratio between the rotation velocity and the axial velocity.

Fig.2 schematically shows the situation in which a rotation enforcing body 21 causes a vortex with everywhere

30 the same angular velocity around the axis (solid body vortex). This vortex is carried via the tapering down 22 to a more spacious flow tube 23, in the process of which vortex break down occurs again and also the annular vortex 24. This device, too, causes an exceptionally intensive

35 intermixing of the gas flow, for instance, when it contains a mixing gas, a mixing fluid or pulverized particles. In addition, it is pointed out that the invention is most suitable for the combustion of pulverized fuel such as coal particles, but also of aluminium that can be burnt to

aluminium oxide, which can possibly be of importance in obtaining solar energy when, by means of solar energy, aluminium oxide can be reduced and the aluminium can later be burnt again as a source of energy.

5

Fig. 3 amplifies how a vortex body is created in front of the exit opening of the vortex chamber, which entirely or almost entirely prevents the counterflow of air. In the drawing in fig.3 at point 25, an underpressure is created
10 by the vortex break down, as a result of which the flow, indicated by the arrow 26, threatens to develop. The cone wall 27, however, forces the outflowing gases, the volume of which has considerably increased by the combustion, back to the axis of the tube, as is indicated by the arrows 29.
15 This ensures that the flow 26 remains slight or is even interrupted, while the flow body 30, due to the underpressure at 25 and the underpressure created by the rapid movement of the gases in its immediate vicinity, remains stabilized and is not blown off.

20

Fig 4. shows a schematic cross-section that represents an advantageous form of the tapering down. It has been found that when the tapering down is too steep it causes a certain thrust and that when it is too flat it takes up too
25 great an axial length and consequently causes too much friction. In the example of fig.4 the angle made by the tapering down with the axis at the end of the tapering down is a little smaller than 60 degrees.

30 In fig. 5 a further example of embodiment is schematically represented. Here, the air-supply slot 2 is shown again, by which axially whirling air enters the space 31, as is indicated by the arrow 32. This arrow bends inwards, because from a ring or annular slot 33 radially inflowing
35 and tangentially whirling gas is introduced, which preferably has an axial velocity as well. This, however, is not shown in fig.5. This air forces the whirling air coming out of the annular slot 2 inwards, as a result of which the latter is narrowed and thus causes an expansion of the

vortex.

In the case of an annular slot with a width of 1/8 to 1/4 of the outside diameter D and that has a narrowing with a diameter of 1/2 D (see fig.1,2 and 4), at an axial velocity in the slot equal to the rotation velocity in situ, a steadily burning burner was obtained with an outside diameter of the slot of 17.5 mm, an inside diameter of the narrowing of 12 mm and a diameter of the burner cone of 90 mm. Such a burner can stand a pressure of introduced combustion air of 1000 N/m² without running the risk of blowing off.

The invention not only provides a compact and most steady burner, it may also serve to manufacture a spray nozzle with a wide adjusting range. Compared to conventional pressure spray nozzles, such a burner-spray-nozzle has two advantages:

- 1) At a low oil through-flow, the atomization is better than at a high oil through-flow. As, however, at a high through-flow the flame is longer and therefore takes up more room in which mixing can occur, a constant combustion quality is obtained at a higher and lower oil through-flow.
- 2) A good air cooling, which prevents the burner from getting dirty and blocked at high temperatures.

For this reason the invention is suitable as a spray nozzle for any type of burner that is to mix fuel with combustion air, for any application with a wide adjusting range.

To elucidate the phenomenon of vortex break down, the following remarks should be noted.

In a rotation-symmetrical two-dimensional continuous flow it is possible to deduce from the equation of continuity

$$\vec{v} \cdot \vec{u} = 0$$

the existence of a flow function ϕ :

$$u_z = \frac{1}{r} \cdot \frac{\delta \phi}{\delta r}$$

and

$$u_r = -\frac{1}{r} \cdot \frac{\delta \phi}{\delta z}$$

If no external forces are present, and the influence of the
5 viscosity is neglected, Navier-Stokes becomes:

$$\frac{D\vec{u}}{Dt} = \vec{u} \cdot \nabla \vec{u} = -\frac{1}{\rho} \nabla p$$

with

$$\vec{\omega} = \nabla \times \vec{u}$$

for the vorticity, this results in:

$$\vec{u} \times \vec{\omega} = \nabla \cdot \left(\frac{p}{\rho} + \frac{1}{2} |\vec{u}|^2 \right) \quad (1)$$

10 The ϕ -component of (1) gives now $U\phi \cdot r = \text{constant} = f(\phi)$
if we assume the area around the axis to be an area with
'solid body' rotation, hence

$$U\phi = \Omega \cdot r$$

and

$$\Omega \cdot r^2 = f(\phi)$$

15 The components of $\vec{\omega}$ now become:

$$\omega_z = u_z \cdot \frac{df}{d\phi}, \quad \omega_r = u_r \cdot \frac{df}{d\phi}$$

and

$$\omega_\phi = \frac{f}{r} \cdot \frac{df}{d\phi} - r \cdot \frac{d}{d\phi} \left(\frac{p}{\rho} + \frac{1}{2} |\vec{u}|^2 \right)$$

Solving ω , from (1) and (2) gives

$$\frac{\delta^2 \phi}{\delta z^2} + \frac{\delta^2 \phi}{\delta r^2} - \frac{1}{r} \cdot \frac{\delta \phi}{\delta r} = r^2 \cdot \frac{d}{d\phi} \left(\frac{p}{\rho} + \frac{1}{2} |\vec{u}|^2 \right) - f \frac{df}{d\phi}$$

so the flow function ϕ is given by

$$\frac{\delta^2 \phi}{\delta z^2} + \frac{\delta^2 \phi}{\delta r^2} - \frac{1}{r} \cdot \frac{\delta \phi}{\delta r} = r^2 \cdot \frac{d}{d\phi} \left(\frac{p}{\rho} + \frac{1}{2} |\vec{u}|^2 \right) - f \frac{df}{d\phi}$$

with $f = \Omega r^2$.

- 5 Now we want to examine what happens if a flow in a cylinder passes to another cylinder with a larger diameter.

Upstream, in the smallest cylinder, we assume in the vicinity of the axis a velocity U_0 in the z-direction, so

$$u_z = \frac{1}{r} \cdot \frac{\delta \phi}{\delta r} = U_0 \quad \rightarrow \quad \phi = \frac{1}{2} U_0 \cdot r^2$$

- 10 hence

$$f = \Omega \cdot r^2 = \frac{2\Omega}{U_0} \cdot \phi$$

and

$$-f \frac{df}{d\phi} = - \left(\frac{2\Omega}{U_0} \right)^2 \cdot \phi.$$

The Bernoulli surfaces in this flow are cylinders, hence the pressure, except for a constant term, is given by

$$p(r) = \frac{1}{2} \rho (U_0^2 + u_\phi^2) \sim \frac{1}{2} \rho u_\phi^2.$$

- 15 Then

$$\frac{p}{\rho} + \frac{1}{2} |\vec{u}|^2$$

except for a constant, is represented by

$$\frac{1}{2} U_0^2 + u_\phi^2 = \frac{1}{2} U_0^2 + \Omega^2 \cdot r^2 = \frac{1}{2} U_0^2 + \frac{2\Omega^2}{U_0} \cdot \phi$$

The expression above gives for

$$r^2 \cdot \frac{d}{d\phi} \left(\frac{p}{\rho} + \frac{1}{2} |\vec{u}|^2 \right) :$$

$$r^2 \frac{d}{d\phi} \left(\frac{p}{\rho} + \frac{1}{2} |\vec{u}|^2 \right) = \frac{2\Omega^2}{U_0} \cdot r^2 .$$

The flow function

$$\phi(r, z) = \psi(r) \cdot r + \frac{1}{2} U_0 r^2$$

5 of a rotating flow in a cylinder is therefore determined by

$$\frac{d^2\psi}{dr^2} + \frac{1}{r} \cdot \frac{d\psi}{dr} + \left(k^2 - \frac{1}{r^2} \right) \psi = 0 , \quad k = \frac{2\Omega}{U_0}$$

a Bessel equation of the order 1.

So for the solution, regular on the axis, we find

$$\begin{aligned} \psi &= A \cdot J_1(kr) \\ \phi &= \frac{1}{2} U_0 r^2 + A \cdot r \cdot J_1(kr) \\ u_z &= \frac{1}{r} \cdot \frac{\delta\phi}{\delta r} = U_0 + A \cdot k \cdot J_0(kr) \\ u_\phi &= \frac{f}{r} = \frac{2\Omega}{U_0} \cdot \frac{\phi}{r} = k \cdot \frac{\phi}{r} \\ u_\phi &= \Omega r + k \cdot A \cdot J_1(kr) . \end{aligned}$$

Upstream, in the smallest cylinder, we assume an axial
10 velocity U_0 in an area with vorticity with a diameter $2r_0$.

Downstream, in the biggest cylinder, we refer to the axial
velocity as U_1 within the area with vorticity with diameter
2 r_1 .

15

For the upstream and downstream flow functions therefore
applies:

$$\frac{1}{2} U_0 r_0^2 = \frac{1}{2} U_0 r_1^2 + A \cdot r_1 \cdot J_1(kr_1)$$

$$A = \frac{U_0(r_0^2 - r_1^2)}{2r_1 \cdot J_1(kr_1)}$$

and

$$\frac{u_z}{U_0} - 1 + \left(\frac{r_0^2}{r_1^2} - 1 \right) \cdot \frac{\frac{1}{2}kr_1}{J_1(kr_1)} \cdot J_0(kr_1) .$$

If we refer to the axial velocity on the edge of the vortex
 5 upstream as U_1 , we find a relation between U_1 , U_0 , kr_0 and
 kr_1 :

$$\frac{U_1}{U_0} - 1 + \left(\frac{k^2r_0^2}{k^2r_1^2} - 1 \right) \cdot \frac{\frac{1}{2}kr_1}{J_1(kr_1)} \cdot J_0(kr_1) .$$

If kr_0 is big enough and/or U_1/U_0 small enough the above
 expression will have no solution. In that case 'vortex
 10 break down' will occur.

In fig 6 the value of kr_1/kr_0 is plotted as a function of kr_0
 This shows that initially two solutions are available at a
 certain value of kr_0 , subsequently just one in a maximum and
 15 finally none at all. In this last domain vortex break down
 will occur, but it should be taken into account that the
 flow has always contained smaller vortices which have not
 been included in the calculation so that the indicated
 relation can only be regarded as an approximation and
 20 cannot be construed as a limitation to the invention.

It is easy to observe vortex break down in a burner,
 because in that case the combustion takes place in a fairly
 small torus shaped zone. This zone is calm and hardly
 25 moves. When oil constitutes the fuel, this zone will have
 a blue colour if the oil had already been completely
 gasified. As the temperature rises, this zone will become a
 deeper blue. In case of a less complete gasification,

yellow radiant coal particles may be present in this zone, but experience shows that with a sufficient supply of oxygen, all unburnt soot particles or hydrocarbons in the residual gas are completely burnt.

5

An important application of the invention is a spray nozzle or atomizer, where the obtained very fine mist, the very thoroughly mixed gas mixture or the very homogeneous suspension of solid particles will not directly be burnt or
10 even not be burnt at all.

It will be clear that the invention is not limited to the pictured and amplified embodiments. For example, it is possible that the mixing substance is brought into rotation
15 prior to coming into contact with the air jet. This is particularly important in the case of mixing with low-calorific gas.

The rotation enforcing body can have any shape, provided
20 that it superimposes a rotation onto the gas flow. In addition, it may also contain moving or rotating parts such as a blade wheel.

Claims:

1. Device for mixing a gas flow with a gaseous, liquid or pulverised mixing substance, such as fuel, where a rotation enforcing body for the gas flow has been devised in order to feed an introduced gas flow to a mainly axially
5 symmetrical tube with an axial component in the axial direction of the tube and with a rotation component relative to the axial direction, while the tube has been tapered down in the direction of the axial component, **characterized in that** before the tapering down a widening
10 is present.
2. Device as recited in claim 1, **characterized in that** the tapering down reduces the diameter of the tube to 0.9 - 0.7 of the diameter before tapering down.
15
3. Device as recited in claim 1-2, **characterized in that** at the backside of the tube a back surface, which has an opening for the introduction of the mixing substance into
20 the widening is present.
4. Device as recited in claim 3, **characterized in that** the widening is in the shape of a cone while the opening corresponds with the apex of the cone.
25
5. Device as recited in any of the preceding claims, **characterized in that** a narrowing is formed by a gas flow, which is introduced to the circumference of the tube with a radially inwards directed component.
30
6. Device for mixing a gas flow with a gaseous, liquid or pulverised mixing substance, such as fuel, where a rotation enforcing body for the gas flow has been devised in order to introduce a mainly cylindrical flow into a mainly
35 cylindrical tube with an axial component in the axial direction of the tube and a rotation component relative to the axial direction, **characterized in that** the rotation

enforcing body has been devised to introduce a gas flow with, besides the tangential component, an inwards directed radial component around the tube and through the cylinder surface of the tube.

5

7. Device as recited in any of the preceding claims, in which the flow section past the tapering down abruptly increases, **characterized in that** the abrupt widening has an increase of the diameter of at least a coefficient of 2.5.

10

8. Device as recited in claim 7, **characterized in that** the coefficient of the increase of the diameter is at least 5.

9. Method for operating of a burner with a burner cone, which burner is provided with a device as recited in claims 7-8, for the introduction of combustion air, **characterized in that** the ratio between the axial and tangential component of the flow and the ratio between the smallest diameter of the tapering down portion and that following the widening have been chosen in such way that the jet explodes (vortex break down) and a vortex occurs in the corner between the back wall of the widening and the beginning of the burner cone.

10. Method as recited in claim 9, **characterized in that** the diameter of the burner cone has such a tapering that past an area of underpressure caused by the explosion of the jet, a stable gas body occurs, which prevents gas from flowing back from the end area of the burner cone to the underpressured area.

35

11. Method as recited in claim 10, **characterized in that** in the upstream area of the tapering down an axial counterflow is created.

12. Method as recited in claim 11 under application of a device as recited in claim 7, **characterized in that** the axial counterflow forces the liquid, coming out of the opening, against the widening.

13. Burner provided with a device as recited in any of the claims 1-8 and suitable for application of the method as recited in the claims 9-12, **characterized in that** the wall of the abrupt widening has been cooled.

5

14. Burner provided with a device as recited in any of the claims 1-8 and suitable to apply the method as recited in claims 9-12, **characterized in that** in a burner cone following the abrupt cross-sectional widening an air slot is present near the wall of the cross-sectional widening.

10

15. Burner provided with a device as recited in any of the claims 1-8 and suitable to apply the method as recited in claims 9-12, **characterized in that** a controllable air tap is present, for air that has entirely or partially passed through the rotation enforcing body.

15

16. Burner as recited in any of the claims 13-15, **characterized in that** the equation:

$$\frac{U_1}{U_0} = 1 + \left(\frac{k^2 r_0^2}{k^2 r_1^2} - 1 \right) \cdot \frac{\frac{1}{2} k r_1}{J_1(k r_1)} \cdot J_0(k r_1) .$$

20 wherein U_0 = axial velocity in the tapering down;

U_1 = axial velocity in the burner cone;

$k = 2\Omega / U_0$ with Ω = the angular velocity and

J_0 and J_1 are Bessel functions of the zeroth and first order, has no real solution.

25

17. Burner as recited in any of the claims 13-16, **characterized in that** there are means to transfer a pulverised or liquid substance onto the surface of the tapering down.

30

18. Burner having a device for mixing substances, such as fuel, with a rotation enforcing body for the gas flow has been devised in order to feed an introduced gas flow to a mainly axially symmetrical tube with an axial component in the axial direction of the tube, with a rotation component

35

relative to the axial direction, while the tube has been tapered down in the direction of the axial component, and with combustion air pressurizing means, **characterized in that** the dimensions of the rotation enforcing body and the
5 tapering down are such that beyond the tapering down vortex break down occurs.

19. Spray nozzle, **characterized in that**, in a device according to claims 1-8 means are provided to bring a
10 pulverized or liquid substance to the edge of the tapering down.

20. Device as recited in claims 1-8, **characterized in that** means are provided to admix a pulverized substance into the air inlet flow.

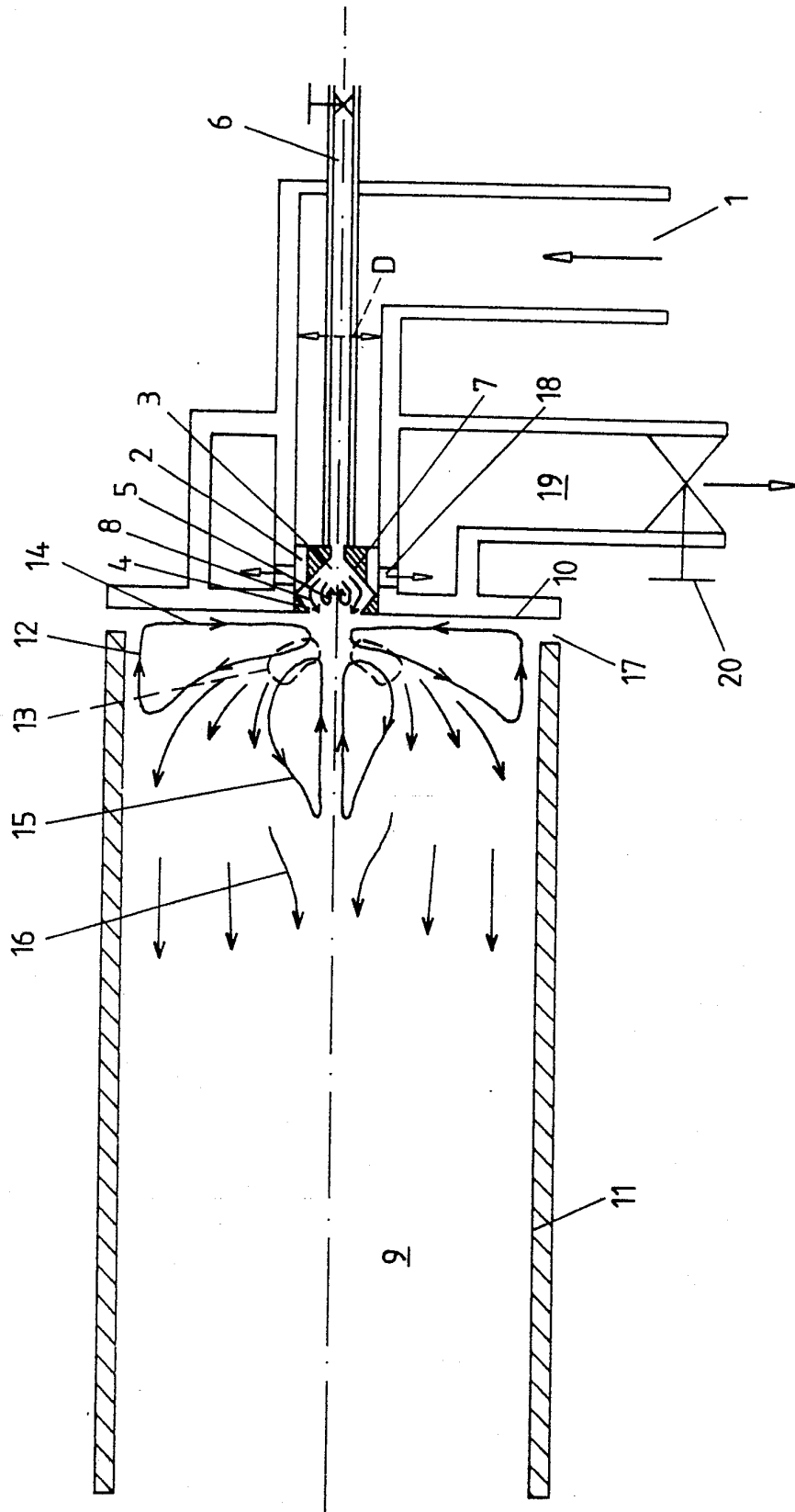


FIG. 1

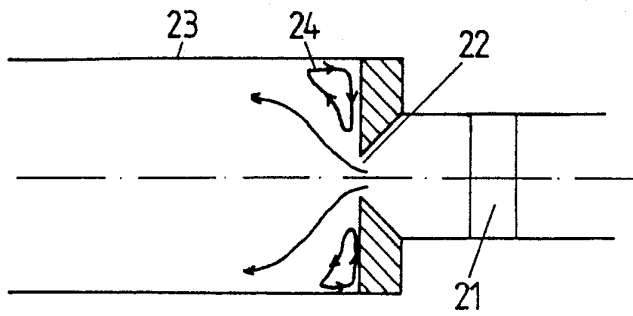


FIG. 2

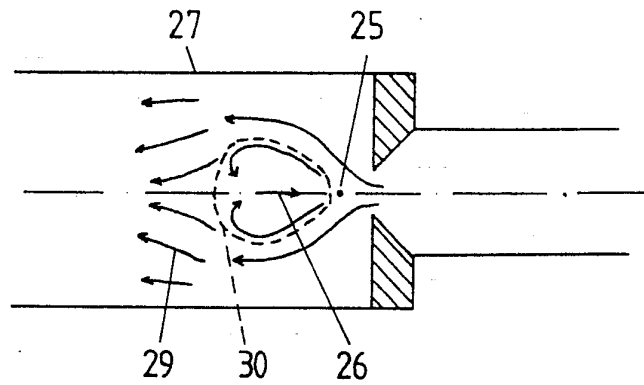


FIG. 3

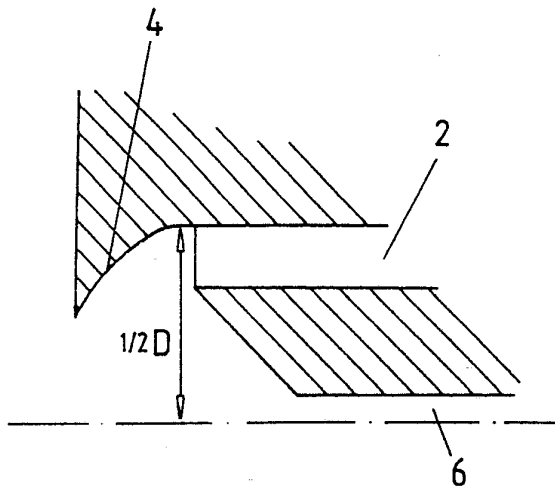


FIG. 4

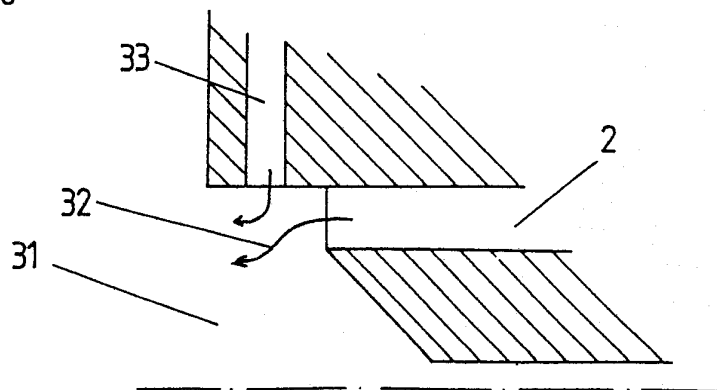


FIG. 5

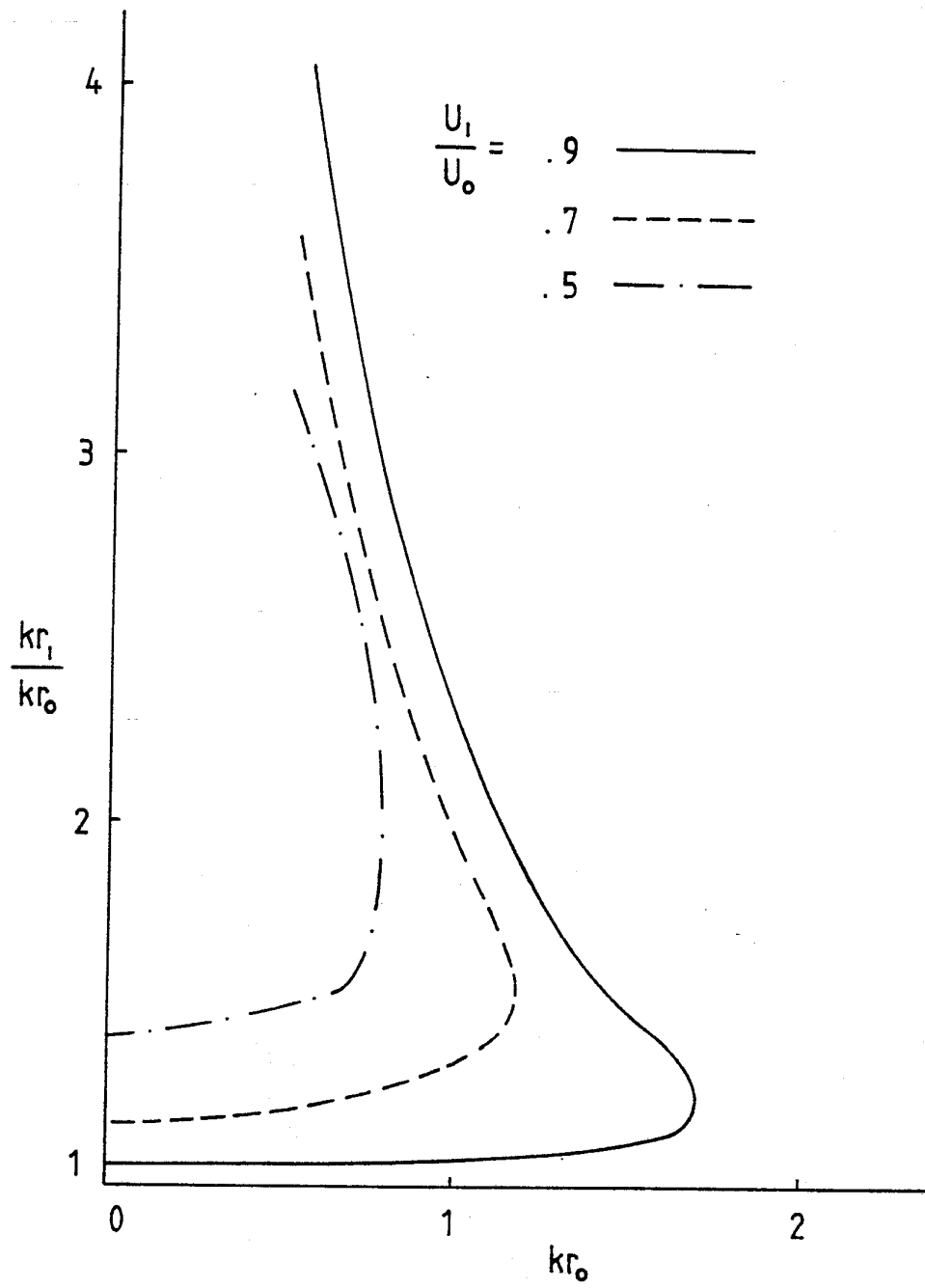
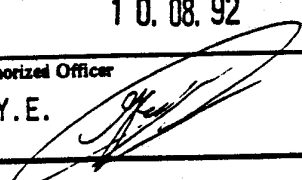


FIG. 6

INTERNATIONAL SEARCH REPORT

PCT/NL 92/00055

International Application No

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) ⁶		
According to International Patent Classification (IPC) or to both National Classification and IPC		
Int.Cl. 5 F23C7/00;	F23D11/10;	B01F5/00; B05B7/10
II. FIELDS SEARCHED		
Minimum Documentation Searched ⁷		
Classification System	Classification Symbols	
Int.Cl. 5	F23C ; F23D ; B01F ; B05B	
Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched ⁸		
III. DOCUMENTS CONSIDERED TO BE RELEVANT⁹		
Category ¹⁰	Citation of Document, ¹¹ with indication, where appropriate, of the relevant passages ¹²	Relevant to Claim No. ¹³
X Y A Y	<p>US,A,3 304 012 (SEM) 14 February 1967 see the whole document</p> <p style="text-align: center;">---</p> <p>US,A,2 806 517 (TE NUYL) 17 September 1957 cited in the application see column 4, lines 1 - 31 see column 5, lines 19 - 55 see column 6, lines 34 - 52 see column 7, lines 32 - 73 see column 8, lines 25 - 46 see figures 1,4</p> <p style="text-align: center;">---</p> <p style="text-align: center;">-/--</p>	<p>1</p> <p>7,8,9 3,4,19</p> <p>7,8,9</p>
<p>¹⁰ Special categories of cited documents :</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> <p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.</p> <p>"&" document member of the same patent family</p>		
IV. CERTIFICATION		
Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report	
14 JULY 1992	1 0. 08. 92	
International Searching Authority	Signature of Authorized Officer	
EUROPEAN PATENT OFFICE	PHOA Y. E. 	

2

III. DOCUMENTS CONSIDERED TO BE RELEVANT

(CONTINUED FROM THE SECOND SHEET)

Category ^o	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No.
-----------------------	--	-----------------------

X

DE,A,3 206 074 (KOERTING HANNOVER AG) 18 August 1983

see page 9, lines 4 - 19
 see page 15, lines 1 - 30
 see page 19, lines 13 - 26
 see page 20, lines 16 - 28
 see figures 1,9,10.13

1

Y

A

Y

 EP,A,0 028 025 (DALA INVEST AB) 6 May 1981
 see page 5, line 25 - page 6, line 12
 see page 9, lines 15 - 31
 see page 11, lines 1 - 5
 see figures 1,5,6,7

7

3,4,11

7

A

A

 EP,A,0 114 062 (STUBINEN UTVECKLING AB) 25 July 1984
 see page 9, line 5 - page 10, line 6
 see figure 3

14

6

**ANNEX TO THE INTERNATIONAL SEARCH REPORT
ON INTERNATIONAL PATENT APPLICATION NO. NL 9200055
SA 58060**

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report. The members are as contained in the European Patent Office EDP file on The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information. 14/07/92

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A-3304012		None	
US-A-2806517		None	
DE-A-3206074	18-08-83	AU-B- 564097	30-07-87
		CA-A- 1223775	07-07-87
		WO-A- 8302993	01-09-83
		EP-A, B 0101462	29-02-84
		JP-B- 2052765	14-11-90
		JP-T- 59500482	22-03-84
EP-A-0028025	06-05-81	AT-T- 3906	15-07-83
		CA-A- 1159356	27-12-83
		WO-A- 8101186	30-04-81
		SE-A- 7908863	26-04-81
		US-A- 4473185	25-09-84
		SE-A- 7908864	26-04-81
		DE-A- 3040215	14-05-81
		SE-A- 7908865	26-04-81
EP-A-0114062	25-07-84	DE-A, C 3309905	19-07-84
		DE-A- 3309906	18-10-84
		AU-B- 557542	24-12-86
		AU-A- 2356084	19-07-84
		CA-A- 1224089	14-07-87
		JP-A- 60089606	20-05-85
		US-A- 4569295	11-02-86
		US-A- 4718359	12-01-88