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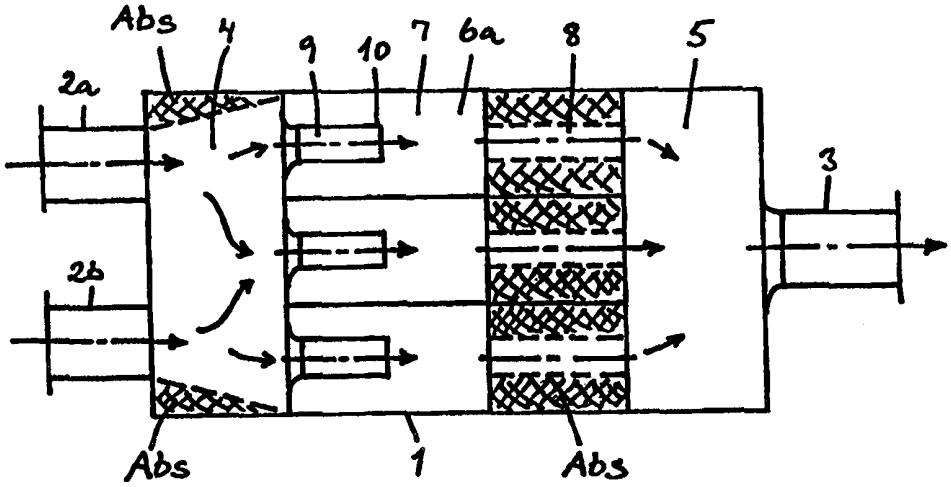
(54) Title: A SILENCER



(57) Abstract

A silencing apparatus which is throughflowed by a gas and which is arranged within a pipe or duct system, the gas flow at one or more stages within the apparatus being divided into three or more preferably substantially parallel subflows, each or substantially each subflow throughflowing a silencing element (6a...) causing reflective silencing provided by changes in cross section area, said silencing elements being arranged beside each other within an outer envelope, at least 80 % of the volume inside said envelope being constituted by air, gas and/or solid materials, and at least a major part of said volume having silencing functions, said subflows merging downstream of said silencing elements, either within said apparatus or further downstream in said pipe or duct system.

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A SILENCER

Most silencers designed according to conventional principles need to be rather long to become effective. A typical example is provided by an exhaust silencer for a stationary gas turbine plant. If the silencer could be made short this would in many cases reduce building costs. However, with conventional silencing techniques, this is difficult, in particular when a broad-banded silencing, covering all audible frequencies, is required, and when the pressure drop is required to be low.

Additional geometric conditions and restrictions sometimes apply for silencers to be installed immediately upstream of heat recovery boilers, catalysers, filters, or other apparatuses in a piping system. Such apparatuses add to the horizontal space requirement of the system. At the same time, they are usually designed with rather large transverse dimensions. In such cases, short and wide silencers are called for. In addition, many boilers and other air- or gas-treatment equipment, etc., require an even flow distribution across their inlet in order to function effectively.

The invention relates to a type of silencer which is particularly fit for such applications.

According to the invention, the total gas flow to be silenced is split into three or more parallel flows which are then each silenced in individual silencer elements which may be relatively small, separate silencer elements. Such elements are preferably designed as reflective silencers, often as reflective and absorptive silencers.

Thus, in one broad aspect, the invention relates to a silencing apparatus which is throughflowed by a gas and which is arranged within a pipe or duct system, the gas flow at one or more stages within the apparatus being divided into three or more subflows which are preferably substantially parallel to each other, each subflow (or substantially each subflow) throughflowing a silencing element causing at least reflective silencing provided by changes in cross-section area, the silencing elements being arranged beside each other within an outer envelope, at least 80% of the volume inside said envelope being constituted by air, gas and/or solid materials, and at least a major part of said volume having silencing functions, said subflows merging

downstream of said silencing elements, either within said apparatus or further downstream in said pipe or duct.

Preferably, each subflow throughflows its own silencing element.

In preferred embodiments, at least 85%, more preferred at least 90%, and even more preferred at least 95% and up to substantially all of the volume inside the envelope is constituted by air gas and/or solid materials, and at least 60%, preferably at least 70%, and more preferably at least 80%, such as up to 90% or even 95% or higher, of the volume has silencing functions, such as will be explained in the following and understood from the drawings. It should be understood that "the volume inside the envelope" is intended to designate the volume defined radially by the exterior envelope and axially by the volume through which the silencers or the majority of the silencers extend.

In practice, at least one of the cross-section area changes (10) preferably takes place inside the silencing elements, the change in cross-section area preferably being at least by a factor two.

All or substantially all of the subflows preferably derive from an upstream plenum chamber or from an upstream diffuser . At any rate, it is preferred that all or substantially all of the subflows merge into a downstream plenum chamber immediately or substantially immediately downstream of the silencing elements.

In a particularly interesting embodiment, the outflows from the silencing elements are utilized to contribute to a substantially even inflow across the inlet section of a downstream device which takes advantage of such a substantially even inflow, e.g., a heat recovery boiler/heat exchanger, a catalyst, or a filter or other equipment, either by direct inflow or via a plenum chamber.

A number of additional advantageous embodiments will be understood from the description which follows in conjunction with the claims of which claims 7-17, like claims 2-6, relate to preferred embodiments of the apparatus defined in claim 1.

The overall concept according to the invention has a number of acoustical advantages: Even in the case of a very wide apparatus it becomes possible to eliminate low-frequent, transverse resonances. By using diffuser technology within the silencer elements, enhanced low-frequent and low-pressure-drop silencing becomes possible. Even if such diffusers are to be rather short, they can be designed for a high efficiency.

By combining silencer elements with the silencing effect of a plenum chamber up- and/or downstream of the elements, the attenuation characteristic of the apparatus can be tailored to what is optimal in the particular application. For instance, with reciprocating engines, maximum attenuation is usually required at lower frequencies. With gas turbines, a more even attenuation across the frequency range is normally called for. Conventional gas turbine silencers are usually of the ´splitter type´, relying mainly on absorptive silencing; it has been found that in many cases such silencers do not provide sufficient low-frequent attenuation. The invention compensates for this deficiency by providing a substantial reflective silencing effect, with moderate or no increase in pressure drop.

A whole series of silencer apparatuses of different sizes can be derived from, e.g., modulized silencing elements manufactured in a limited number of standardised sizes. The assembly of silencing elements can be designed in such a way that the various elements support each other mechanically. Thus, moderate plate thickness and moderately advanced materials can be selected. All these factors will tend to reduce manufacturing costs.

Sometimes silencers are placed upstream of heat recovery boilers, catalysers, filters, or other equipment with an inlet cross section which is much bigger than the general cross section of the exhaust system. In such cases, the invention provides additional advantages:

* The subdivision of the gas flow can be designed to contribute to an even inlet flow distribution to the downstream apparatus.

* The distance between the silencer and the downstream apparatus can be made short.

* The silencer element assembly will act as a flow straightener, which protects the downstream apparatus from fluid-dynamic forces which could otherwise compromise its mechanical integrity.

The invention will now be described in more detail by reference to figures 1 to 7 which show various embodiments.

Fig. 1 is a longitudinal section of a first embodiment according to the invention
Fig. 2 is a longitudinal section of a second embodiment.
Fig. 3 is a cross-section of the second embodiment.
Fig. 4 is a further cross-section of the second embodiment.
Fig. 5 is a longitudinal section of a third embodiment.
Fig. 6 is a cross-section of the third embodiment.
Fig. 7 is a longitudinal section of part of a fourth embodiment.

Fig. 1 illustrates the principle of dividing a gas flow into three or more parallel flows in silencer elements.

The silencing apparatus is contained within a casing 1. In this example, two inlet pipes or ducts, 2a and 2b, lead exhaust gas into the apparatus. For instance, 2a and 2b could be connected to the two exhaust manifolds of a V-type diesel engine. An upstream plenum chamber 4 collects the two incoming gas flows and distributes the merged gas flows to a number of silencer elements 6a ... . At the same time, chamber 4 contributes to overall silencing, by sound reflection at inlet and outlet changes in cross-sectional area, and by function of inserted sound absorptive material, Abs. Silencer elements 6a... are divided into two main parts, 7 and 8, being mainly reflective and absorptive in their respective acoustic function. An internal pipe, 9, leads gas flow into the first part at position 10, where a major change in cross-sectional area causes sound reflection. The divided gas flows merge in plenum chamber 5, from which they leave the apparatus via exhaust pipe or duct 3.

Figs. 2, 3, and 4 show a second embodiment of the invention.

Here, the gas flow is distributed to in total nine silencer elements 6a ... i. In each of these, a diffuser 14 is fitted onto pipe 9, to recover dynamic pressure, thereby lowering the pressure drop across the apparatus.

A heat recovery boiler/heat exchanger, a catalyser, a filter, or other equipment with a large cross sectional area, 12, is placed immediately downstream of the assembly 6a ... of silencing elements. The parallel part flows merge once again in plenum chamber 5, downstream of apparatus 12. It can be seen that an even inflow to apparatus 12 is achieved with a vanishing distance to the silencing part.

Inlet pipe or duct 2 is fitted with a diffuser 15, consisting of a conical first part 16 and a combined axial-radial diffuser 17, into which flow-dividing splitters 18 are inserted. This diffuser serves, both recovery of dynamic pressure and even distribution of flow to each of the nine silencer elements 6a ... i.

Plenum chamber 4 is contained within an end cap 19 and a casing 20, which is made up of four curved parts, for the purpose of minimising shell noise transmitted through the casing. Likewise, curved parts 21 have been fitted onto the plane outer sides of silencer elements 6a, b, c, d, f , g, h, and i. Typically, thermal insulation (not shown) will be fitted onto the entire casing of the apparatus.

Figs. 5 and 6 show a third embodiment of the invention.

Here, in contrast to the second embodiment, each silencer element 6a ... f has been made as a separate unit with its own casing 13. As in the second embodiment, a downstream apparatus (boiler etc.), 12, is placed downstream of the silencing element assembly, which contributes to an even inflow distribution to apparatus 12, here via plenum chamber 5. In the centre, between silencing elements, and outside the elements, two cavities, 22 and 23, exist. Both cavities are closed at the left end by division wall 24, so that there is no flow within the cavities, and so that cavities are acoustically isolated at the left end. At the other end the cavities communicate acoustically with plenum chamber 5, via a perforated plate 25. The outer cavity, 23,

is empty, so that it acts as a quarter-wave sound absorber. By fitting an extra member into cavity 23, the centre frequency of the absorption could be raised, e.g. to target a known peak in the unattenuated frequency spectrum. At its right end, central cavity 22 is provided with sound absorptive material to attain more broad-banded sound absorption.

At its upstream end the silencing apparatus has been fitted directly onto a gas turbine, 26. Thus, first diffuser part 16 of the apparatus at the same time is an outlet diffuser of the gas turbine. Instead of an upstream plenum chamber, the entire flow distribution to silencer elements 6a ... f takes place within the second part, 17, of diffuser 15. By careful design, major flow separation can be avoided all the way from gas turbine exhaust at 27 to conical diffuser outlets 10 inside silencer elements, i.e. with a minimum loss of total pressure. Pressure recovery may take place in all parts 16, 17, and 14. Alternatively, one may prefer to have pressure recovery only in parts 16 and 14, to provide added margin towards flow separation in part 17, which is the most separation-prone flow part element. Regardless of which of these two diffuser design philosophies is selected, a very high degree of recovery of dynamic outlet pressure from the gas turbine can be attained, i.e. higher than with a simple gas turbine outlet diffuser. Since gas turbines are very sensitive to back-pressure, this is an important feature.

This increased flow-dynamic efficiency can be utilised either for gaining gas turbine shaft work or for selecting rather narrow total flow area within pipes of silencer elements, retaining a pressure drop across the unit which is equal to the pressure drop across a conventional silencer. In this way, especially low-frequent sound attenuation can be enhanced.

Finally, fig. 7 shows the inlet part of a fourth embodiment according to the invention, being a variation of the third embodiment. Here, a chamber 4 has been fitted onto inlet diffuser 15, to communicate acoustically with the pipe /duct system prior to gas entering silencing elements 6a ... . This communication is achieved by providing guide plate 27 with apertures 28. Chamber 4, which is not throughflowed, is filled with sound absorptive material, Abs. Thus, space outside diffuser 15 is utilised for sound attenuation, both high- and low-frequent.

It can be seen that the invention is extremely flexible in several respects: Silencers can be tailored to many forms of inlets (squared, rectangular, circular) to boilers, catalysers, and filters, with an even flow distribution attained within a short distance in flow direction.

The acoustic attenuation characteristic can be tailored individually to varying demands for low-, mid- and high-frequent attenuation in a particular application. In general, broad-banded low- and mid-frequent attenuation is achieved with reflective sound reduction, and mid- and high-frequent attenuation by sound absorption. Peaks in unattenuated spectra can be targeted by frequency-selective built-in resonators.

CLAIMS

1. A silencing apparatus which is throughflowed by a gas and which is arranged within a pipe or duct system, the gas flow at one or more stages within the apparatus being divided into three or more preferably substantially parallel subflows, each or substantially each subflow throughflowing a silencing element (6a ...) causing reflective silencing provided by changes in cross-section area, said silencing elements being arranged beside each other within an outer envelope, at least 80% of the volume inside said envelope being constituted by air, gas and/or solid materials, and at least a major part of said volume having silencing functions, said subflows merging downstream of said silencing elements, either within said apparatus or further downstream in said pipe or duct system.

2. An apparatus according to claim 1 in which at least one of the cross-section area changes (10) takes place inside said silencing elements, the change in cross-section area being at least by a factor two.

3. An apparatus according to claim 1 in which said subflows all or substantially all derive from an upstream plenum chamber (4).

4. An apparatus according to claim 1 in which said subflows all or substantially all derive from an upstream diffuser (15, 17).

5. An apparatus according to any of the preceding claims in which said subflows all or substantially all merge into a downstream plenum chamber (5) immediately or substantially immediately downstream of the silencing elements.

6. An apparatus according to any of the preceding claims in which the outflows from the silencing elements are arranged to contribute to a substantially even inflow across the inlet section of a downstream heat recovery boiler/heat exchanger, catalyst, filter or other equipment (12), either by direct inflow or via a plenum chamber.

7. An apparatus according to claim 4 in which the diffuser is provided with one or more flow division element(s) (18) so that at least the outlet part of said diffuser becomes a splitter diffuser (17).

8. An apparatus according to claim 4 or 7 in which the diffuser is designed so that no major flow separation occurs from diffuser inlet (27) to inlets (10) to the silencer elements.

9. An apparatus according to claim 4, 7 or 8 in which each or substantially each inflow to silencing elements 6a.... is designed to avoid or substantially avoid flow separation and includes at least one further diffuser (14) recovering pressure in the inflow to the silencing element.

10. An apparatus according to any of claims 4, 7, 8, and 9, in which the outlet part of the diffuser (15) is provided with one or more apertures (28) which communicates/communicate with a chamber (4) arranged upstream of the silencing elements.

11. An apparatus according to any of the preceding claims in which said silencing elements (6a ...) fill out substantially the entire cross section contained within an outer contour.

12. An apparatus according to any of claims 1-10 in which the contours of at least some of the silencing elements are shaped so that one or more cavities (22) are created between said silencing elements (6a), each or substantially each such cavity being provided with a member (24) which prevents both gas flow and sound energy from being transmitted in bypass to said silencing elements, and said cavity/cavities communicating either with the gas flow upstream of said silencing elements and/or with the gas flow downstream of said silencing elements.

13. An apparatus according to any of claims 1-12 in which one or more cavities (23) are defined outside the contours of said silencing elements, each or substantially each such cavity being provided with a member (24) which prevents both gas flow and sound energy from being transmitted in bypass to said silencing elements, and said

cavity/cavities communicating either with the gas flow upstream of said silencing elements and/or with the gas flow downstream of said silencing elements.

14. An apparatus according to claim 12 or 13 in which one or more of said cavities is/are designed so as to function as a quarter-wave resonator of a kind known *per se.*

15. An apparatus according to claim 12 or 13 in which one or more of said cavities is/are designed to act as a resonator of the Helmholz resonator type known *per se.*

16. An apparatus according to any of claims 12-15 in which one or more of said cavities is/are fitted with sound absorptive material (Abs).

17. An apparatus according to any of the preceding claims in which part of said inlet pipe or duct to the diffuser is an exhaust diffuser of a gas turbine (26).

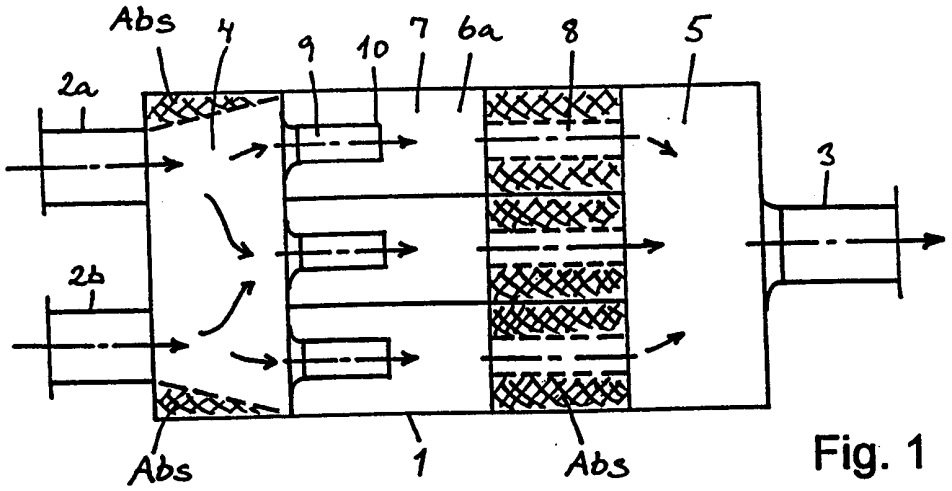

Fig. 1

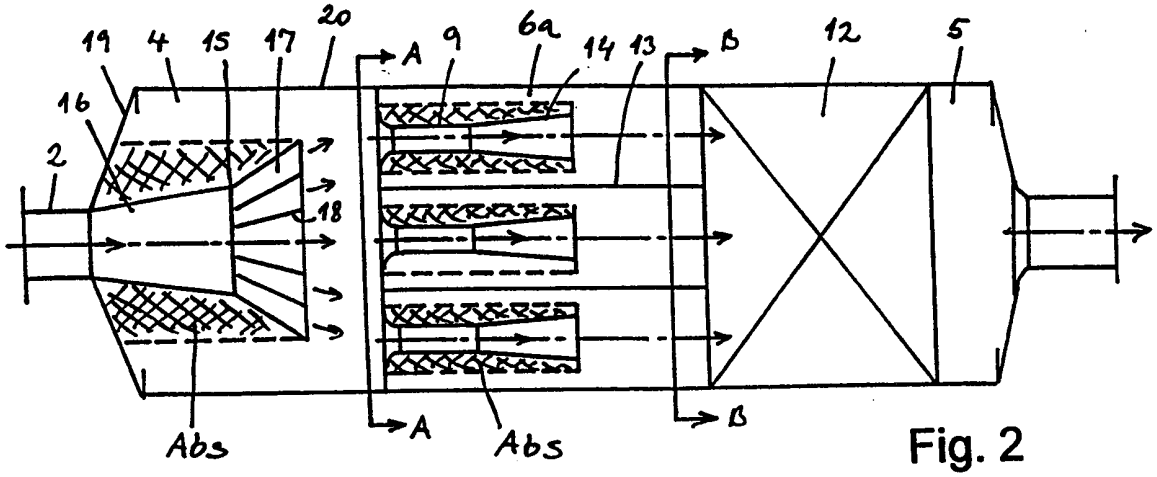

Fig. 2

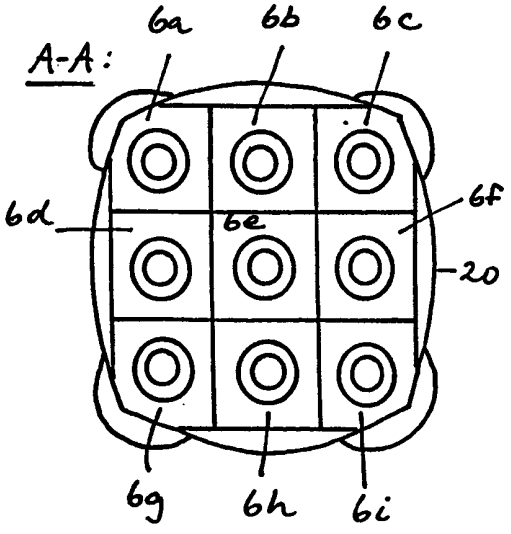

Fig. 3

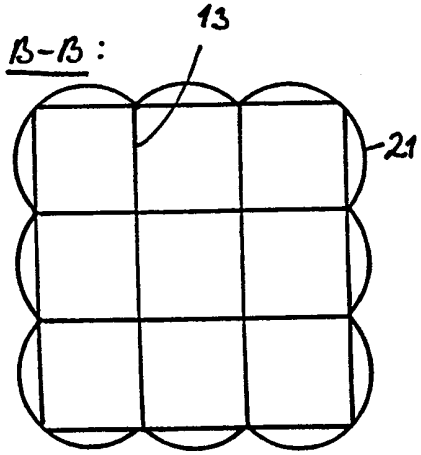

Fig. 4

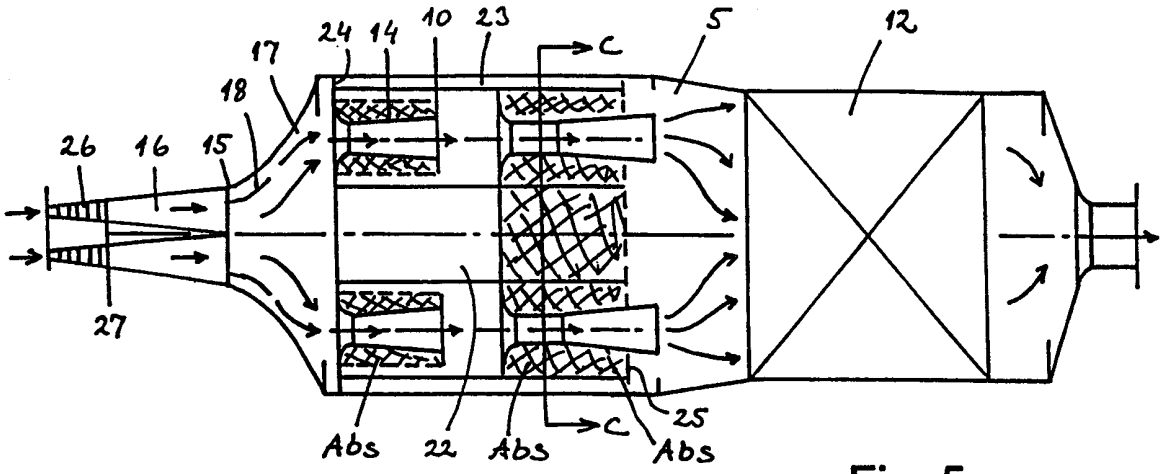

Fig. 5

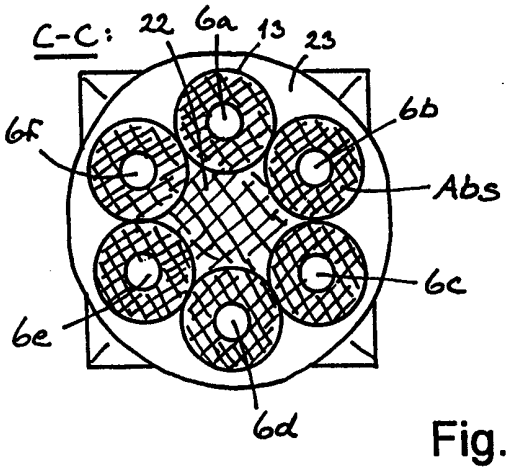

Fig. 6

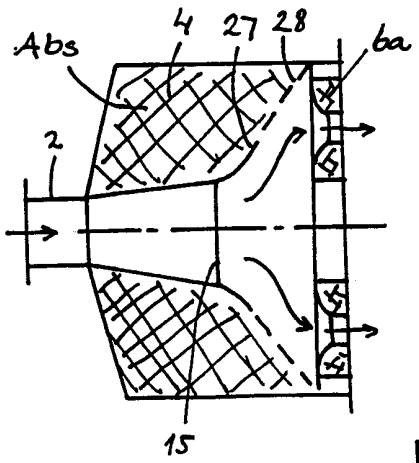

Fig. 7

INTERNATIONAL SEARCH REPORT

Inte onal Application No
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A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 F01N1/08 F01N1/10 F01N7/04

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 F01N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

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C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 578 277 A (WHITE SCOTT T ET AL) 26 November 1996 see the whole document ---	1,3
X	WO 96 32572 A (VOELUND DANSTOKER A S ;LUND AGNER (DK); FREDERIKSEN SVEND (SE)) 17 October 1996 see page 7, paragraph 2 see page 17, paragraph 3 see abstract ---	1,3
X	US 2 075 316 A (E.O.E. TYDÉN) 30 March 1937 see page 1, right-hand column, line 5 - right-hand column, line 54 see page 2, right-hand column, line 31 - right-hand column, line 60 --- -/--	1

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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19 March 1999	31/03/1999

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Inte onal Application No
PCT/DK 98/00588

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	US 4 392 549 A (WROBEL STANISLAW ET AL) 12 July 1983 see column 1, line 55 - column 2, line 2 see column 2, line 22 - column 2, line 55; figure 1	1,3,4
A	EP 0 131 350 A (CHILLCOTTS LTD) 16 January 1985 see claim 1; figure 1	1,3
A	US 4 105 089 A (JUDD FREDERICK V H) 8 August 1978 see claim 1; figures 1,3	1

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INTERNATIONAL SEARCH REPORT

Information on patent family members

Int ional Application No
PCT/DK 98/00588

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5578277 A	26-11-1996	DE 19522935 A	04-01-1996
		JP 8014033 A	16-01-1996
WO 9632572 A	17-10-1996	AU 5333496 A	30-10-1996
		EP 0823016 A	11-02-1998
		PL 322747 A	16-02-1998
US 2075316 A	30-03-1937	NO 56196 C	
US 4392549 A	12-07-1983	CH 660625 A	15-05-1987
		DE 3208640 A	21-10-1982
		GB 2094887 A,B	22-09-1982
		SU 1123549 A	07-11-1984
EP 0131350 A	16-01-1985	BR 8401217 A	23-10-1984
		DE 3472581 A	11-08-1988
		GB 2136502 A,B	19-09-1984
		IN 161747 A	30-01-1988
		JP 59218321 A	08-12-1984
		US 4598791 A	08-07-1986
		ZA 8401799 A	31-10-1984
US 4105089 A	08-08-1978	US 4180141 A	25-12-1979