



Title: Magnet and device for magnetic density separation

The invention relates to a magnet and a device for magnetic  
5 density separation (MDS).

Density separation is used in raw materials processing for the  
classification of mixed streams into streams with particles of different types  
of materials. In an accurate form of density separation, a liquid medium is  
used in which the lighter material float and the heavier materials sink. The  
10 process requires a liquid medium that has a density that is intermediate  
between the density of the light and heavy materials in the feed, yet is  
inexpensive and safe. In magnetic density separation this is provided using  
a magnetic liquid. The magnetic liquid has a material density which is  
comparable to that of water. However, when a gradient magnetic field is  
15 applied to the magnetic liquid, the force on a volume of the liquid is the sum  
of gravity and the magnetic force. In this way, it is possible to make the  
liquid artificially light or heavy, resulting in a so called cut density. For  
magnetic density separation, use is made of a large planar magnet. The field  
decays with the height above the magnet, preferably exponentially with the  
20 height above the magnet surface. EP 1 800 753 and WO 2009/108047  
disclose a method and apparatus for magnetic density separation.

For accurate separation on density in a magnetic liquid preferably  
a magnet is used that, within the volume of magnetic liquid above the  
magnet, creates a field with a substantially constant intensity in each plane  
25 parallel to the magnet. The result is that magnetic forces on the liquid are  
essentially perpendicular to these planes, and depend essentially only on  
the coordinate perpendicular to the plane.

The magnet proposed in EP 1 800 753 requires a relatively large  
amount of complex-shaped permanent magnetic material, which is  
30 expensive. In an attempt to economize on material, an improved magnet for  
magnetic density separation has been proposed in "Magnet designs for

magnetic density separation of polymers', The 25<sup>th</sup> conference on solid waste, technology and management, March 27-30, 2011, Philadelphia, PA, USA, The journal of solid waste technology and management, ISSN 1091-8043 (2011) 977-983.

5            In this publication, a planar magnet according to the preamble of claim is proposed, which includes a flat steel support, onto which a series of poles is mounted. The poles are alternately made from steel and from a magnetic material, and have a specially shaped cap made from steel. A gap filled with air or non-magnetic compound such as a polymer resin separates  
10 consecutive poles.

          Although successful in its efficient construction, in contrast to what was expected, the field of the magnet did not have substantially constant intensity in the respective parallel planes.

          The invention aims to provide a planar magnet for magnetic  
15 density separation which is of cost effective construction, yet maintains a field of substantially constant intensity in each plane parallel to the magnet.

          Thereto the invention provides for a planar magnet for magnetic density separation, comprising an array of pole pieces succeeding in longitudinal direction of a mounting plane, each pole piece having a body  
20 extending transversely along the mounting plane with a substantially constant cross section that includes a top segment that is curved to distribute the magnetic field associated with the top surface of the pole piece such that its strength transverse to the mounting plane is substantially uniformly distributed in planes parallel to the mounting plane, the curved  
25 top segments having a length (l) in transverse direction of the mounting plane, a width (x) in longitudinal direction of the mounting plane and a height (h) transverse to the mounting plane, characterized in that the top segments of successive pole pieces are unequal in length (l), height h) and/or width (x).

Within this context, the term unequal in length, height or width is to be understood as a respective length, height or width of a pole that is neither the same nor a natural integer multiple of a successive pole.

Arranging the top segments of successive poles to be curved in accordance to the same function of shape, yet to extend over a different length, width and/or be positioned at different heights, differences in the intensity of the magnetic fields of the successive poles can be compensated for, while maintaining the uniform characteristics of the individual fields. It has been found, that a shift in height of the top portion does not require a different shape of the top portion to generate the uniform field distribution in planes parallel to the magnet. Alternatively or in addition, a difference in length and or width of the top segment may also be used for field correction if the top segments of the poles are provided with the same basic curvature.

In longitudinal direction of the mounting plane, each successive pole piece in longitudinal direction in the array of pole pieces may be unequal in height, length and/or width to its predecessor, or only a part of the total number of poles pieces in longitudinal direction in the array may be unequal in height, length and/or width to its predecessor, e.g. a subgroup of two, three or more successive pole pieces. The poles pieces at odd and/or even positions may be identical, and the leading and/or trailing pole pieces may be of smaller width than the interposed pole pieces.

To facilitate construction, the mounting plane may be a support plate onto which the pole pieces are mounted. Preferably, the support plate is made of a magnetisable material, in particular ferromagnetic material, in particular steel. As an alternative, the pole pieces may be mounted individually or in smaller groups onto a support.

By having the pole pieces extend parallel in transverse direction of the mounting plane uniform distribution of the field in transverse direction of the field may be achieved relatively easily. As an alternative,

the magnetic permeability of the gaps between successive pole pieces may be changed to compensate for an alignment of pole pieces.

To reduce the number of pole pieces further, the successive poles may be spaced apart in longitudinal direction of the mounting plane. Gaps  
5 between the successive poles may be filled with magnetically permeable filler material, for example air, non magnetisable metal and/or polymer resin.

To save costs of construction, in longitudinal direction of the mounting plane, the pole pieces may alternately be embodied as magnets  
10 and magnetisable poles. The magnets may e.g. be permanent magnets, such as neodymium magnets, or electro-magnets. The magnetisable poles may be made of a magnetisable material, preferably a ferromagnetic material, in particular steel. In such arrangement, successive pole pieces that are embodied as magnets may be of the same polarity, in particular in a north  
15 to south or south to north configuration transverse to the mounting plane.

To save costs on construction, the magnets may include a magnetic base portion and a separate top portion of magnetisable material that includes the curve top segment. For example, the magnet pole may include a base portion that is rectangular in cross section onto which a steel  
20 top portion is placed which is machined to have a curved top.

Seen in longitudinal direction, the pole pieces at the leading end and/or trailing end of the mounting plane may be magnetic pole pieces.

Seen in longitudinal direction, the pole pieces at the leading end and/or trailing end of the mounting plane may have a width that is be more  
25 than half the width of any of the interposed pole pieces. The width may, however be less than the width of any of the interposed pole pieces.

The invention also relates to a magnetic density separation device including a planar magnet.

The invention will be further elucidated on the basis of a non-limitative exemplary embodiment which is represented in a drawing. In the drawing:

Fig. 1 shows a schematic exploded view of a planar magnet for magnetic density separation;

Fig. 2 shows a schematic side view of a detail of the array of pole pieces of the planar magnet of Fig. 1, in which the difference in height and or width of the pole pieces has been drawn exaggeratedly to increase visibility;

Fig. 3 shows a schematic side view of a magnetic separation device including the magnet of Fig.1.

It is noted that the figures are merely schematic representations of a preferred embodiment of the invention. In the figures, identical or corresponding parts are represented with the same reference numerals.

Fig. 1 shows a planar magnet 1 for magnetic density separation. The magnet 1 comprises an array of pole pieces 2, 3 succeeding in longitudinal direction  $l$  of a mounting plane 4. In the embodiment shown, the mounting plane 4 is a thick steel support plate 5 onto which the pole pieces 2, 3 are mounted. Each pole piece 2, 3 has a body 6 extending in transverse direction  $t$  along the mounting plane 4. Each body 6 extends transversely along the mounting plane 4 with a substantially constant cross section 7. In the embodiment shown, the pole pieces 2, 3 extend parallel in transverse direction  $t$  of the mounting plane 4. The cross section 7 of the body 6 of each pole piece 2, 3 includes a top segment 8 that is curved to distribute a magnetic field associated with the top surface 9 such that its strength transverse to the mounting plane is substantially uniformly distributed in planes parallel to the mounting plane 4. This is illustrated in Fig. 2.

The top segments of the pole pieces in the array are provided with the same basic curvature.

As set out in the publication “Magnet designs for magnetic density separation of polymers, The 25<sup>th</sup> International conference on solid waste, technology and management, March 27-30, 2011, Philadelphia, PA, USA, The journal of solid waste technology and management, ISSN 1091-8043 (2011) 977-983”, in particular pages 979-981 the curvature of the top surface may be mathematically represented by the following formula:

$$z = \frac{p}{\pi} \ln \sin \left( \frac{\pi x}{p} \right)$$

In this formula,  $z$  is the height of points at the top surface with respect to a fixed reference point (the highest point) of the top surface, as a function of the horizontal coordinate  $x$ ,  $0 < x < p$ , running along the cross-section of the magnet as in Figs. 1 and 2. The parameter  $p$  is the interval in  $x$  over which the profile is periodic.

As can be taken from Fig. 2, the curved top segments 8 have a width  $x$  in longitudinal direction 1 of the mounting plane 4 and a maximum height  $h$  transverse to the mounting plane 4.

In accordance with the invention, the top segments 8 of successive pole pieces in longitudinal direction 1 are unequal in height  $h$  and/or width  $x$ . In the embodiment shown, in longitudinal direction 1 of the mounting plane 4, each successive pole piece 2,3 in the array of pole pieces is unequal in height  $h$  or width  $x$  to its predecessor. The leading and trailing pole pieces 2' at the respective leading end 15 and trailing end 16 of the magnet 1 are of smaller width  $x_1$  than the width  $x_2$  of the pole pieces 2, 3 interposed between the leading and trailing pole pieces 2'. The width  $x_1$  of the leading and trailing pole pieces 2' can e.g. be 60 mm, while the width  $x_2$  of the interposed pole pieces 2, 3 of the interposed pole pieces can e.g. be **80 mm**. The leading and trailing pole pieces 2' are magnetisable pole pieces. Their

width  $x_1$  is however larger than half the width  $x_2$  of the interposed magnetisable pole pieces 2. This allows to reduce loss of laterally extending magnetic flux at the leading and trailing end of the support plate 5.

In the embodiment shown, the interposed pole pieces 2, 3 are embodied as magnets 2 at odd pole positions, and as magnetisable pole pieces 3 at even positions. The interposed magnetisable pole pieces 3 have a top surface 9 that is identical in shape to the top surface 9 of the interposed magnetic pole pieces 2, and the width  $x$  of these pieces is identical, but the position of their top surfaces 9 is shifted vertically upward in the same orientation so that the height  $h_2$  of the magnetisable pole pieces 3 is higher than the height  $h_1$  of the magnetic pole pieces 2. In practice, the height  $h_1$  can e.g. be 60 mm, the height  $h_2$  can be e.g. 80 mm.

This allows the magnetisable pole pieces 2 to have more volume of material, so that the weaker field strength of the magnetisable material compared to the magnetic material can be compensated for, yet the distribution of the field lines over the top surface is still such that it creates a field with a substantially constant intensity in each plane parallel to the pole piece and, due to the compensation, for the whole planar magnet.

The length ( $l$ ) of the top segments 8 of the pole pieces 2, 3 transverse to the longitudinal direction is in this embodiment the same for all pole pieces, but may also be varied to compensate. In particular, the leading and/or trailing pole pieces may be provided with a greater length ( $l$ ).

As can be taken from Fig. 2, in this exemplary embodiment, successive pole pieces that are embodied as magnets 2 are of the same polarity. In particular, the north-south orientation of these pole pieces 2 is aligned and transverse to the mounting plane 4.

With reference to Figures 1 and 2, it is shown that successive poles 2, 3 may be spaced apart in longitudinal direction  $l$  of the mounting plane 4. Gaps 10 between successive poles are in this example filled with magnetically permeable filler material, in this example polyester resin 11.



This prevents clogging of the gaps 10 with foreign material. The resin 11 also extends over the tops of the pole pieces 2, 3 to provide a smooth surface 12 of the magnet 1. The gaps are filled with magnetically permeable filler material.

5           In longitudinal direction of the mounting plane 4, the pole pieces 2, 3 are alternately embodied as magnets 2 and magnetisable poles 3. In the embodiment shown, the pole pieces with reference numeral 2 are embodied as neodymium magnets, and the pole pieces provided with reference numeral 3 are embodied as steel magnetisable pole pieces. For  
10 ease of manufacture, the magnets 2 include a magnetic base portion 13 with a rectangular cross section, and a top portion 14 of steel that has been machined to include the curved top surface 9.

          In accordance with the invention, the top segments 8 of successive pole pieces 2,3 are unsymmetrical in a mirror plane normal to the mounting  
15 plane and extending in transverse direction through the center of the gap 10 between successive magnets: the height positions of the successive interposed top segments is not equal, and the width of the pole pieces at the ends is not such that the successive poles each other's whole or half image.

          As an example, in Table 1 below, measurements are provided of  
20 the extremes of the magnetic field along the x-axis of a magnet ( $p=0.12$  m) designed with a corrective widening of the magnet poles at the upper and lower edges. It is shown that the corrective widening improves the field homogeneity with respect to the uncorrected version in the sense that the differences between the extremes is now everywhere less than 0.05 Tesla.  
25 Especially near the leading or trailing end where the separation of the products takes place and the field homogeneity is most important, the differences are even smaller.

Table 1:

X [mm]	Bz [Tesla]
-600	0.22
-480	-0.20
-360	0.25
-240	-0.20
-120	0.25
0	-0.20
+120	0.25
+240	-0.20
+360	0.25
+480	-0.20
+600	0.22

Fig. 3 shows a magnetic density separation device 17, including a planar magnet 1 of the type discussed above. In this example, the magnet may have a surface area of  $4\text{m}^2$ . Material to be separated, e.g. a mix of scrapped bottles 18 made of a lighter and a heavier plastic material, is fed in a preferably laminar flow of magnetic liquid, in this example ferrofluid, through a channel 19 of the separation device 17 in a flow direction  $f$ . A wall 20 of the channel includes the planar magnet 1 arranged with its longitudinal direction aligned with the flow direction. The magnet 1 applies a cut density to the magnetic liquid flowing through the channel 19. The cut density causes the bottles 18a made of the lighter plastic to flow in an upper portion of the channel 19, and the bottles 18b made of the heavier plastic flow to a lower portion 19 of the channel. The surface 12 of the magnet 1 is covered by a portion of an endless conveyor belt 20 circulating between diverting wheels 21, so that debris is conveyed away from the surface 12 of the magnet 1. Downstream of the magnet 1 a dividing wall 22

is positioned in the channel 19 that splits the channel 19 in a top portion 19a for the bottles 18a made of material of lower density, and a bottom portion 19b for the bottles 18b made of material of higher density.

The invention is not limited to the exemplary embodiment  
5 represented here. For example, successive pole pieces in longitudinal direction may be embodied as magnets, e.g. electro-magnets, and may have alternating polarity. Such variations shall be clear to the skilled person and are considered to fall within the scope of the invention as defined in the following claims.

## Reference numerals

	1	Magnet
	2	Pole piece, magnet
5	3	Pole piece, magnetisable
	4	Mounting plane
	5	Support plate
	6	Body
	7	Cross section
10	8	Top segment
	9	Top surface
	10	Gap
	11	Resin
	12	Surface
15	13	Base portion
	14	Top portion
	15	Leading end
	16	Trailing end
	17	Separation device
20	18	Bottles (a lower density, b higher density)
	19	Channel (a top, b bottom)
	20	Conveyor belt
	21	Diverting wheels
	22	Dividing wall (a top, b bottom)
25	f	Flow direction
	l	Longitudinal direction
	t	Transverse direction
	h	Height
	x	Width
30	l	Length

### Claims

1. A planar magnet for magnetic density separation, comprising an array of pole pieces succeeding in longitudinal direction of a mounting plane, each pole piece having a body extending transversely along the mounting plane with a substantially constant cross section that includes a top segment that is curved to distribute the magnetic field associated with the top surface of the pole piece such that its strength transverse to the mounting plane is substantially uniformly distributed in planes parallel to the mounting plane, the curved top segments having a length (l) in transverse direction of the mounting plane, width (x) in longitudinal direction of the mounting plane and a height (h) transverse to the mounting plane, characterized in that the top segments of successive pole pieces are unequal in length, height and/or width.
2. The magnet of claim 1, wherein the mounting plane is a support plate onto which the pole pieces are mounted.
3. The magnet of any of the preceding claims, wherein the pole pieces extend parallel in transverse direction of the mounting plane.
4. The magnet of any of the preceding claims, wherein the successive poles are spaced apart in longitudinal direction of the mounting plane.
5. The magnet of any of the preceding claims, wherein in longitudinal direction of the mounting plane the pole pieces are alternatingly embodied as magnets and magnetisable poles.
6. The magnet of any of the preceding claims, wherein successive pole pieces that are embodied as magnets are of the same polarity.
7. The magnet according to any of the preceding claims, wherein the magnets include a magnetic base portion and a top portion of magnetisable material that includes the curved top segment.

8. The magnet according to any of the preceding claims, wherein the curved top segments of the pole pieces in the array are provided with the same basic curvature.

9. The magnet according to claim 8, wherein the curvature of the top segments of the pole pieces is represented by the formula:

$$z = \frac{p}{\pi} \ln \sin \left( \frac{\pi x}{p} \right)$$

10. The magnet according to any of the preceding claims, wherein the leading and/or trailing pole pieces at the respective leading and/or trailing end of the magnet are of a width  $x$  that is smaller than the width  $p$  of any of the pole pieces interposed between the leading and trailing pole pieces, but that is larger than half the width of any of the pole pieces interposed between the leading and trailing pole pieces.

11. A magnetic density separation device, including a channel for flowing magnetic liquid there through in a flow direction, a wall of the channel including a planar magnet in accordance to any of claims 1-10 arranged with its longitudinal direction aligned with the flow direction so as to apply a cut density to the magnetic liquid flowing through the channel.

12. The magnetic density separation device according to claim 11, wherein the surface of the magnet is covered by a portion of an endless conveyor belt circulating between diverting wheels.

13. The magnetic density separation device according to claim 12, wherein downstream of the magnet a dividing wall is positioned in the channel that splits the channel.

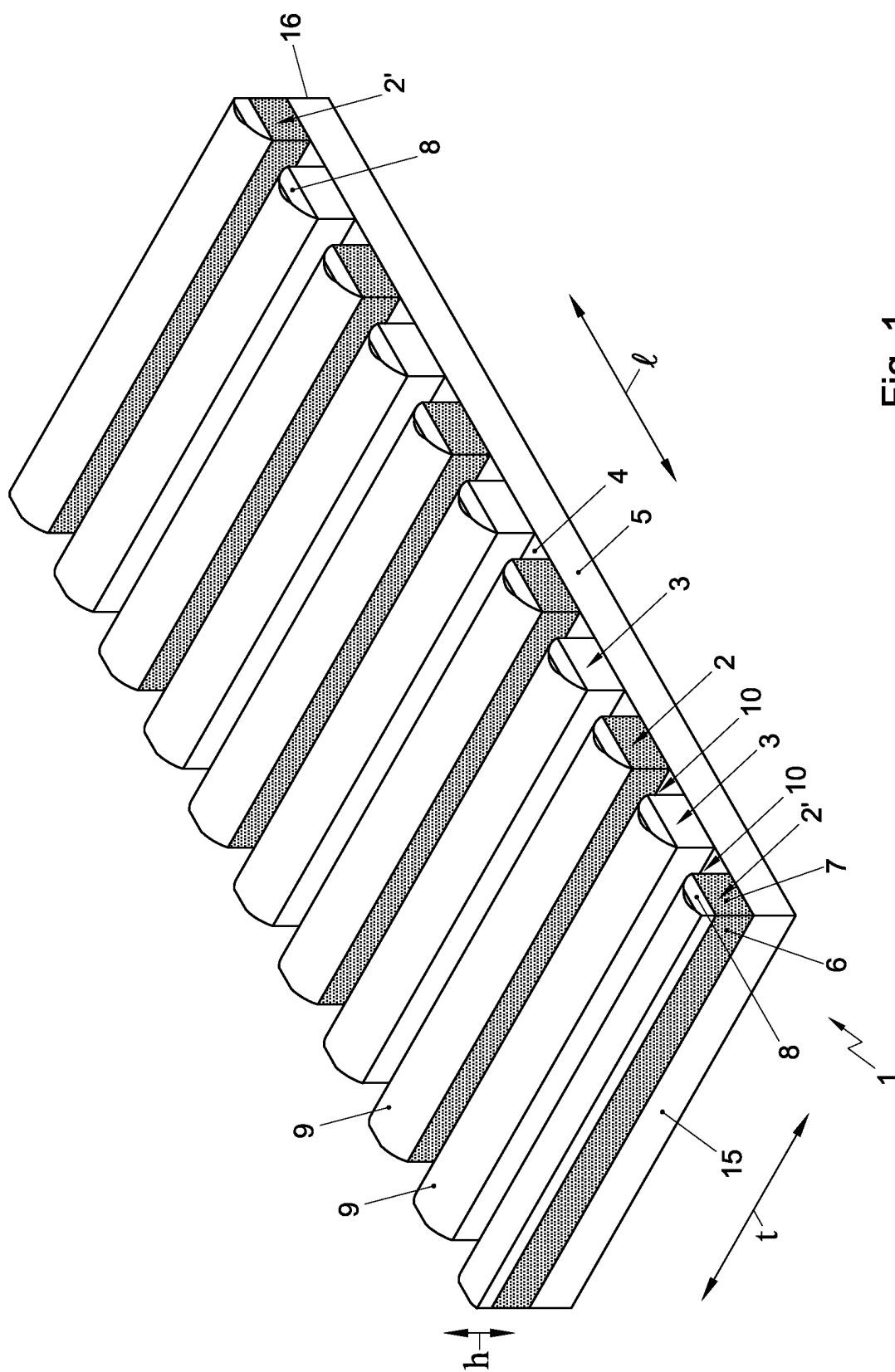


Fig. 1







# INTERNATIONAL SEARCH REPORT

International application No PCT/NL2014/050177
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<b>A. CLASSIFICATION OF SUBJECT MATTER</b>				
INV. B03C1/28	B03C1/033	B03C1/01		
B03B5/44	H01F7/02	B03C1/32		
B03B5/30				
ADD.				
According to International Patent Classification (IPC) or to both national classification and IPC				
<b>B. FIELDS SEARCHED</b>				
Minimum documentation searched (classification system followed by classification symbols) B03C B03B H01F				
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched				
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPO-Internal, WPI Data				
<b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>				
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.		
X	DOMENICO LAHAYE ET AL: "Magnet designs for magnetic density separation of polymers", INTERNATIONAL CONFERENCE ON SOLID WASTE TECHNOLOGY AND MANAGEMENT : ICSW; THE 25TH CONFERENCE ON SOLID WASTE, TECHNOLOGY AND MANAGEMENT, PHILADELPHIA, PA, 1 January 2011 (2011-01-01), pages 977-983, XP008166490, ISSN: 1091-8043 cited in the application figures 2, 4, 5 page 978 - page 982  -----  -/--	1-13		
<input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C. <span style="margin-left: 200px;"><input checked="" type="checkbox"/> See patent family annex.</span>				
* Special categories of cited documents :  <table style="width: 100%; border: none;"> <tr> <td style="width: 50%; border: none; vertical-align: top;"> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier application or patent 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> </td> <td style="width: 50%; border: none; vertical-align: top;"> <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 when the document is taken alone</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>"&amp;" document member of the same patent family</p> </td> </tr> </table>			<p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier application or patent 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 when the document is taken alone</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>"&amp;" document member of the same patent family</p>
<p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier application or patent 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 when the document is taken alone</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>"&amp;" document member of the same patent family</p>			
Date of the actual completion of the international search	Date of mailing of the international search report			
30 April 2014	14/05/2014			
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer  Menck, Anja			

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International application No

PCT/NL2014/050177

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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A	EP 1 800 753 A1 (BAKKER HOLDING SON B V [NL]) 27 June 2007 (2007-06-27) cited in the application figures 2-6 -----	1-13
A	GB 2 278 231 A (EEV LTD [GB]) 23 November 1994 (1994-11-23) figure 3 -----	1-13
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Information on patent family members

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