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(54) **PISTON COMPRESSOR**

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(57) **ABSTRACT**

A compressor comprising a cylinder (**1**) with an axially reciprocating piston (**5**) which compresses gas in the cylinder. At least two circumferential rows of flat fan spray nozzles (**10**) spray water into the cylinder during compression. Each nozzle is arranged such that the spray is in a plane substantially parallel to the axis (**4**) of the cylinder and is directed towards a central region of the cylinder.

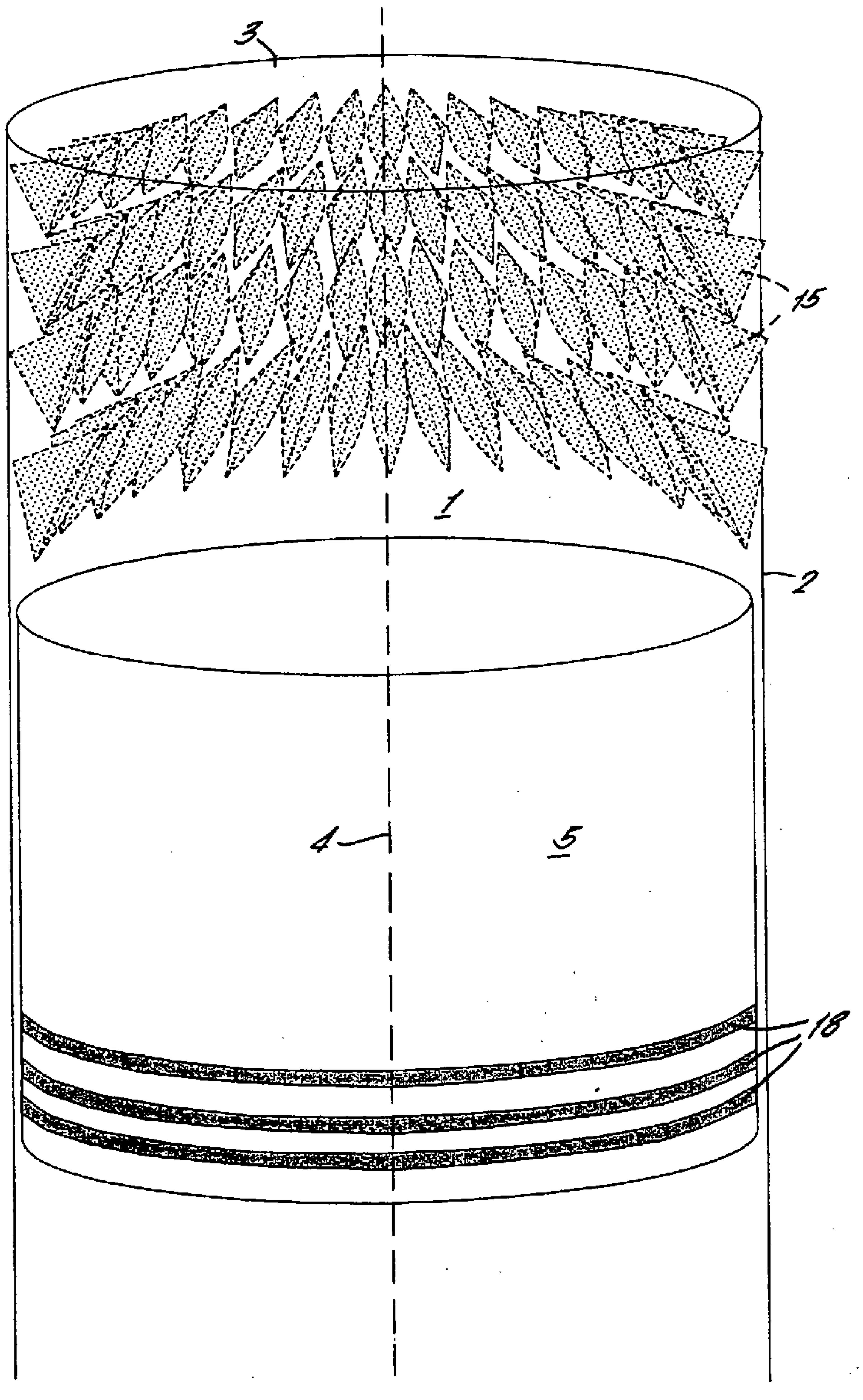


FIG. 1.

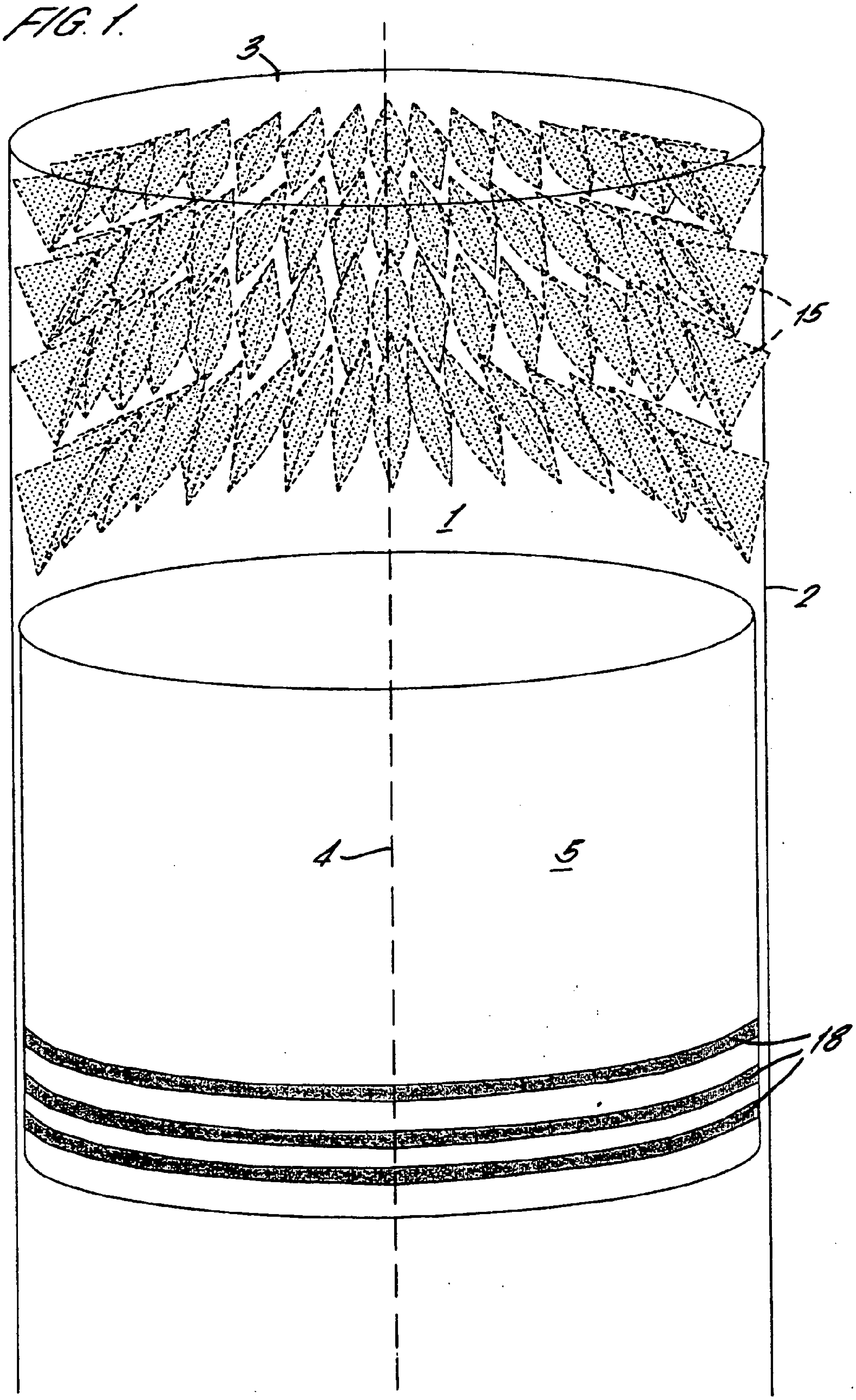


FIG. 2A.

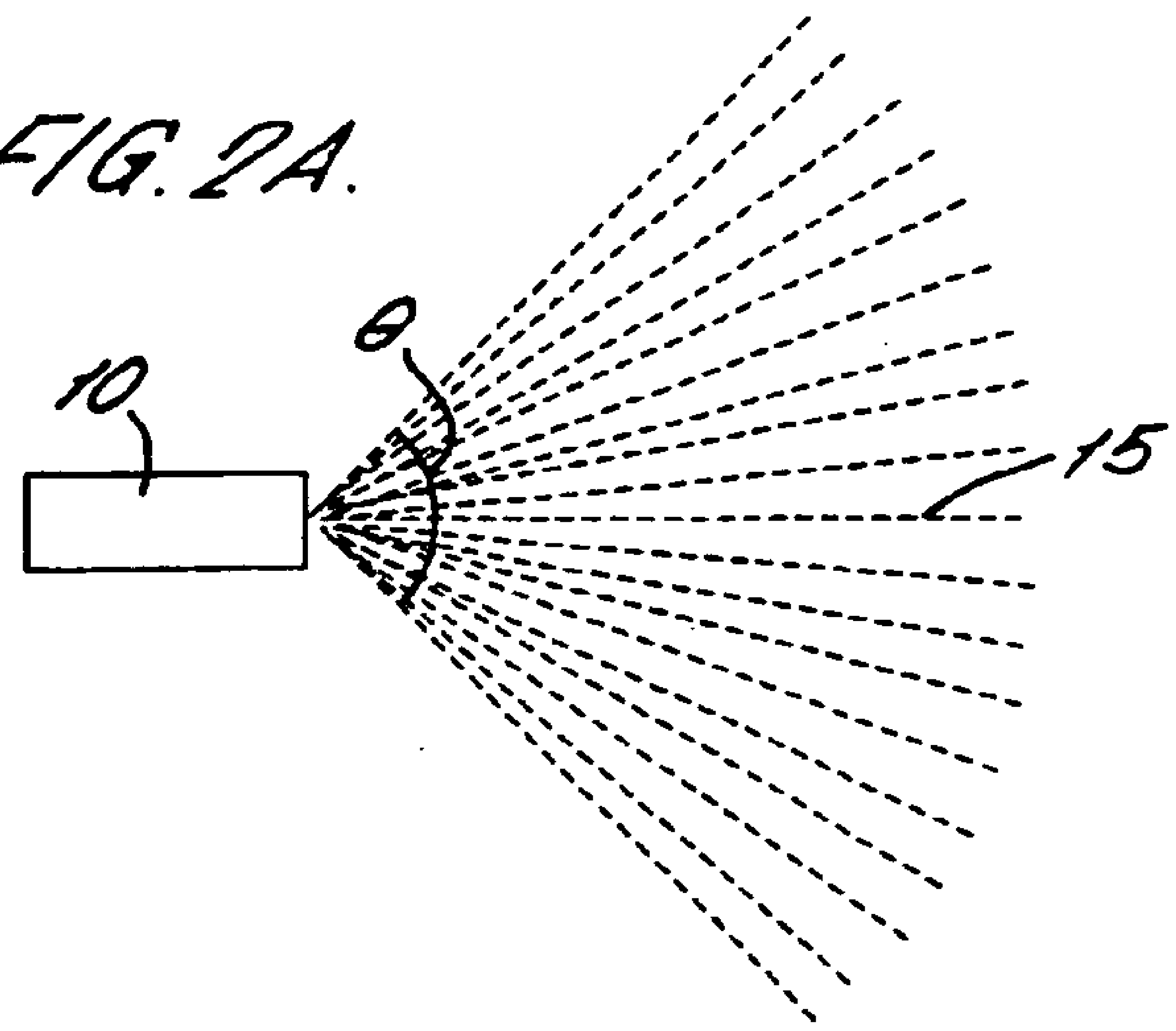


FIG. 2C.

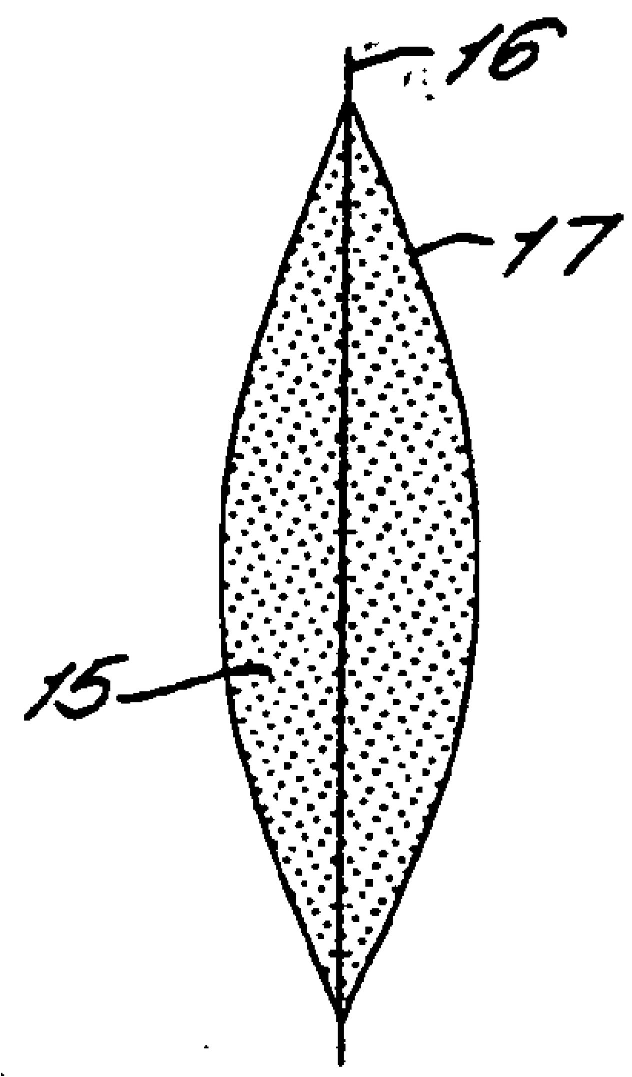
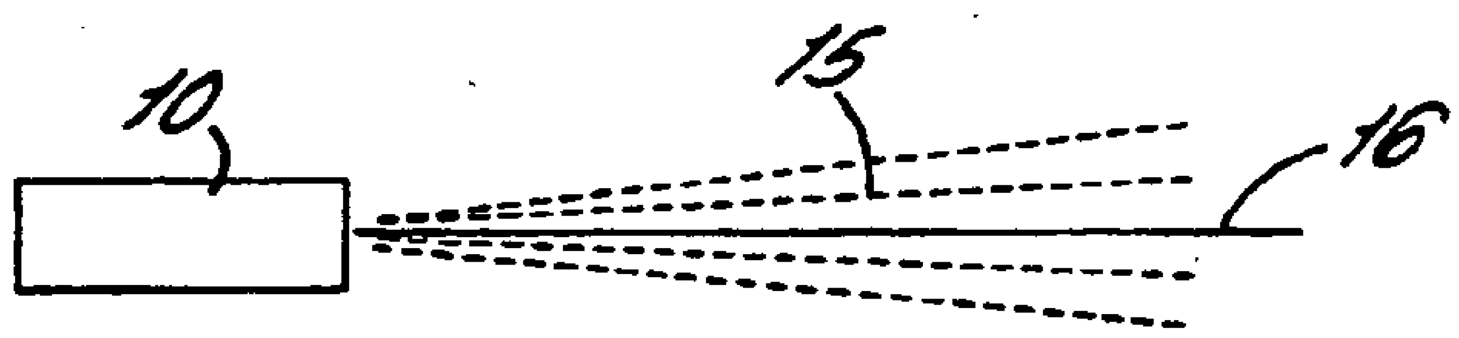


FIG. 2B.



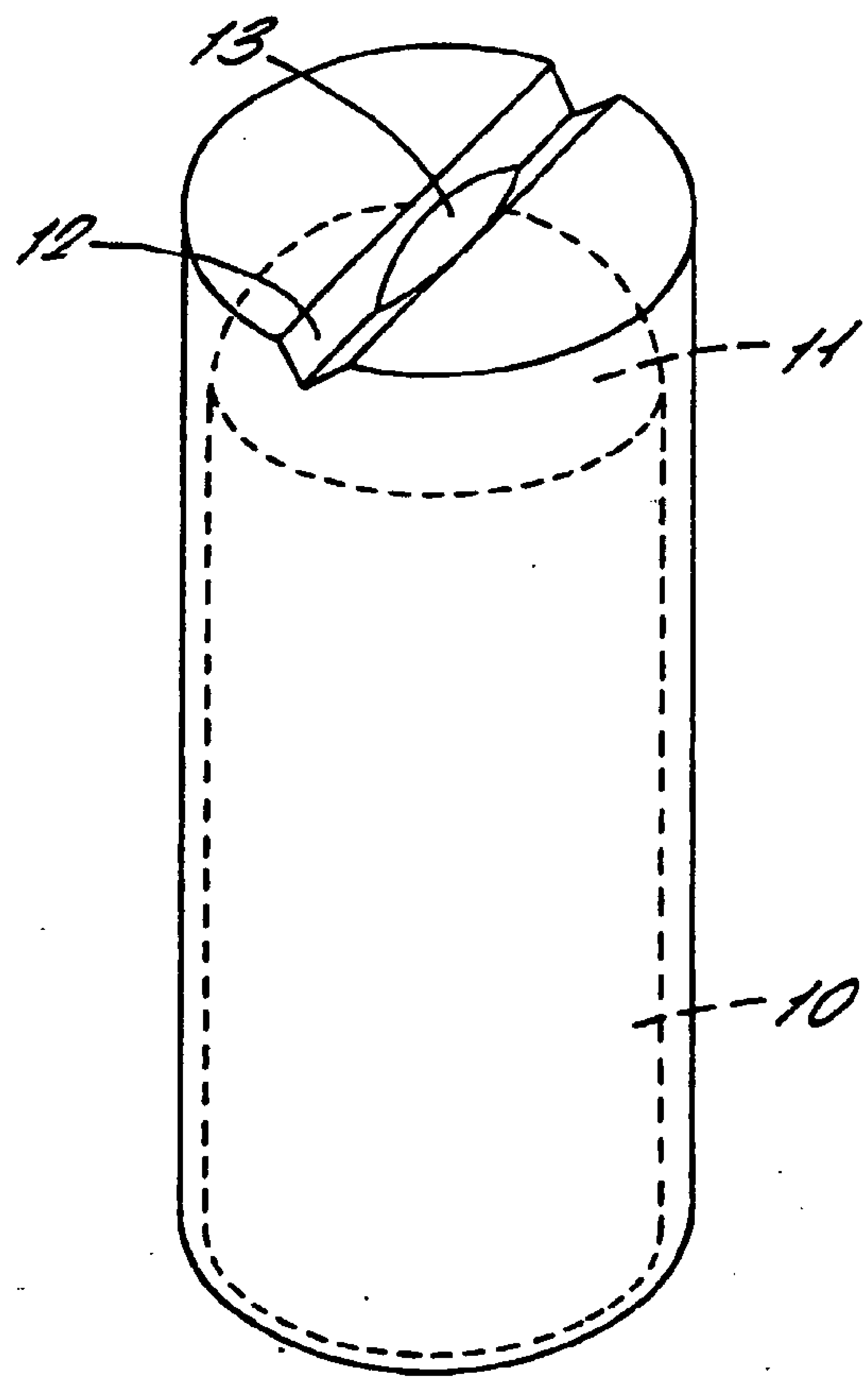


FIG. 3.

PISTON COMPRESSOR

[0001] The present invention relates to a compressor comprising a cylinder having an axis, a piston reciprocally movable along the cylinder axis to compress gas in the cylinder and at least two circumferential rows of spray nozzles to spray water into the cylinder during compression. Such a compressor will subsequently be referred to as "of the kind described".

[0002] A compressor of the kind described is disclosed in our earlier application WO 98/16741. This discloses the use of swirl nozzles which impart a rotary motion to the liquid being injected to produce a hollow cone spray pattern of fine droplets. The nozzles are arranged circumferentially and are placed close enough to each other so that the cones intersect one another to fill the empty space within each cone with droplets from an adjacent nozzle. Various methods of aligning the hollow cone sprays in order to achieve good overall distribution of droplets within the cylinder are described.

[0003] A present invention aims to improve the distribution of droplet in a compressor of the kind described.

[0004] According to the present invention, in a compressor of the kind described, the nozzles are flat fan spray nozzles each of which is arranged such that the spray is in a plane substantially parallel to the axis of the cylinder and is directed towards a central region of the cylinder.

[0005] The invention provides a spray arrangement which is particularly suitable for larger compressors which operate at high speed and pressure. As the size, speed and pressure of the compressor increases, it has been found that the drag force of the gas prevents the droplets from penetrating sufficiently far into the cylinder to cool the gas at further distances from the nozzles within the time available. Further, it becomes less important to produce the finest possible droplets such as those produced by hollow cone spray nozzles as the high drag forces tend to break up the larger droplets. Under the circumstances, the most important consideration is to achieve maximum penetration of the water droplets through the gas space. This aim is considerably assisted if the hollow cone spray nozzles are replaced by the flat fan nozzles which are directed towards the central region of the cylinder but still achieve a sufficiently wide distribution in the direction parallel to the axis of the cylinder. It has been found desirable to minimize the interaction between the neighbouring nozzles in order that the kinetic energy of the water is applied to achieve a maximum penetration towards the centre axis of the cylinder and this is achieved by the above arrangement. The spray nozzles are preferably in a plane which is inclined at less than 10° to the axis of the cylinder and is preferably inclined at less than 5° to the axis of the cylinder.

[0006] In order to maximise the penetration of the liquid, the flat fan spray nozzles are preferably directed substantially at the axis of the cylinder.

[0007] Preferably at least three or four circumferential rows of spray nozzles are provided. In order to minimise interference between adjacent rows of nozzles, an offset of one half of the nozzle pitch is introduced between nozzles in adjacent rows.

[0008] In order to reduce or eliminate water from nozzles closest to the cylinder head impinging on the cylinder head, the angle of divergence of the fan spray of each row of nozzles preferably decreases towards the cylinder head. This also has the advantage that the sprays become more concentrated towards the end of the piston stroke, when the rate of heat generation by compression is at its highest. Effectively, this means that the nozzles closest to the cylinder head have a less divergent spray than those further from the cylinder head so that the spray closest to the cylinder head is concentrated into a smaller axial length of the piston. To increase the distribution of liquid down the cylinder, the nozzles are preferably inclined such that the lower extremity of the spray from the row of nozzles furthest from the cylinder head is at a smaller angle with respect to the cylinder wall than for nozzles closer to the cylinder head.

[0009] The nozzles are preferably mounted with their central axes inclined downwardly with respect to the cylinder axis. One way of increasing a downward incline of the nozzles with respect to the cylinder axis is to taper the top part of the cylinder wall in which the nozzles are mounted inwardly towards the cylinder head. Under the circumstances, the piston will also need to be provided with a complementary taper.

[0010] To achieve rapid penetration of the gas at an earlier stage of compression, it is preferable to allow the nozzles to extend to a distance from the cylinder head of at least 20%, preferably at least 25% and more preferably at least 30% of the piston stroke. To avoid problems of interference between the piston rings and the nozzles it is advantageous for the piston rings to be offset from the top of the piston such that they remain below the lowermost nozzles at top dead centre.

[0011] An example of the compressor constructed in accordance with the present invention will now be described with reference to the accompanying drawings, in which:

[0012] **FIG. 1** is a schematic perspective view showing the inside of the compressor cylinder and an arrangement of nozzles;

[0013] **FIG. 2A** is a side view of a single flat fan spray nozzle;

[0014] **FIG. 2B** is a top view of the flat fan spray nozzle of **FIG. 2A**;

[0015] **FIG. 2C** shows a typical spray pattern of a flat fan nozzle of **FIGS. 2A and 2B**; and

[0016] **FIG. 3** is a perspective view showing the construction of one type of flat fan nozzle suitable for the compressor of the kind described.

[0017] As shown in **FIG. 1**, the compressor comprises a cylinder **1** having a cylinder wall **2**, a cylinder head **3** and an axis **4**. A piston **5** is axially reciprocable within the cylinder **1**. Air introduced into the cylinder **1** through an inlet valve (not shown) in the cylinder head. This air will typically have been pre-compressed to 2 to 5 bar. Compressed air is exhausted through an outlet valve (not shown) in the cylinder head **3**. The compressed air will typically have a pressure of at least 20 bar, preferably at least 40 bar, and more preferably at least 60 bar. The general operation of the compressor is as described in our earlier application WO98/16741.

[0018] During compression, water is sprayed into the cylinder **1** through a plurality of flat fan spray nozzles **10** as described below. The water is supplied under pressure to the nozzles through nozzle manifolds (not shown) which surround the cylinder. A suitable arrangement is disclosed in PCT/GB 01/01457. As shown in that document, different manifolds may be used to supply the different rows of nozzles, so that different profiles of flow rate versus time may be supplied to the different rows. The water in the cylinder is forced out of the cylinder through the outlet valve to a separator where the water is removed from the compressed air.

[0019] A common design of flat fan spray nozzles are shown in more detail in **FIGS. 2A,2B** and **3**. The nozzle **10** has a hollow cylindrical housing. At the end of the nozzle, the internal end face **11** is hemispherical. A groove **12** is cut across the outer end face of the nozzle and intersects with the hemispherical end face **11** forming an orifice **13** which has a generally elliptical shape with tapered ends. The orifice is typically 3 mm long and 1 mm across. The water flows along the cylindrical passage until it meets the hemispherical end face **11** on each size of the groove **12** whereupon it is diverted towards the opposite side of the groove. The two halves of the flow impact on each other at the groove and are forced out of the orifice **13** forming the characteristic spray. Other designs of flat fan spray nozzles are known in the art and may also be used in place of those shown in **FIG. 3**.

[0020] As shown in **FIG. 2A-2C** the spray **15** has the flat fan shape which is generally planar in a plane **16** as shown in **FIG. 2B**. There is some inevitable divergence of the spray **15** out of the plane **16** resulting in a flow profile **17** having a tapered elliptical shape corresponding to the shape of the orifice **13**.

[0021] The arrangement of the flat fan spray nozzles **10** within the cylinder **1** will now be described with reference to **FIG. 1**. In this figure, the sprays **15** are shown projecting only a very short distance into the cylinder. This has been done for the purposes of the clarity of the figure. In practice, the spray will penetrate into the central region of the cylinder. Also, for clarity, only the sprays **15** and not the nozzles **10** have been shown in **FIG. 1**.

[0022] Four circumferential rows of nozzles are shown in **FIG. 1**. Each nozzle **10** is arranged such that the plane **16** of each spray **15** is parallel to the axis **4** of the cylinder and is directed towards this axis. Each of the spray nozzles **10** is mounted such that its central axis is directed downwardly with respect to the axis **4**. The angle θ of divergence of the spray is smallest for the spray **15** adjacent to the piston head **3** and gets progressively larger further from the piston head **3**. This ensures that a narrower spray is produced closest to the piston head substantially reducing or eliminating contact between the spray and the piston head and providing the most concentrated spray to the region closest to the cylinder head. As a consequence of this, the lowermost sprays inject water closer to the cylinder wall **2** and the uppermost sprays ensuring that a wider region within the cylinder is reached by the spray. Although not shown in **FIG. 1**, each row of nozzles is preferably staggered with respect to an adjacent row by an amount equal to half of the pitch between the adjacent nozzles thereby reducing further the possibility of interference between the adjacent rows of nozzles.

[0023] As shown in **FIG. 1**, the piston rings **18** are positioned towards the bottom of the piston **5**. This is done in order to ensure that, at top dead centre, the piston rings **18** are still below the lowermost nozzles. The flow of water is controlled such that only a little water is injected by a row of nozzles once the top of the piston has passed the nozzles. The amount of water is preferably sufficient only to fill the crevice above the piston rings **18** so as to avoid reducing the efficiency of the compressor.

1: A compressor comprising a cylinder having an axis, a piston reciprocally moveable along the cylinder axis to compress gas in the cylinder and at least two circumferential rows of spray nozzles to spray water into the cylinder during compression, wherein the nozzles are flat fan spray nozzles each of which is arranged such that the spray is in a plane substantially parallel to the axis of the cylinder and is directed towards a central region of the cylinder.

2: A compressor according to claim 1, wherein the plane of the nozzles is inclined at less than 10° to the axis of the cylinder.

3: A compressor according to claim 1, where a nozzle plane is inclined at an angle of less than 5° with respect to the axis of the cylinder.

4: A compressor according to any one of claim 1 wherein the nozzles are directed substantially at the axis of the cylinder.

5: A compressor according to claim 1, wherein an offset of one half of the nozzle pitch is introduced between nozzles in adjacent rows.

6: A compressor according to claim 1, wherein the angle of divergence of the fan spray of each row of nozzles decreases towards the cylinder head.

7: A compressor according to claim 1, wherein the nozzles are inclined such that the lower extremity of the spray from the row of nozzles furthest from the cylinder head is at a smaller angle with respect to the cylinder wall than for nozzles closer to the cylinder head.

8: A compressor according to claim 1, wherein the nozzles are mounted with their central axis inclined downwardly with respect to the cylinder axis.

9: A compressor according to claim 8, wherein the top part of the cylinder wall in which the nozzles are mounted is tapered inwardly towards the cylinder head, and the piston is provided with a complementary taper.

10: A compressor according to claim 1, wherein the nozzles extend to a distance from the cylinder head of at least 20%, preferably at least 25% and more preferably at least 30% of the piston stroke.

11: A compressor according to claim 1, wherein the piston rings are offset from the top of the piston such that they remain below the lowermost nozzles at top dead centre.

12: A compressor according to claim 1, further comprising a pre-compressor to compress the gas upstream of the cylinder to a pressure of 2 to 5 bar.

13: A compressor according to claims claim 1, wherein the cylinder is capable of withstanding a peak pressure of at least 20 bar, preferably at least 40 bar and most preferably at least 60 bar.

14: A compressor according to claim 1 further comprising means to control the profile of flow rate versus time to the rows of nozzles to allow different profiles for different rows of nozzles during the compression stroke.

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