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3,177,945

WELL LINER WITH INWARDLY CONVERGENT PASSAGES

Filed June 27, 1963

Fig. 1.

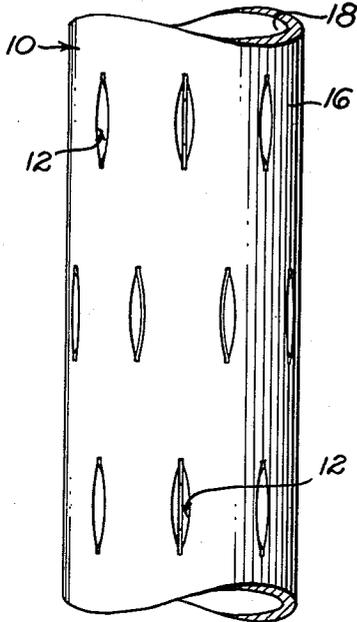


Fig. 3.

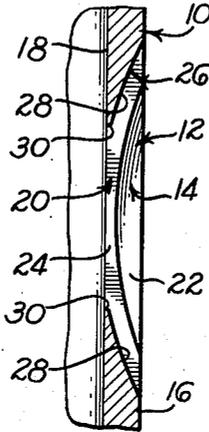


Fig. 2.

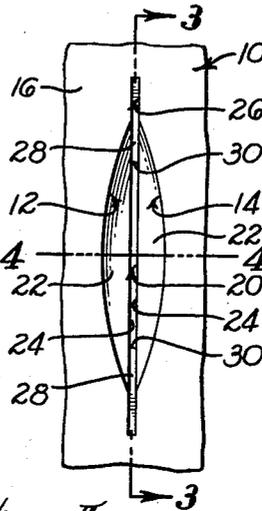


Fig. 6.

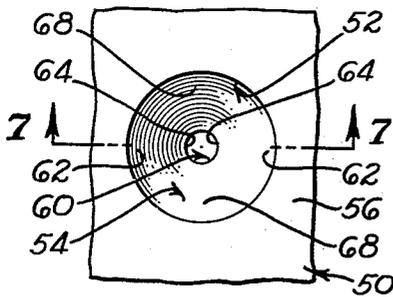


Fig. 4.

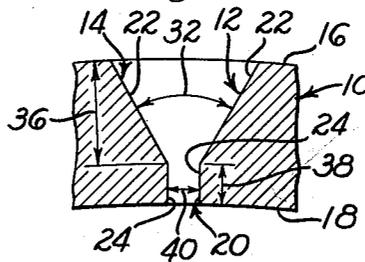


Fig. 5.

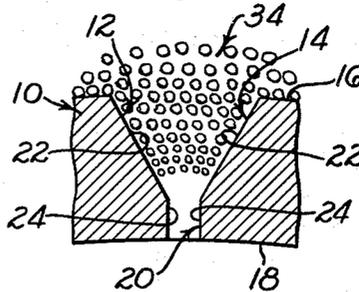
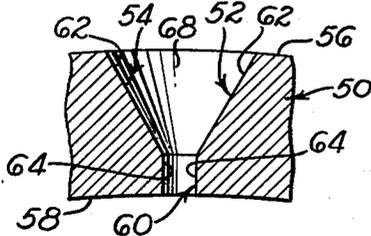


Fig. 7.



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WELL LINER WITH INWARDLY CONVERGENT
PASSAGES

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12 Claims. (Cl. 166-227)

The present invention relates in general to liners for wells, especially oil wells, and a general object is to provide a liner having therein radial passages, such as perforations, which are so shaped as to be particularly effective in minimizing the entry of sand, or other formation particles, into the interior of the liner, without, however, significantly interfering with the flow of oil, or other well fluid, into the liner.

More specifically, the invention relates to a liner of the type which relies on bridges of sand, or other formation particles, in achieving sand control, and a primary object is to provide a liner having therein perforations, or other passages, so shaped as to be extremely effective in establishing and maintaining sand bridges, or other formation-particle bridges, which efficiently filter or strain the well fluid without significantly reducing the permeability of the liner to well fluid.

The foregoing primary object of the invention may be achieved by providing, and it is an important object to provide, a liner having therein radial passages, such as perforations, each of which includes: an outer zone extending radially inwardly from the outer surface of the liner and defined by radially inwardly converging outer walls; and an inner zone extending radially inwardly from the apex of the outer zone into communication with the interior of the liner and defined by nonconvergent inner walls.

Expressing the foregoing more specifically, an important object of the invention is to provide perforations, or other radial passages, each of which, when viewed in central cross section, i.e., when viewed in section in a transverse plane through its midpoint, includes: an outer zone extending radially inwardly from the outer surface of the liner and defined by radially inwardly converging outer walls including therebetween an angle at least as large as twice the angle of repose of any particles in a well formation in which the liner is to be used so as to establish an arch or bridge of formation particles for filtering or straining oil entering the liner by way of such perforation, this included angle being small enough, however, to maintain the desired arch or bridge; and an inner zone extending radially inwardly from the apex of the outer zone into communication with the interior of the liner and defined by substantially parallel inner walls the radial dimension of which is not more than about twice the distance therebetween. The term "angle of repose" is defined on page 101 of "Van Nostrand's Scientific Encyclopedia," Third edition, published by D. Van Nostrand Company, Inc. in 1958.

I have found that an effective sand bridge can be established with an included angle, between the radially inwardly converging walls of the outer zone of the perforation, or other passage, in its central transverse plane, of as low as about 60°, although this included angle may be as little as about 55° with some formation particles having a smaller angle of repose. With regard to the high end of the range, I have found that a sand bridge cannot be maintained against the action of well fluid and the action of gravity with an included angle of more than about 90°, although, with some formation particles, the upper limit of the operative range may be as high as about 105°.

Expressed somewhat differently, satisfactory bridges will not form with included angles below about 55° to

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60°, and cannot be maintained with included angles above about 90° to 105°, the bridges tending to slough downwardly out of the passages with included angles larger than 90° to 105°. Thus, I have found that angles of about 55° and 105° represent absolute limits, while angles of about 60° and 90° represent the preferred range.

As stated, the hereinbefore outlined angular and dimensional limits are with reference to a midplane across the passage, and do not necessarily apply with reference to sections in planes parallel to such midplane.

I have found that the foregoing configuration for the liner passages forms and maintains sand bridges which are very efficient in preventing the entry of sand into the interior of the liner, and which, at the same time, do not significantly increase the resistance to flow through, or the uniformity of flow through, the passages. With conventional liner passages which do not converge inwardly, or which diverge inwardly, it is virtually impossible to form and maintain satisfactory sand bridges, with the result that large volumes of sand enter along with the oil. Furthermore, since the included angle of the inwardly convergent outer zone of each passage is at least equal to twice the angle of repose of the formation particles encountered, such particles cannot become frictionally locked in the passage. Consequently, the flow passages may easily be cleaned by reverse washing whenever necessary, either immediately after running of the liner, or after it has been in service for some time. With conventional liner passages which do not converge inwardly, or which diverge inwardly, friction locks which are either virtually or completely impossible to remove by reverse washing may occur. Such friction locks sometimes occur with conventional liners to such an extent, merely in running the liner into the well, as to render it virtually or completely useless. The particular configuration of the liner passage of the present invention avoids these problems, which is an important feature.

Other objects of the invention are to provide radial flow passages having the form of perforations which are vertically elongated or circular in elevation, and which have the characteristics hereinbefore outlined when viewed in central cross section, i.e., in transverse sections taken in the horizontal midplanes thereof.

Another object in connection with one embodiment of the invention is to provide a vertically elongated perforation the outer and inner zones of which are lenticular and rectangular, respectively, and the inner zone of which is provided with radially inwardly converging end walls, at the upper and lower ends of the perforation. Such end walls provide support for the sand bridge formed in the outer zone of the perforation against sloughing out in the downward direction, which is an important feature. Similar considerations are applicable to the embodiment hereinbefore mentioned which is circular when viewed in elevation, the upper end lower walls of the radially inwardly convergent outer zone providing support against downward sloughing of the sand bridge out of the perforation.

Another object of the invention is to provide a vertically elongated perforation of the foregoing nature which is so formed as to provide more metal thickness at the upper and lower ends of the inner zone of the perforation, whereby to better withstand any sand cutting action resulting from flow concentrations inherently tending to occur at the upper and lower ends of the inner zone of the perforation as a consequence of the radial inward convergence of the end walls of such inner zone.

The foregoing objects, advantages, features and results of the present invention, together with various other objects, advantages, features and results thereof which will be evident to those skilled in the liner art in the light of this disclosure, may be achieved with the exemplary em-

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bodiments of the invention described in detail hereinafter and illustrated in the accompanying drawing, in which:

FIG. 1 is a fragmentary elevational view of an oil well line perforated in accordance with one embodiment of the present invention;

FIG. 2 is an enlarged elevational view of one of the perforations shown in FIG. 1;

FIG. 3 is a central longitudinal section through the perforation shown in FIG. 2 and is taken as indicated by the arrowed line 3—3 of FIG. 2;

FIGS. 4 and 5 are central cross sections taken along the broken line 4—4 of FIGS. 2, FIG. 4 showing various angular and dimensional relations and FIG. 5 showing a typical sand bridge, and both FIGS. 4 and 5 being on an enlarged scale;

FIG. 6 is a fragmentary elevational view of another perforation embodiment of the invention; and

FIG. 7 is a central cross section through the perforation of FIG. 6 and is taken as indicated by the arrowed line 7—7 of FIG. 6.

Referring initially to FIG. 1 of the drawing, fragmentarily illustrated therein is an oil well liner 10 provided with vertically elongated perforations 12 arranged in any desired pattern. In the particular pattern illustrated, the perforations 12 are arranged in longitudinally spaced, circumferential rows, the perforations of each circumferential row being circumferentially staggered with respect to the perforations of adjacent circumferential rows. However, any other desired perforation pattern may be used.

Turning to FIGS. 2 to 5 of the drawing, each perforation 12 includes, in accordance with the invention, an outer perforation zone 14 which extends radially inwardly from the outer surface 16 of the liner 10 and which terminates short of the inner surface 18 of the liner. The perforation 12 also includes an inner perforation zone 20 which communicates with the outer perforation zone 14 and extends radially inwardly through the inner surface 18 of the liner 10 into communication with the interior of the liner.

The outer perforation zone 14 is defined by side walls 22, sometimes referred to herein as the outer walls of the perforation 12, which converge radially inwardly to the inner perforation zone 20. The latter includes side walls 24, sometimes referred to herein as the inner walls of the perforation 12, which extend radially inwardly from the apex of the outer walls 22, and which are substantially parallel.

In the particular construction illustrated, the outer perforation zone 14 is lenticular when viewed in elevation from the exterior of the liner 10, and the inner perforation zone 20 is a rectangular slot. To achieve these configurations, the perforation 12 may be formed in a single operation by a rotary cutter, not shown, having a tapered cutting portion for producing the lenticular outer zone 14, and having a parallel-sided, peripheral cutting portion for producing a parallel-sided groove 26 which longitudinally bisects the lenticular outer zone 14 and the longitudinally intermediate portion of which defines the rectangular inner perforation zone or slot 20. Alternatively, the perforation 12 may be formed in two operations by two cutters respectively designed to form the lenticular outer perforation zone 14 and the bisecting longitudinal groove 26.

It will be noted that the foregoing configuration for the perforation 12 provides the perforation with end walls 28 which are formed by the bottom of the groove 26 at the ends of the rectangular inner perforation zone, and which arcuately converge radially inwardly toward each other, all as best shown in FIG. 3 of the drawing. The cutting procedure outlined tends to produce feathered edges at the ends of the inner perforation zone 20, and these may be blunted, as indicated at 30, by means of a suitable hand tool, such as a file, radially inserted through the perforation 12.

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This specific configuration for the perforation 12 has various advantages. First, the arcuately radially inwardly converging walls 28 formed at the ends of the inner perforation zone 20 tend to assist in maintaining a sand bridge within the outer perforation zone 14 against downward sloughing, as will be discussed in more detail hereinafter. Second, the arcuate nature of the groove 26 forming the inner perforation zone or slot 20 inherently results in greater radial dimensions for the inner walls 24 at the ends of the zone or slot 20 as compared to the longitudinal midpoint thereof. Consequently, the flow concentrations at the ends of the inner perforation zone or slot 20, which inherently result from the funnel-like actions of the arcuately inwardly converging end walls 28, occur at points where more metal is available to better withstand any erosive action resulting from such flow concentrations. Further, the arcuately inwardly converging end walls 28 tend to deflect flow through the perforation 12 toward the longitudinal midpoint of the inner perforation zone or slot 20, thereby achieving more uniform flow distribution along the entire length of the slot 20.

Turning now to a consideration of various critical angular and dimensional relationships involved in the perforation 12, these must be taken into consideration with reference to a central cross section through the perforation, i.e., a section taken in a transverse plane through the longitudinal midpoint of the perforation, such a section being shown in FIG. 4 of the drawing, and also in FIG. 5 thereof. As will be apparent, cross sections other than central cross sections are not applicable with the particular lenticular configuration shown for the outer perforation zone 14, because of the fact that this zone tapers both circumferentially and radially from its longitudinal midpoint toward its ends. Therefore, the following discussion of critical angular and dimensional relationships is with reference to a central cross section through the perforation 12, the same being true of the appended claims.

Turning to FIG. 4 with the foregoing in mind, the included angle 32 between the walls 22 of the outer perforation zone 14 must be at least equal to twice the angle of repose of the sand, or other formation particles, being dealt with. In most instances, the included angle 32 must be at least 60°, although it may be as low as 55° with some formation particles. Otherwise, a proper sand bridge, or other formation-particle bridge, designated by the numeral 34 in FIG. 5, and discussed in more detail hereinafter, will not form. Instead, the sand will pass into and/or through the inner perforation zone or slot 20, with the possibility that sand grains will frictionally lock in the slot to plug it. Thus, approximately 60° represents a preferred lower limit for the included angle 32, while about 55° represents an absolute lower limit.

With regard to the upper limit for the included angle 32, about 90° represents the preferred upper limit while approximately 105° represents the absolute upper limit. With any larger included angle 32, it is almost impossible to form a bridge, and, if one does form, it is almost impossible to maintain and will tend to slough downwardly out of the perforation 12 under the influence of fluid action and the action of gravity.

Another factor is that, in order to provide for the formation of a bridge 34 of adequate size to produce the desired filtering or straining action, the radial dimension 36 of the outer perforation zone 14 (still considering it in central cross section through the perforation 12) must be at least approximately one-eighth inch.

Still another factor is that the radial dimension 38 of the walls 24 of the slot 20 must not be more than about twice the width 40 of the slot, and is preferably of the same order of magnitude as the width 40 of the slot. This is to prevent plugging of the slot 20 in operation.

Although the invention is not to be regarded as limited thereto, some typical dimensions for the slot 20 will now

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be given. For example, the slot width 40 may be the typical slot width widely used for oil well liners, viz., 0.060 inch. It will be understood, however, that this width may be varied, depending on formation particle size, or other factors. The radial dimension 38 of the slot 20 (again at its longitudinal midpoint) may be of the order of $\frac{1}{16}$ inch. The radial dimensions of the slot 20 at its ends are preferably about twice this, or about $\frac{1}{8}$ inch, thereby providing the hereinbefore-discussed additional metal at the ends of the slot 20 to better resist erosion due to flow concentrations at the ends of the slot 20 resulting from the arcuately inwardly converging end walls 28. The over-all length of the slot 20, i.e., the distance between the blunt ends 30 thereof, may be of the order of $1\frac{3}{8}$ inches, and the over-all length of the groove 26, measured parallel to the axis of the liner 10, may be of the order of $2\frac{3}{4}$ inches. As previously indicated, the typical dimensions enumerated in this paragraph are intended as illustrative only, and not as limiting.

I have found that when the perforation 12 is formed within the angular and dimensional limits hereinbefore outlined, a sand bridge 34, capable of excluding sand from the interior of the liner 10 with a high degree of efficiency, while permitting oil to flow into the interior of the liner freely, will form in the convergent outer perforation zone 14 readily, and will be maintained therein against fluid action and against the action of gravity, the arcuately inwardly converging bottom walls 28 of the groove 26 assisting in preventing sloughing of the bridge downwardly out of the perforation 12. The bridge 34 does not extend downwardly into the straight-walled zone 20 of the perforation 12, being bottomed slightly outwardly therefrom, approximately as shown in FIG. 5 of the drawing. By keeping the included angle 32 less than 105° , and preferably less than 90° , the bridge 34 is held radially outwardly away from the slot 20. Thus, none of the area of the slot 20 is blocked by sand so that maximum flow through the perforation is achieved.

By using an included angle 32 of at least about 55° , and preferably of at least about 60° , the formation particles forming the bridge 34 are lightly held in place in the outer perforation zone 14 by the viscous oil flowing through the bridge, but with no tendency to frictionally lock the formation particles in the perforation 12. Consequently, when the liner 10 is run into the well, there is no possibility of plugging the perforations 12 by frictional locking of formation particles therein, something which frequently occurs with conventional liners having inwardly non-converging, or inwardly diverging, perforation walls. The aforementioned taper of each outer perforation zone 14 from its longitudinal midpoint toward its ends also helps to prevent plugging while running in because any mud, sand, or the like, entering same is constantly pushed out the upper end thereof. Further, since the particles forming the bridge 34 are never frictionally locked in place in the perforation 12, high permeability is maintained while still achieving maximum sand control, and, if the bridge becomes filled with muck and fines, it can easily be removed by reverse washing to permit a new, clean bridge to form. Such reverse washing can be carried out very easily and at relatively low differential pressures, even with widths for the slot 20 much narrower than the illustrative example hereinbefore given. In fact, it may be possible in many instances to remove the bridge 34 merely by agitating the fluid within the liner 10.

Generally similar results may be achieved with a perforation which is circular when viewed in elevation, such a perforation being shown in FIGS. 6 and 7 as formed in a fragmentarily-illustrated liner 50, and being designated generally by the numeral 52. Essentially, the perforation 52 includes a radially inwardly converging outer perforation zone 54 extending radially inwardly from the outer surface 56 of the liner 50, but terminating short of the inner surface 58 thereof. A cylindrical inner perforation zone 60 extends radially inwardly from the apex of

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the outer perforation zone 54 through the inner surface 58 of the liner 50. As will be apparent, the perforation 52 may be formed in one operation by a suitable combination drilling and countersinking tool, or it may be formed in two separate operations by two corresponding tools.

Viewed in central cross section, as in FIG. 7, the perforation 52 is identical to the perforation 12, and the outer perforation zone 54 may be regarded as having radially inwardly converging outer walls 62 corresponding to the walls 22. Similarly, the inner perforation zone 60 may be regarded as having substantially parallel inner walls 64 corresponding to the walls 24. The various angular and dimensional relations hereinbefore set forth in connection with FIG. 4 of the drawing are equally applicable to the central cross section shown in FIG. 7, so that no further description is necessary.

It will be noted that the upper and lower walls 68 of the outer perforation zone 54 have the same anti-sloughing action, with respect to a bridge formed in the outer perforation zone 54, as do the radially inwardly converging end walls 28 of the perforation 12.

Although exemplary embodiments of the invention have been disclosed herein for purposes of illustration, it will be understood that various changes, modifications and substitutions may be incorporated in such embodiments, and that the invention may be incorporated in other passage or perforation embodiments, all without departing from the spirit of the invention, as defined by the claims which follow.

I claim:

1. A well liner provided therein with a plurality of radial passages each of which, viewed in central cross section, includes:

- (a) an outer zone extending radially inwardly from the outer surface of the liner and defined by radially inwardly converging outer walls including therebetween an angle at least equal to about 55° , but not greater than about 105° , the radial dimension of said outer zone being at least of the order of $\frac{1}{8}$ inch; and
- (b) an inner zone substantially coextensive with the apex of said outer zone and extending radially inwardly from the apex of said outer zone into communication with the interior of the liner and defined by substantially parallel inner walls, the radial dimension of said inner walls being not more than about twice the distance therebetween.

2. A well liner provided therein with a plurality of radial passages each of which, viewed in central cross section, includes:

- (a) an outer zone extending radially inwardly from the outer surface of the liner and defined by radially inwardly converging outer walls including therebetween an angle at least equal to about 60° , but not greater than about 90° , the radial dimension of said outer zone being at least of the order of $\frac{1}{8}$ inch; and
- (b) an inner zone substantially coextensive with the apex of said outer zone and extending radially inwardly from the apex of said outer zone into communication with the interior of the liner and defined by substantially parallel inner walls, the radial dimension of said inner walls being not more than about twice the distance therebetween.

3. A well liner provided therein with a plurality of radial passages each of which, viewed in central cross section, includes:

- (a) an outer zone extending radially inwardly from the outer surface of the liner and defined by radially inwardly converging outer walls including therebetween an angle at least equal to about 55° , but not greater than about 105° ;
- (b) an inner zone extending radially inwardly from the apex of said outer zone into communication with the interior of the liner and defined by substantially parallel inner walls;
- (c) the radial dimension of said outer zone being suffi-

cient to enable said outer walls to form and sustain a sand bridge substantially preventing passage of sand into said inner zone; and

(d) the distance between said inner walls being so related to the radial dimension thereof as to resist plugging of said inner zone by sand.

4. A well liner provided therein with a plurality of radial passages each of which, viewed in central cross section, includes:

(a) an outer zone extending radially inwardly from the outer surface of the liner and defined by radially inwardly converging outer walls including therebetween an angle at least equal to about 60°, but not greater than about 90°, the radial dimension of said outer zone being at least of the order of 1/8 inch; and

(b) an inner zone substantially coextensive with the apex of said outer zone and extending radially inwardly from the apex of said outer zone into communication with the interior of the liner and defined by substantially parallel inner walls.

5. A well liner provided therein with a plurality of radial passages each of which, viewed in central cross section, includes:

(a) an outer zone extending radially inwardly from the outer surface of the liner and defined by uniformly radially inwardly converging outer walls including therebetween an angle at least equal to about 60°, but not greater than about 90°, the radial dimension of said outer zone being at least of the order of 1/8 inch; and

(b) an inner zone substantially coextensive with the apex of said outer zone and extending radially inwardly from the apex of said outer zone into communication with the interior of the liner and defined by substantially parallel inner walls.

6. A well liner provided therein with a plurality of radial passages each of which, viewed in central cross section, includes:

(a) an outer zone extending radially inwardly from the outer surface of the liner and defined by uniformly radially inwardly converging outer walls including therebetween an angle at least equal to about 60°, but not greater than about 90°, the radial dimension of said outer zone being at least of the order of 1/8 inch; and

(b) an inner zone substantially coextensive with the apex of said outer zone and extending radially inwardly from the apex of said outer zone into communication with the interior of the liner and defined by substantially parallel inner walls, the radial dimension of said inner walls being not more than about twice the distance therebetween.

7. A well liner provided therein with a plurality of

radial passages each of which, viewed in central cross section, includes:

(a) an outer zone extending radially inwardly from the outer surface of the liner and defined by radially inwardly converging outer walls including therebetween an angle at least equal to about 55°, but not greater than about 105°, the radial dimension of said outer zone being at least of the order of 1/8 inch; and

(b) an inner zone substantially coextensive with the apex of said outer zone and extending radially inwardly from the apex of said outer zone into communication with the interior of the liner and defined by substantially parallel inner walls.

8. A well liner according to claim 7 wherein each of said passages is vertically elongated when viewed in elevation from the exterior of the liner.

9. A well liner according to claim 7 wherein each of said passages is circular when viewed in elevation from the exterior of the liner.

10. A well liner according to claim 7 wherein each of said passages is vertically elongated when viewed in elevation from the exterior of the liner and wherein said outer zone of each passage is lenticular when so viewed.

11. A well liner according to claim 7 wherein each of said passages is vertically elongated when viewed in elevation from the exterior of the liner and wherein said outer and inner zones of each passage are lenticular and rectangular, respectively, when so viewed.

12. A well liner according to claim 7 wherein each of said passages is vertically elongated when viewed in elevation from the exterior of the liner and wherein said outer and inner zones of each passage are lenticular and rectangular, respectively, when so viewed, said inner zone of each passage having radially inwardly converging end walls.

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