

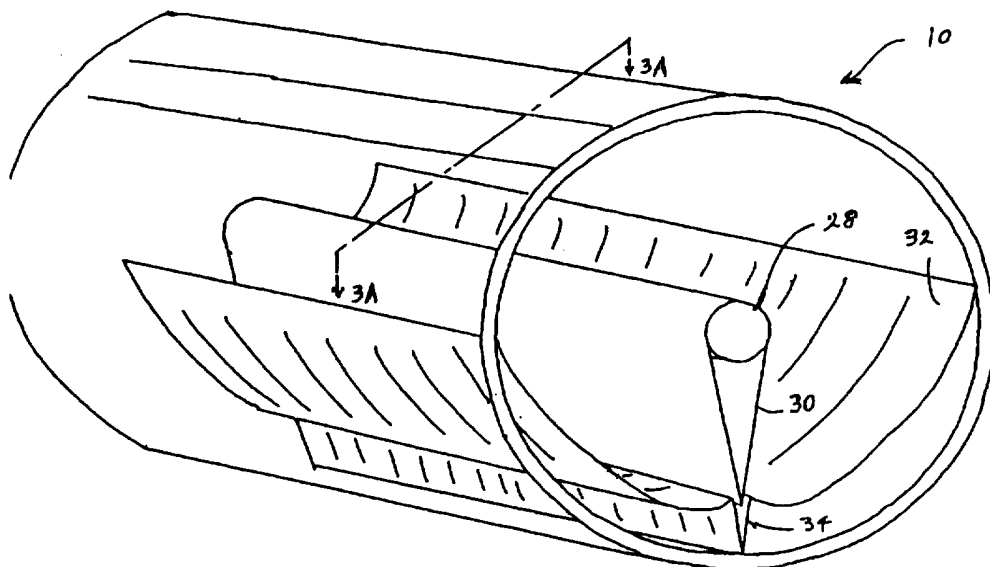


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(21) International Application Number: PCT/US95/16867 (22) International Filing Date: 22 December 1995 (22.12.95) (30) Priority Data: 08/363,610 23 December 1994 (23.12.94) US (71) Applicant: SOLAR ENTERPRISES INTERNATIONAL, L.L.C. [US/US]; 5217C South University Avenue, Chicago, IL 60615 (US). (72) Inventors: WINSTON, Roland; 5217C South University Av- enue, Chicago, IL 60615 (US). O'GALLAGHER, Joseph; 2919 Embassy Row, Flossmoor, IL 60422 (US). JENK- INS, David, G.; 6022 S. Drexel Avenue #602, Chicago, IL 60637 (US). DUFF, William; 1404 Lindenwood Drive, Fort Collins, CO 80524 (US). (74) Agents: RECHTIN, Michael, D. et al.; Reinhart, Boerner, Van Deuren, Norris & Rieselbach, S.C., Suite 2100, 1000 North Water Street, Milwaukee, WI 53202-0900 (US).		(81) Designated States: AU, JP, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE). Published <i>With international search report.</i> <i>Before the expiration of the time limit for amending the</i> <i>claims and to be republished in the event of the receipt of</i> <i>amendments.</i>

(54) Title: NONIMAGING SOLAR COLLECTOR

Perspective View of 40° Ice Cream Cone w/ V Groove



(57) Abstract

A nonimaging solar collector (10). A method and article of manufacture of a solar collector includes an outer housing (24) transparent to light, a reflector element (32) positioned within the outer housing (24), an absorber (28) concentrically disposed relative to the outer housing (24), and a heat conduction fin (30) coupled to the absorber and having a wedge shape which tapers to a smaller thickness as a function of increasing radial separation from the absorber.

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NONIMAGING SOLAR COLLECTOR

The present invention is concerned with a nonimaging concentrator for light. More particularly, the invention is concerned with a solar energy concentrator or collector having an absorber concentrically disposed within a glass housing enabling nonimaging light concentration, such as an evacuated cylindrical reflector tube. This absorber geometry also includes a gap loss reduction V groove which is positioned in a complementary manner relative to a wedge shaped heat conductor fin coupled to the absorber.

Nonimaging concentrators and their advantages are well known in the art (see, for example, U.S. Pat. Nos. 3,957,031; 4,002,499; 4,003,638; 4,230,095; 4,387,961; 4,359,265; and 5,289,356 incorporated by reference herein). In these previous methodologies, the device is constructed using a given absorber shape, usually a cylindrical tube, and then the appropriate nonimaging reflector is designed. This emphasis was therefore primarily on developing new reflector designs to optimize collector efficiency. There has recently been made available new types of high performance absorber materials which can even be disposed on flexible substrates. These absorbers have an absorbtance typically greater than 90% over the solar spectrum, while the hemispherical emittance at operating temperatures is quite low.

It is therefore an object of the invention to provide an improved nonimaging solar collector and method of use thereof.

It is another object of the invention to provide a novel nonimaging solar collector having an absorber concentrically disposed within a glass housing enabling nonimaging light concentration.

It is a further object of the invention to provide an improved nonimaging solar collector having an outer housing and a concentrically disposed tubular absorber with a radially coupled wedge shaped heat conduction fin.

It is also an object of the invention to provide a novel nonimaging solar collector having a cylindrical reflector and tubular absorber coupled to a conically shaped cross sectional heat conductor.

It is yet another object of the invention to provide an improved solar collector having an absorber concentrically disposed within a reflector and coupled conical cross section heat conductor.

It is still a further object of the invention to provide a solar collector utilizing absorbers having high efficiency and which are disposable on flexible substrates designed to optimize collection properties.

It is another object of the invention to provide a method and article of manufacture for providing high solar collector efficiency with a concentric heat exchange channel design which enables easy construction and assembly without need for solar tracking drives.

Other objects and advantages of the invention will be apparent from the detailed description and drawings described hereinbelow.

Brief Description of the Drawings

FIGURE 1 illustrates a prior art solar collector with a flat fin conductor;

FIGURE 2 illustrates a prior art nonimaging solar collector of 35° acceptance angle with an absorber disposed noncentrically within a cusp shaped reflector;

FIGURE 3A illustrates a cross-sectional view along 3A-3A on FIG. 3D of a nonimaging solar collector having an absorber concentrically disposed within a cylindrical reflector with a V-groove gap loss suppresser and the absorber further includes a coupled heat conductor fin having a conically shaped cross section;

FIG. 3B shows a ray trace for the collector of FIG. 3A; FIG. 3C illustrates a perspective view of the solar collector of FIG. 3A; and FIG. 3D illustrates a plot of thermal performance of the 40° V-groove collector of FIG. 3A and the 35° ICPC collector of FIG. 2 when displaced from ideal positioning;

FIGURE 4 illustrates another version of the collector of FIG. 3 but with increased angle of acceptance;

FIGURE 5 illustrates a variation on the solar collector of FIG. 3 but without the V-groove gap loss suppresser element;

FIGURE 6A illustrates a nonimaging collector with a concentric tubular absorber and raised reflector contour providing a five degree acceptance angle and FIG. 6B illustrates a ray trace for the collector of FIG. 6A;

FIGURE 7 illustrates angular acceptance properties of the collector of FIG. 6.

Detailed Description of Preferred Embodiments

A nonimaging solar collector constructed in accordance with the invention is shown in FIGS. 3-6 and indicated generally at 10. Several prior art collector designs are shown for comparison in FIGS. 1 and 2. The prior art collector 12 of FIG. 1 has heat conductor fins 14 and 16 which both radiate heat so that thermal performance is poor at temperatures above about 100°C. Prior art nonimaging collector 18 of FIG. 2 has relatively good thermal performance at elevated temperatures, but absorber 20 is noncentrically disposed and requires manufacture of a somewhat intricate reflector geometry 22.

The inventive nonimaging solar collector 10 includes an outer glass tube housing 24 which is transparent, allowing entry of light rays 26 (see FIG. 3B) into the evacuated interior of the housing 24. The housing 24 is shown as cylindrical in shape but can take on other geometries suitable for the functions described herein. The light rays 26 either directly strike absorber tube 28 or reflect from

reflector surface 32 to impinge upon the absorber tube 28 and thereby concentrate the collected light. In the preferred embodiment this absorber tube 28 can be shapes other than shown in the figures but is concentrically positioned relative to the housing 24. The absorber tube 28 further can include a wedge shaped heat conductor 30 (see FIG. 3C) which in cross-section collectively appears with the absorber tube 28 as an "ice cream cone" geometry, as noted in FIGS. 3A, 3B, 4 and 5.

In a preferred embodiment (see FIGS. 3, 4 and 5) reflector surface 32 includes a gap loss reduction V-groove 34. This groove 34 suppresses energy absorption gap loss which would otherwise occur when there is a space between the reflector surface 32 and the wedge shaped heat conductor 30. In FIG. 3A the angle of acceptance for the absorber is about 40° which would make the collector 10 suitable for east-west orientation without need of any solar tracking mechanism. This particular angular acceptance with the associated V-groove 34 provides excellent tolerance for vertical positioning errors in placement of the absorber 30, as well as good tolerance for horizontal displacements (see FIG. 3D).

The collector 10 of FIG. 4 has a smaller radius of curvature for the reflector surface 32, resulting in a wider, 70° angle of acceptance. This embodiment would allow the collector 10 to be suitable for north-south or east-west orientation without need of any solar tracking device.

The collector 10 of FIG. 5 is the limiting case of the embodiments of FIGS. 3 and 4 where the radius of curvature of the reflector surface 32 is coincident with the inner surface of the glass tube housing 24. This embodiment has an acceptance angle approaching 90° . This form of the collector 10 further simplifies the construction procedure for manufacture of the collector 10.

In the embodiment of FIGS. 6A and 6B, the reflector surface 32 has a relatively large radius of curvature such that the angle of acceptance is about 5°

and would require some crude solar tracking device, operative either continuously or intermittently. This design includes a small cusp arising from the small angle of acceptance. The thermal performance is quite good at elevated temperatures.

FIG. 7 shows the efficiency versus incident angle of the embodiment of FIG. 6 for concentration factors of two, three, four and five with reflection or Fresnel losses ignored. Concentrations of about four are achieved with efficient 5° acceptance properties.

Thermal performance for the illustrated embodiments of the figures are shown in Table I below. Calculations have been performed based on an average meteorological year in Albuquerque, New Mexico. The emittance assumed for the absorber is 0.05 at $T = 100^\circ\text{C}$ and an absorptance of 0.95.

TABLE I
Thermal Performance

Property	5° ICPC (FIG. 6)	40° ICPC (FIG. 2)	40° VG (FIG. 3)	70° VG (FIG. 4)	90° Circle (FIG. 5)	Flat Fin (FIG. 1)
Concent.	<u>4.00</u>	1.47	1.16	1.01	0.94	0.46
Gaploss	~0%	0%	0.25%	0.5%	4%	4%
Thermal Efficiency (T=100 C)	<u>82.4</u>	62.6%	67.4%	70.1%	68.5%	64.6%
Thermal Efficiency (T=150 C)	<u>79.7</u>	57.6%	61.0%	62.7%	60.6%	50.8%
Thermal Efficiency (T=200 C)	<u>76.1</u>	50.8%	52.2%	52.5%	49.8%	32.8%
Thermal Efficiency (T=250 C)	<u>71.1</u>	42.0%	40.8%	39.3%	35.9%	12.7%
North South Orientation Allowed	<u>Required</u>	No	No	Yes	Yes	Yes
Need Reflector Insert	Yes	Yes	Yes	Yes	No	No
Reflector Silvering Required	Yes	Yes	Yes	Yes	Yes	No
Concentric Glass-to- Metal Seals	Yea	No	Yes	Yes	Yes	Yes
Shaping of Glass Tube Allowed	Yes	Yes	No	No	Yes	Yes
Active Tracking Required	<u>Yes</u>	No	No	No	No	No

In construction of the collector 10, it is also preferable to utilize several classes of high performance solar absorber coatings on the absorber tube 28 and the heat conductor 30. Coatings can be, for example, cermets having a very low emittance (about 0.02 at 20°C) and a high absorptance (about 0.92) over the solar spectrum. Cermets are conventional materials which have layers of dielectric materials which contain a particular fraction of metal composition disposed on a metal reflector layer having an anti-reflection coating. The top layers have lower metal fractions in the dielectric material than those layers below them. The higher metal fraction layer at the bottom absorbs more energy because visible light passes through the top layers easily. The emission of black body radiation ($> 2\text{mm}$ wave length) is however reflected by the cermet dopant quite efficiently. Thus, emission of radiation from the bottom layer is trapped inside the absorber material, and only the low doped top layer radiates away heat. The graded metal content increases the amount of atoms seen by the incoming light so more is absorbed and also reduces the number of atoms which can radiate away heat.

Another class of materials useful as absorbers are certain ceramics which can easily be made using vacuum deposition. For example, conventional layers of TiN_xO_y and $\text{SiO}_2/\text{TiN}_x\text{O}_y$ can be deposited onto an aluminum or copper substrate until a set amount of accumulation has been measured. Both of these types of materials have a TiN_xO_y layer about 53 nm thick on a substrate. The second type of absorber material has a 90 nm layer of SiO_2 added. The thermal properties of such materials are very favorable for use as solar absorbers. On copper substrates an absorptance of 0.90 or higher can be achieved with an emittance of 0.06 at $T=200^\circ\text{C}$ while aluminum substrates achieve absorptance as high as 0.95 and an emittance of 0.03 at $T=100^\circ\text{C}$.

The above described preferred embodiments utilize a concentrically disposed absorber tube within a cylindrical reflector housing which has been

evacuated. The absorber tube further includes a wedge shaped heat conduction fin coupled to the absorber, and preferably includes an absorber layer (absorbance greater than 0.90) with low emittance (less than about 0.05) to achieve a very efficient solar collector. The simplicity of this basic design allows easy manufacturing, reducing construction costs thereby making solar collector usage more practical.

Further advantages and features of the invention will be appreciated by reference to the claims set forth hereinafter. While preferred embodiments have been described, it will be clear to those of ordinary skill in the art that changes and modifications can be made without departing from the spirit and scope of the invention in its fullest aspects.

What Is Claimed Is:

1. A nonimaging solar collector, comprising:
an outer housing at least partially transparent to light;
a reflector element disposed within said outer housing;
an absorber concentrically disposed within said outer housing; and
a heat conduction fin coupled to said absorber and having a wedge shape tapering to lesser thickness as a function of increasing radial separation from said absorber.
2. The solar collector as defined in Claim 1 wherein said outer housing is sealed and evacuated.
3. The solar collector as defined in Claim 1 wherein said outer housing comprises a transparent glass.
4. The solar collector as defined in Claim 1 wherein said outer housing comprises a cylindrically shaped element.
5. The solar collection device as defined in Claim 4 wherein said absorber comprises a tubular shaped element.
6. The solar collector device as defined in Claim 1 further including a V-groove element as part of said reflector element.
7. The solar collector device as defined in Claim 6 wherein said heat conductor fin includes a tapered end and said V-groove element is symmetrically disposed relative to the tapered end of said heat conduction fin.
8. The solar collection device as defined in Claim 7 wherein the tapered end extends into said V-groove element.
9. The solar collection device as defined in Claim 8 wherein said collection device has an angle of acceptance of 40° and the tapered end extends about 2 mm into said V-groove element.

10. The solar collection device as defined in Claim 8 wherein said collection device has an angle of acceptance of 70° and the tapered end extends about 1 mm into said V-groove element.

11. The solar collector as defined in Claim 1 wherein said reflector element comprises a reflective layer disposed on a substrate positioned within said outer housing.

12. The solar collector as defined in Claim 11 wherein said reflective layer substrate comprises a radius of curvature greater than that of said outer housing.

13. The solar collector as defined in Claim 11 wherein said outer housing has an inner wall and said reflective layer substrate comprises a radius of curvature of said inner wall.

14. The solar collector as defined in Claim 1 wherein said absorber comprises a substrate coated with a highly efficient absorber.

15. The solar collector as defined in claim 14 wherein said highly efficient absorber is selected from the group consisting of a cermet and ceramic materials.

16. The solar collector as defined in Claim 15 wherein said ceramic materials are selected from the group consisting of $Ti N_x O_y$ and $Si O_2/Ti N_x O_y$.

17. The solar absorber as defined in Claim 16 wherein said substrate is selected from the group consisting of Al and Cu.

18. The solar collector as defined in Claim 15 wherein said cermet comprises a layer structure having a variable fraction of metal content from layer to layer.

Prior Art

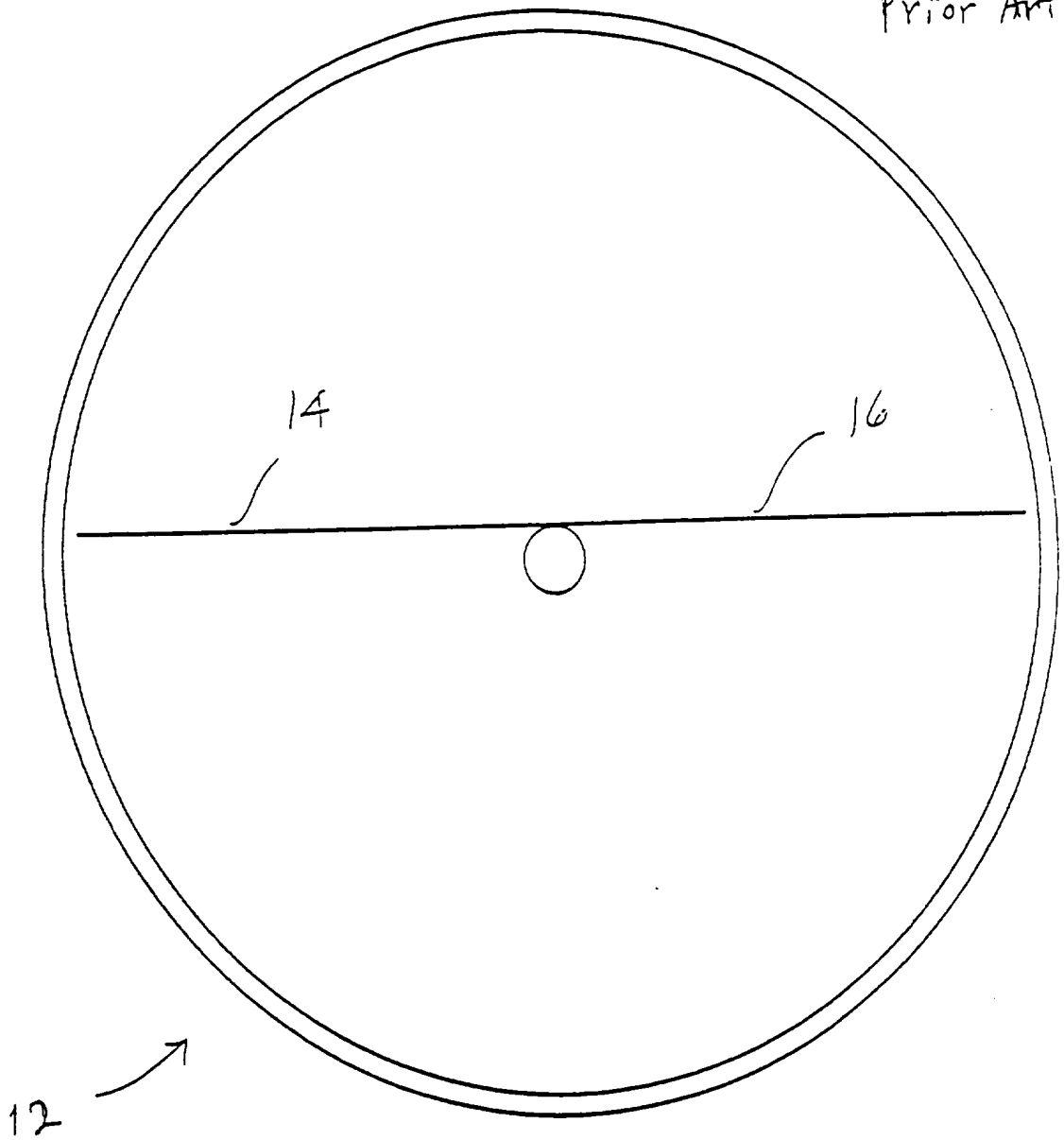


Figure 1

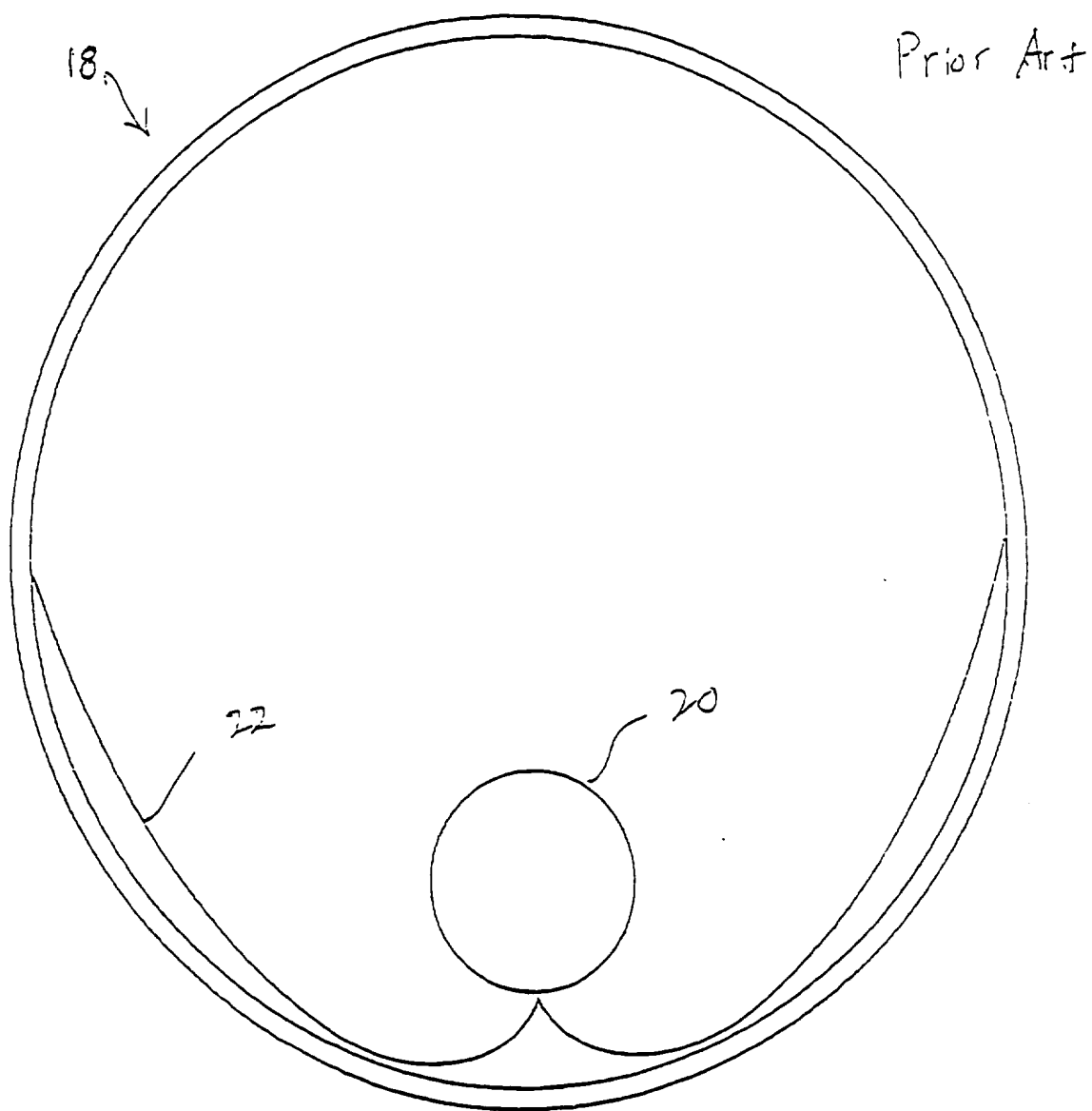


Fig. 2

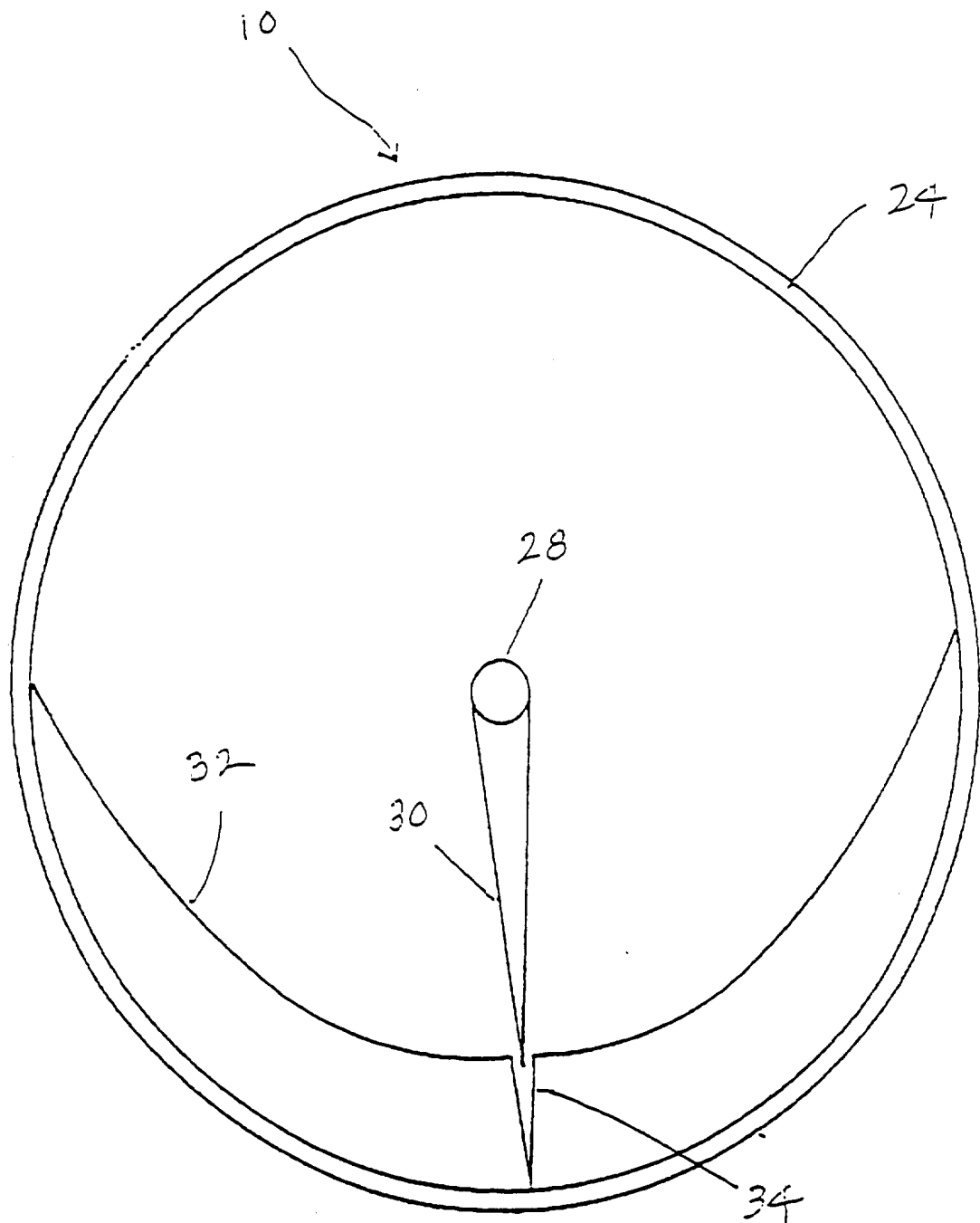


Figure 3A

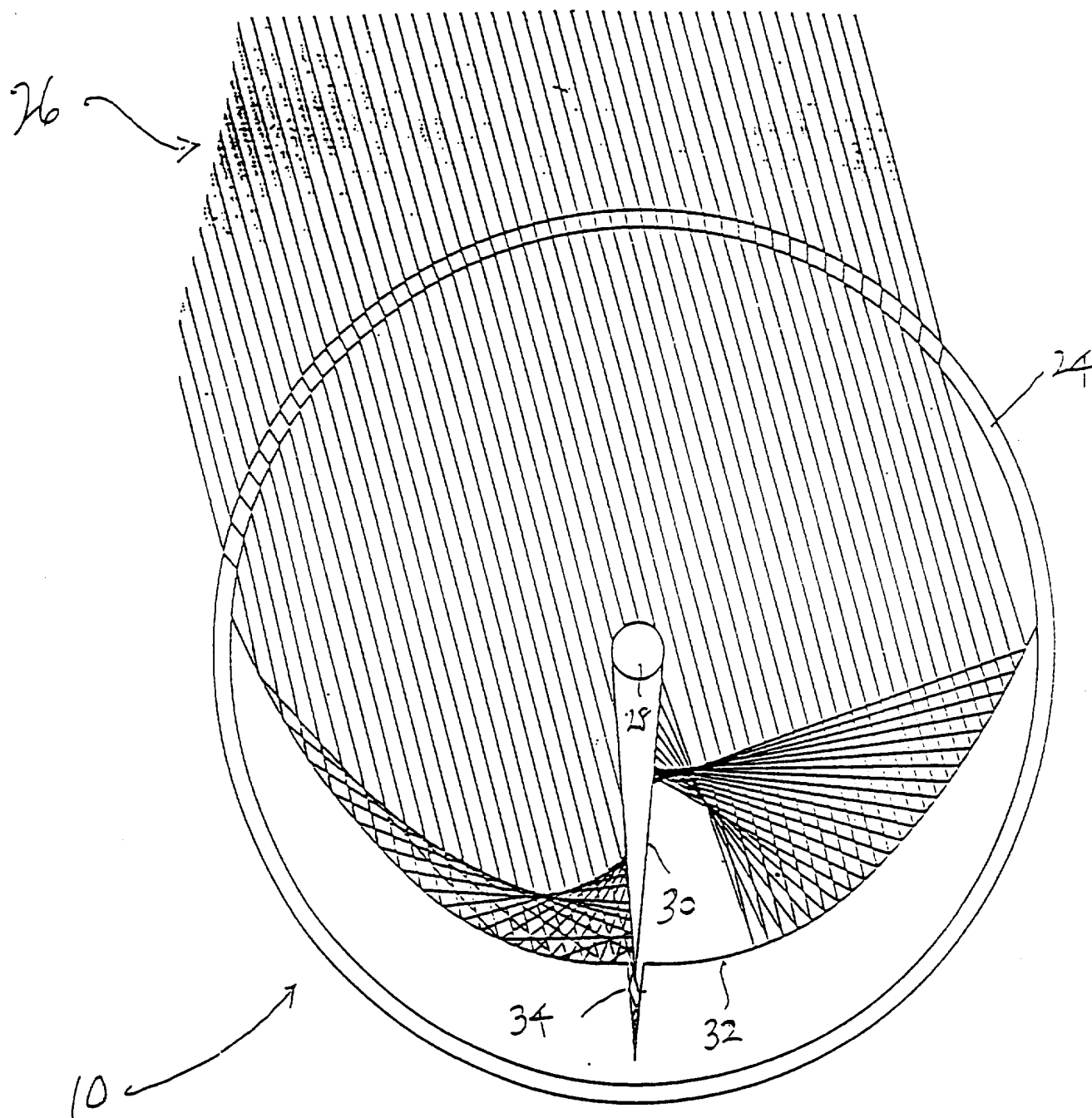


FIG. 3B

Perspective View of 40° Ice Cream Cone w/ V Groove

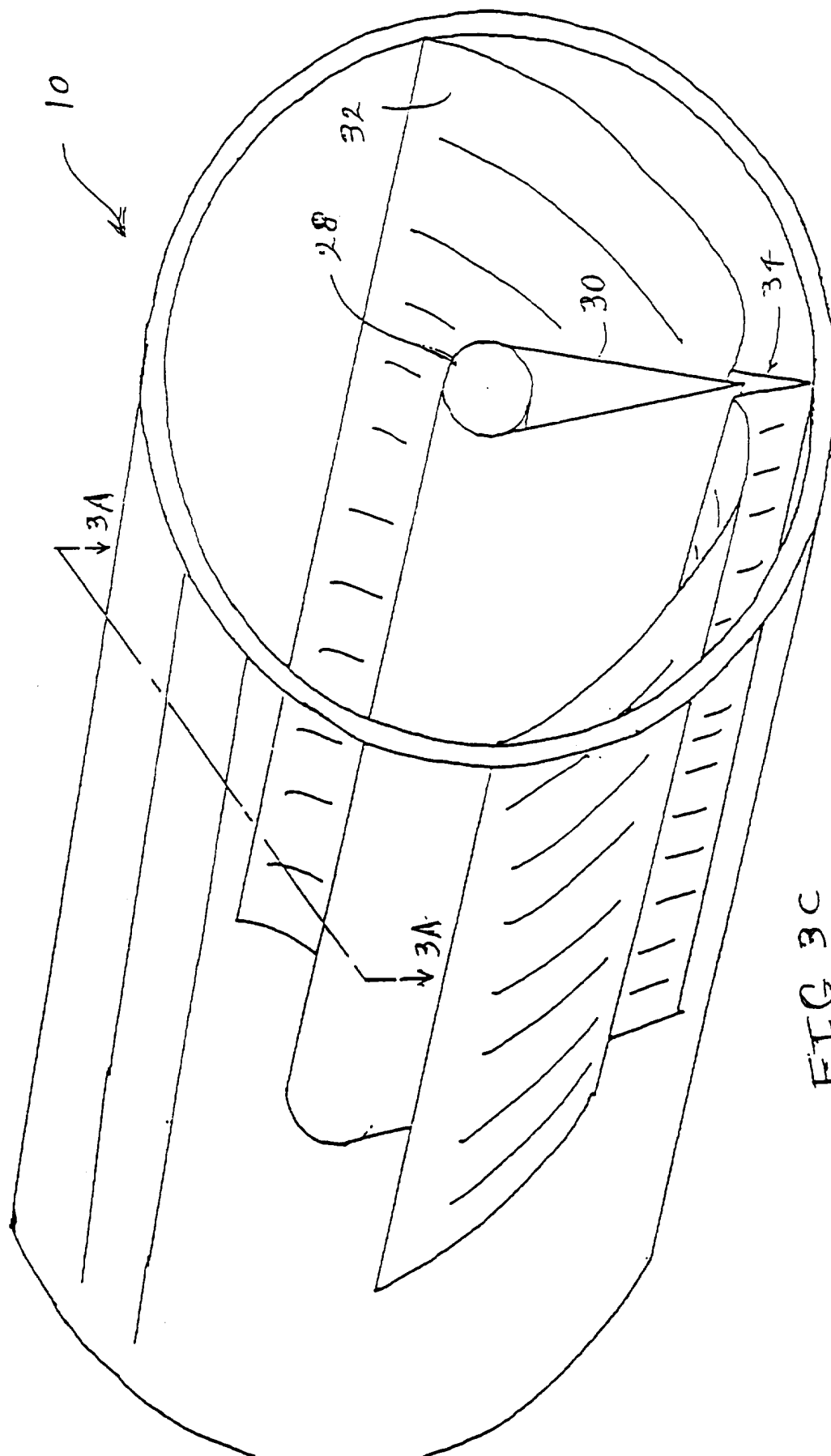


FIG. 3C

Perfect Weather Model Thermal Efficiency (%)

Thermal Performance of 40° V groove collector + 40° ITCPC collector
for Various Absorber Positional Errors

$$\epsilon = 0.05 + 0.0001 \left(\frac{T - 100^\circ \text{C}}{^\circ \text{C}} \right), \quad C = 1.06, \quad \text{Absorber-Reflector Gap 2mm for } 40^\circ \text{ Vg. Collector}$$

$$C = 1.33, \quad \text{Absorber-Reflector Gap 1mm for } 40^\circ \text{ ITCPC collector}$$

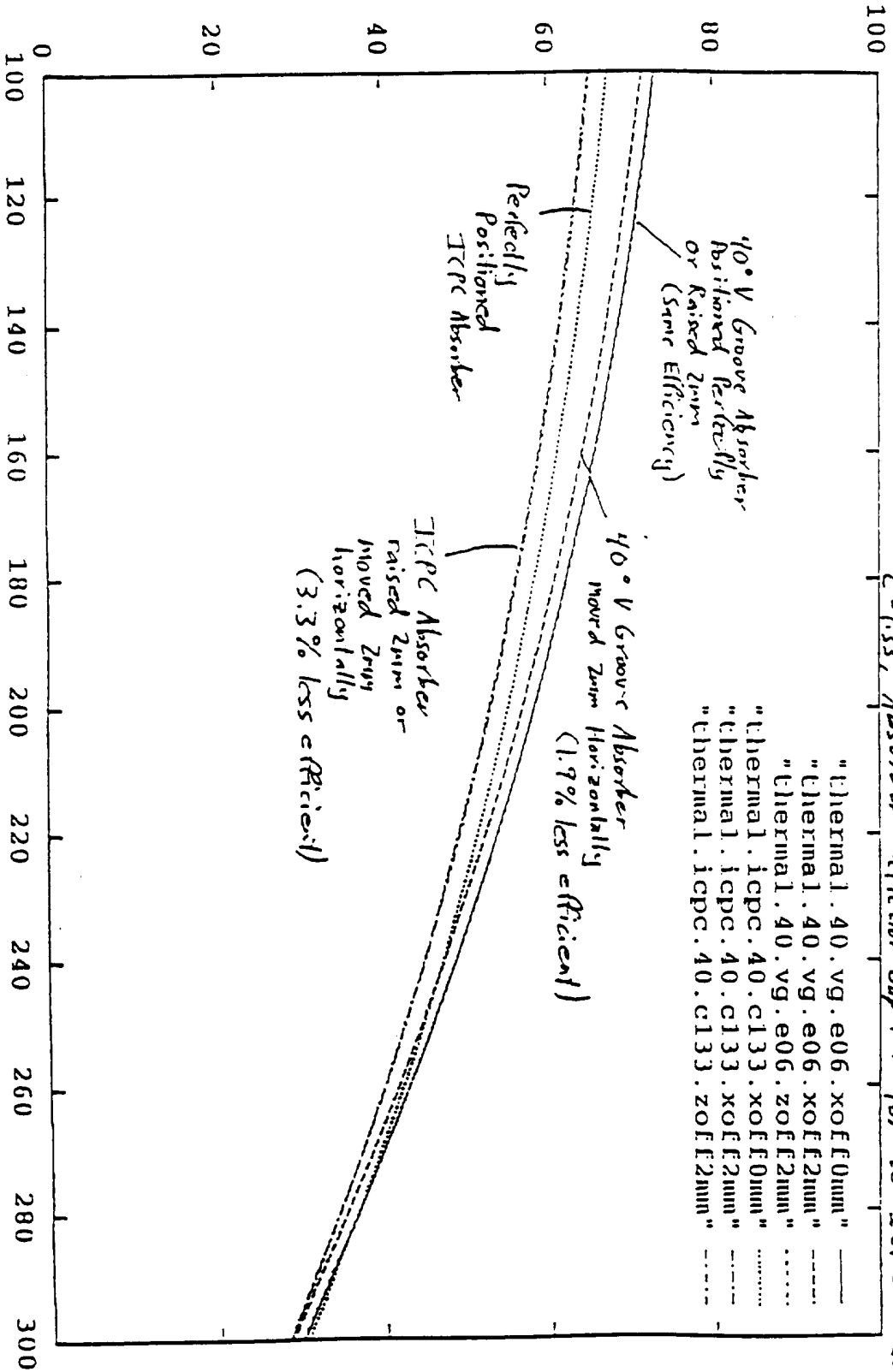


FIG. 3D

Absorber Temperature (°C)

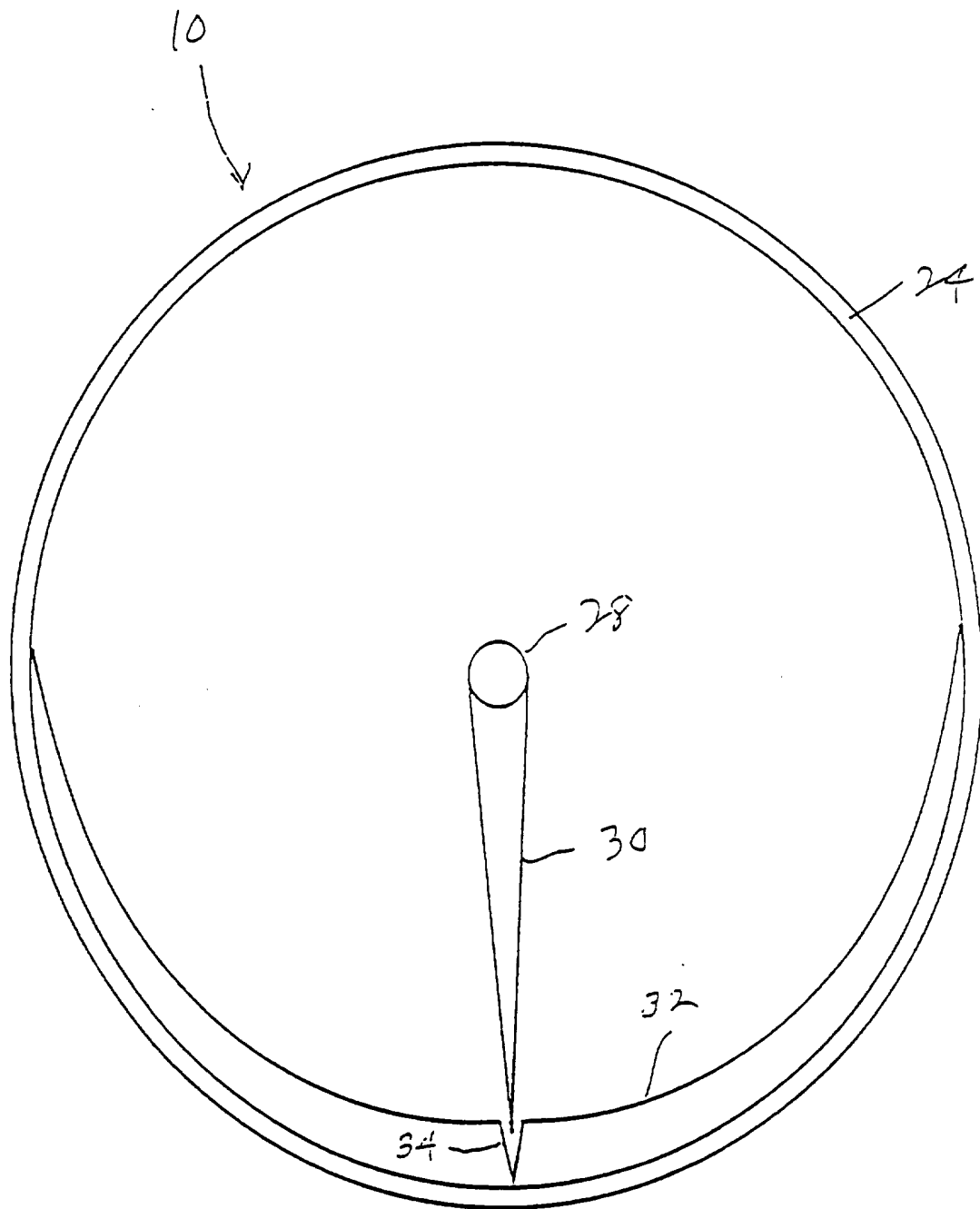


Figure 4

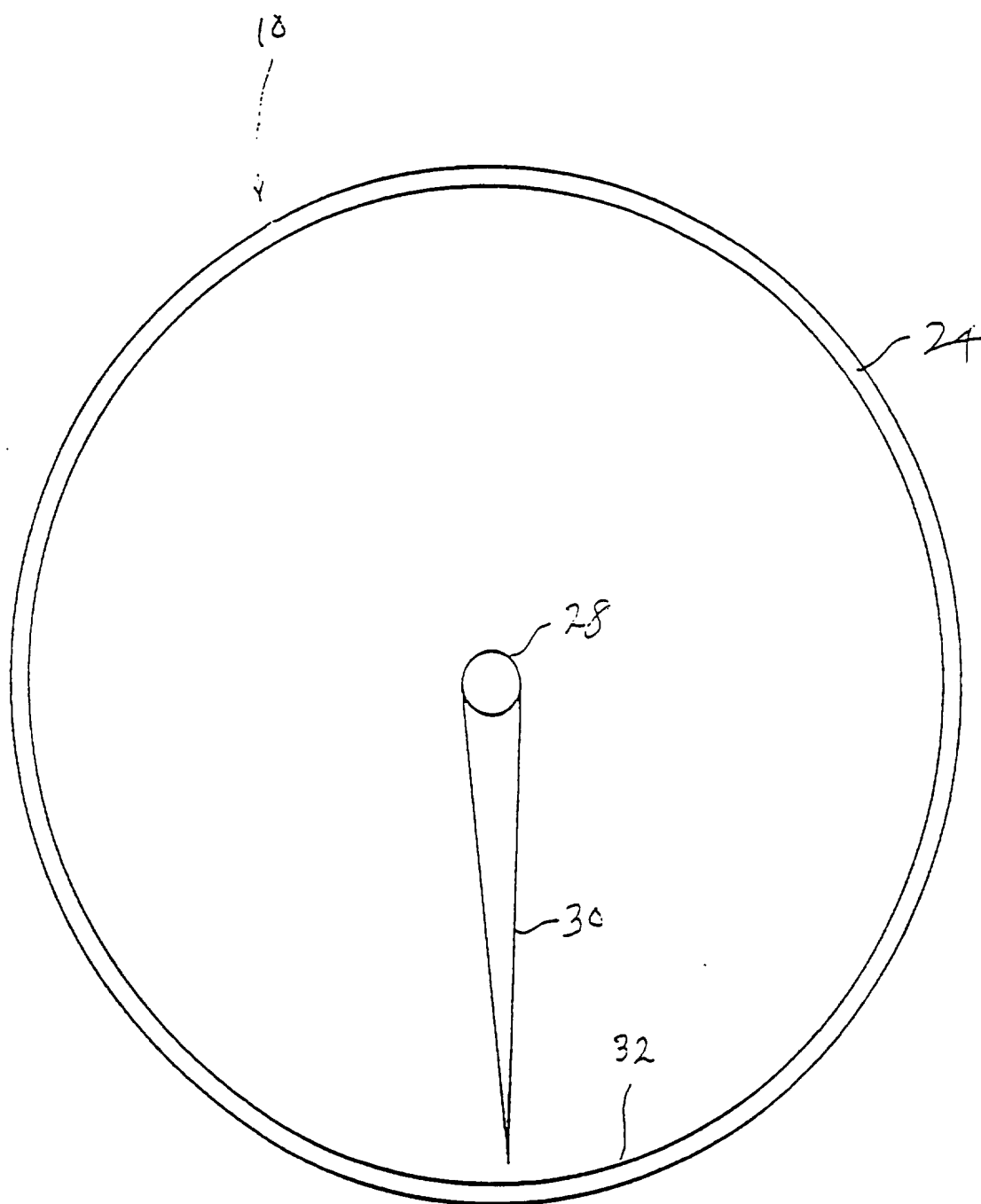


Figure 5

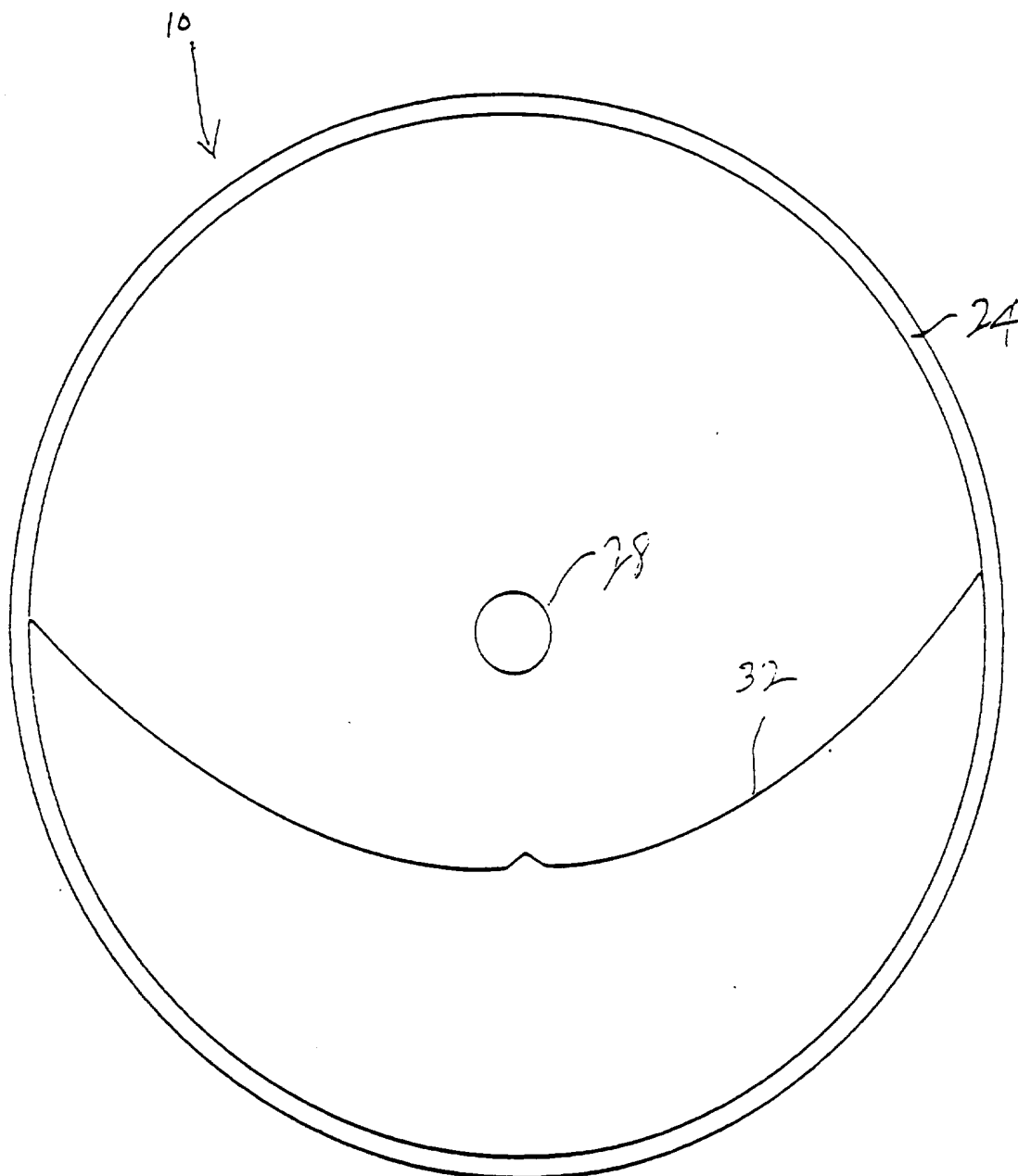


Figure 6A

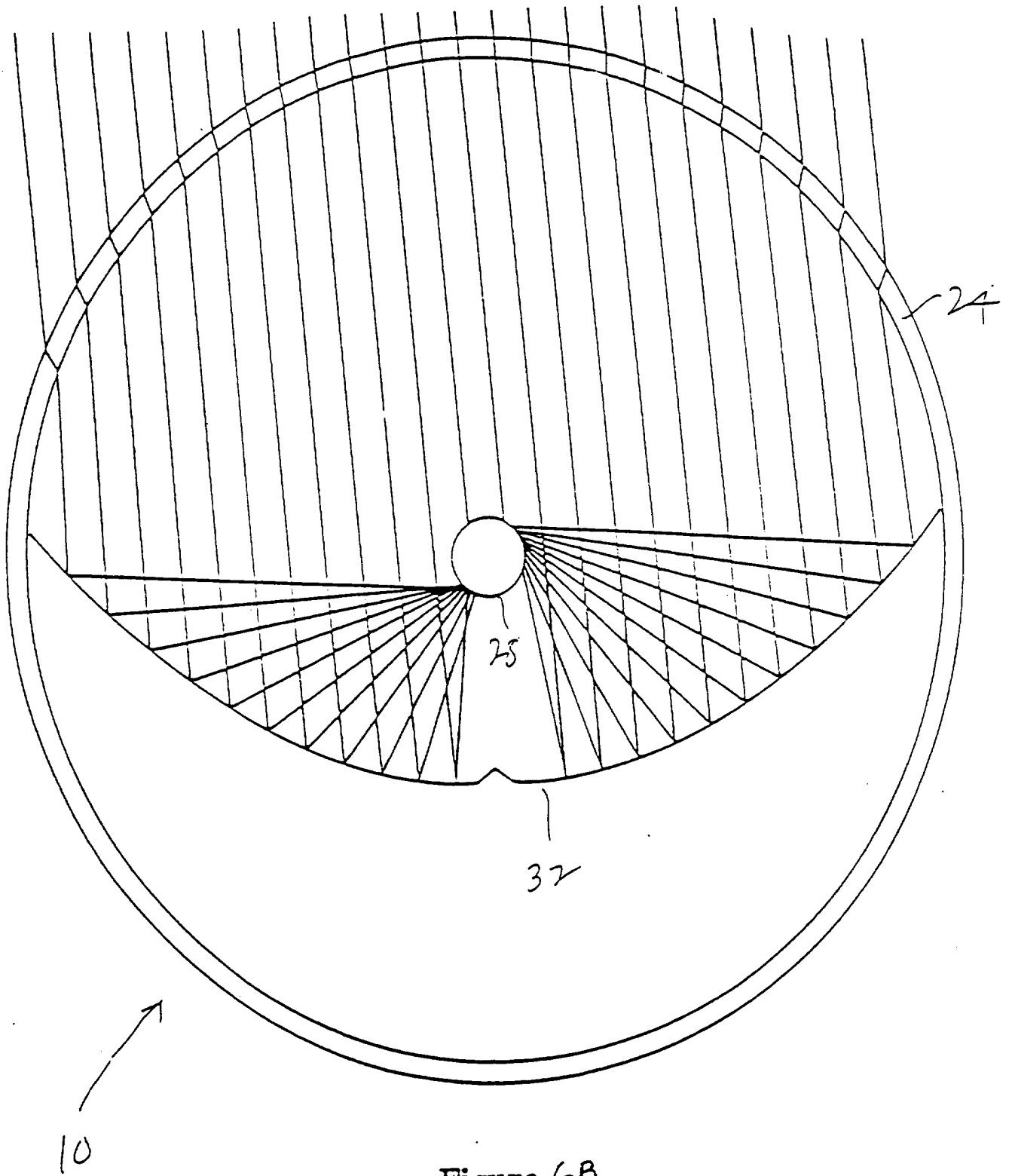


Figure 6B

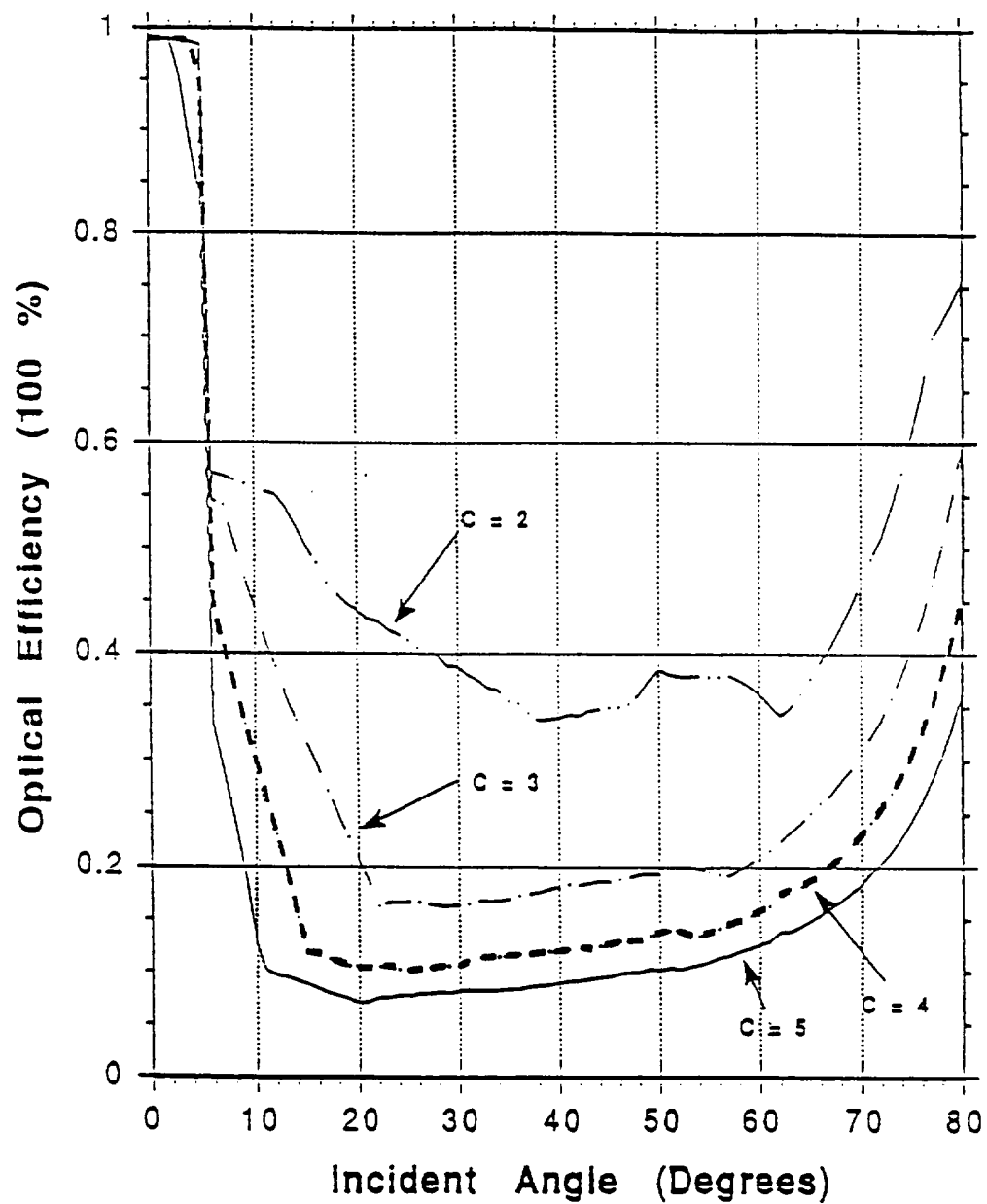


Figure 7

INTERNATIONAL SEARCH REPORT

 International application No.
PCT/US95/16867

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) : F24J 2/10

US CL : 126/657

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)

U.S. : 126/652-654, 657-662

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)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP,A, 60-78251 (KOGYO) 02 May 1985, see entire document.	1-7,11-18
Y	Optical Materials Technology for Energy Efficiency and Solar Energy Conversion XII, 1993, M. Lazarov et al., "Optimization of SiO ₂ -TiN _x Oy-Cu Interference Absorbers: Numerical and Experimental Results," 12 pages, see entire article.	14-18
Y	Optical Materials Technology for Energy Efficiency and Solar Energy Conversion XII, 1994, H. Schellinger et al., "Improved Selective Properties of SiO ₂ /TiN _x Oy -Al Tamden Absorbers Effected By Tempering", 10 Pages, see entire article.	14-18

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 ☐ See patent family annex.

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Date of the actual completion of the international search

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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	International Solar World Congress, Budapest, 1993, Qi-Chu Zhang, "Very Low Emittance Solar Selective Absorber Coatings", pages 1-6, see entire article.	14-18